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Report of Investigations
No. 11

STRATIGRAPHIC ASPECTS

OF THE

Blewett-Cle Elum Iron Ore Zone

Chelan and Kittitas Counties, Washington

By
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FOREWORD

As a part of a comprehensive program of re-examination of all the iron deposits of Washington, the Division of Geology has completed both an economic and a stratigraphic study of the iron zone extending from Cle Elum River in Kittitas County to Peshastin Creek in Chelan. The economic aspects of the iron deposits of this zone are presented in Report of Investigations No. 10 for the Blewett end, and in No. 12 for the remainder of the entire belt. This paper reports the stratigraphic aspects of the rocks of the iron zone.

The Division of Geology was fortunate in having the services of Doctor R. L. Lupher, Associate Professor of Paleontology at the State College of Washington, for a period of several weeks in the field season of 1942. During this time he carried on stratigraphic studies across the entire belt from Cle Elum River to the Blewett region.

Dr. Lupher's discussion of the stratigraphy is supplemented by about 60 detailed sections comprising the appendix. This will be especially useful to geologists as a record of significant features observed by the author in the field.

The present report of his investigations emphasizes the stratigraphic importance of certain beds in the iron belt, those containing most of the iron, by removing them from the basal section of the Swauk formation where they were placed by Smith, and elevating them to formational rank by the designation "Cle Elum formation." The technically trained reader will note other important differences between the interpretations of Dr. Lupher and earlier students of the area.

In a geologic situation such as that presented by the Blewett-Cle Elum iron belt with abundant conflicting data, it is inevitable that equally competent students will reach different conclusions. This presentation of Dr. Lupher's view, however different from those held by others, will not fail to be very stimulating to future students of this region.

Harold E. Culver.

July 22, 1944.

INTRODUCTION

The general geology of the region was studied first by George Otis Smith and his associates, especially F. C. Calkins, in the period of 1897 to 1902. Iron oxide deposits on Cle Elum River were discussed by Kimball (1898) but it is difficult to recognize, in that report, the character and geologic relations of the deposits as made known by later writers. The Cle Elum iron deposits were described by Smith and Willis in 1901, and this was followed by the Mt. Stuart folio (Smith, 1904) and the Snoqualmie folio (Smith and Calkins, 1906). The iron deposits have been discussed by Shedd (1902) and by Shedd, Jenkins, and Cooper (1922), but their information was drawn largely from the work of Smith and Willis (1901). Broughton (1943) has described the deposits of the Blewett district and Zapffe (1944) has described those of the Cle Elum district.

This report presents the results of a stratigraphic study of the iron deposits. The structure of the deposits in relation to the enclosing rocks necessarily constitutes an integral part of the work. There is included a description of the iron deposits and some conclusions as to their origin. The field work was done during the period of June 30 to September 11, 1942. The writer was ably assisted in the field by Alton K. Guard.

In the following pages the reader will note frequent letter and number combinations in parentheses. These refer to a series of "representative sections" of the Cle Elum belt which are presented separately as an appendix. This plan makes it possible to record field observations, upon which statements in the main body of the report are based, without frequent repetition.

GENERAL GEOLOGY

The rocks of the region include a basement complex of peridotite, serpentine, schist, and altered volcanic rocks which is overlain by a thick sequence of sedimentary and volcanic formations. Intrusives are present in both major units. The deposits that contain iron oxide lie at the base of the sedimentary and volcanic sequence.

BASEMENT COMPLEX

Easton schist.—The oldest rock unit of the pre-iron terrane of Mt. Stuart region is the Easton schist. It is largely quartz and hornblende schist, possibly derived from sedimentary and volcanic rocks. The Easton schist lies beneath the Swauk formation. It is exposed along the upper Yakima River and its tributaries at points ranging from 5 to 27 miles southwest and south of the iron deposits. The antiquity of the Easton schist is indicated principally by intense metamorphism.

Peshastin and Hawkins formations.—In the immediate region of Mt. Stuart, altered sedimentary and volcanic formations lie beneath the Cle Elum formation. These are the Peshastin formation of sedimentary rocks, largely slates, and the Hawkins formation of diabasic lavas, tuffs, and breccias. The time relations of Hawkins and Peshastin formations are unknown. The formations have been considerably folded, locally metamorphosed, and invaded by a peridotite batholith, but they are less altered than the Easton schist.

Peridotite and serpentine.—This rock unit is believed to be the source rock of the iron deposits. Therefore, several excerpts from Smith's (1904) description are given here.

> The rock which is referred to as peridotite is largely altered to serpentine and shows the greatest possible variation in color and general appearance. In one part of the area the serpentine may be reddish brown and massive in its erosion forms, while in another locality the rock is bright green and somewhat schistose in structure. * * * Bluish black, dark green, light red, and yellow are other colors frequently noticed. * * * Except where markedly schistose, the serpentine has a dense, compact texture, with a somewhat waxy luster. In the massive phases it has a porphyritic appearance due to the shining cleavage faces of crystals in the dull aphanitic groundmass. * * * The glistening mineral is bastite, an alteration product of enstatite, and this, with the occurrence of the mineral serpentine, which is plainly derived from olivine, shows the rock to have been originally an olivine-enstatite rock, the variety of peridotite to which the name saxonite has been given. * * * Examined microscopically, some specimens of this rock are found to contain remnants of the original constituent minerals, showing that the alteration of the peridotite to serpentine has not been complete in all cases. * * * Magnetite is an abundant constituent, being present both in crystals and in fine grains.

GRANODIORITE AND GABBROID INTRUSIONS

The central area of the Mt. Stuart region, more than 11 miles in diameter, is occupied by the Mt. Stuart granodiorite. Smith (1904, page 5) concluded that the granodiorite is younger than the peridotite because of "the occurrence on the western flank of Mt. Stuart of dikes of the granodiorite intrusive in the adjacent serpentine." The age of the Mt. Stuart with reference to the Cle Elum beds and the sedimentary and volcanic formations above them cannot be so reliably determined because the large central mass of Mt. Stuart granodiorite is surrounded by peridotite and older rocks, and, so far as known, is not in contact with the Cle Elum and later formations. However, Smith (1904) and Smith and Calkins (1906) concluded that the granodiorite is older than the Swauk formation because of inferred depositional contacts between the Swauk and three distant small supposed apophyses of the Mt. Stuart granodiorite, one on Cle Elum River near Fortune Creek, one on upper Peshastin Creek, and one on lower Peshastin Creek. At Fortune Creek the Swauk-granodiorite contact is concealed by talus but the Swauk sandstones above the talus are metamorphosed, granitized, and also cut by acidic dikes, thus showing a stronger suggestion of an intrusive contact than a depositional contact. The area of "Mt. Stuart granodiorite" mapped by Smith on upper Peshastin Creek does not exist; instead there are only a few acid dikes in the peridotite area. The lower Peshastin Creek occurrence was not examined by the writer. Certain acidic dikes of the type referred by Smith to the Mt. Stuart episode are known to be intrusive in the Swauk formation (F-27). The problem is somewhat complicated by the fact that the Swauk and some later formations are intruded by granodiorite west of the iron region and this rock, termed the Snoqualmie granodiorite, is "practically identical in petrographic character" with the Mt. Stuart granodiorite. (Smith and Calkins, 1906.) Thus the evidence that granodiorite constituted a part of the pre-iron terrane in the Mt. Stuart region is indirect and unconvincing when based only upon direct contact relations, and, as noted on a later page, the lithologic evidence furnished by the Cle Elum and Swauk sediments is also unsatisfactory.

A somewhat similar situation exists with respect to some gabbroid intrusions. Three of these intrusions lie within the serpentine belt and cut the serpentine and older units. A fourth gabbroid mass occurs as a sill in the Swauk formation, and, because of lithologic similarity of the four masses, Smith (1904) considered them as later than the Swauk formation.

Therefore it can be said with certainty only that the pre-iron terrane, in the immediate environs of the iron deposits, presented extensive exposures of peridotite and more restricted exposures of Peshastin and Hawkins formations. The Easton schist constituted an important element of the basement rock a few miles southwest of the iron zone, but its degree of proximity to the iron deposits is concealed by the Swauk formation. The Mt. Stuart granodiorite may have been present a few miles north of the Cle Elum belt, but there is no concrete evidence on this point. Available evidence indicates that the gabbroid intrusions are younger than the iron deposits.

CLE ELUM FORMATION

At some time after the emplacement of the peridotite, the rocks of the Mt. Stuart region were deeply eroded so that the peridotite was widely exposed and a land surface of moderate or low relief was developed. Upon this land surface were formed thin discontinuous deposits of mudstones, sandstones, and conglomerates derived from the peridotite and older rocks and containing various amounts of iron oxide. These lenses are exposed at a number of places (pl. 1) in a linear distance of 22 miles from upper Peshastin Creek near Blewett Pass westward to and beyond the Cle Elum River. Only in a few localities do they exceed a thickness of 25 feet and the maximum observed thickness is about 450 feet. Nevertheless they constitute a sharply defined stratigraphic unit here called the Cle Elum formation.

SWAUK FORMATION

The basement complex and its partial cover of thin lenses of the Cle Elum formation were covered by continental arkosic sandstones in which are occasional beds of conglomerate and shale. The sandstone section is at least 5,000 ft. thick and the maximum thickness may greatly exceed this figure. They were derived from granitoid rocks similar to the Mt. Stuart granodiorite. Because of their high content of feldspar and quartz, they are light gray and light buff color and, in composition as well as in general appearance, they contrast markedly with the dark gray, black, brown and red of the underlying Cle Elum beds which are composed almost entirely of peridotite waste and iron oxide. With few exceptions, the basal contact of the sandstones with the Cle Elum formation and, where that is absent, with the pre-iron basement rock, is very abrupt rather than transitional. The sandstones and conglomerates are very well-lithified so that in some places they are as resistant as granitoid igenous rocks.

The sandstones and Cle Elum beds appear to be concordant in structure. In the central and western parts of the iron area both units dip steeply away from the central mass of crystalline and metamorphic rocks of the Mt. Stuart region. In the Peshastin Creek area, at the east end of the iron belt, the standstones lie in fault contact with the Cle Elum and older rocks. West of the Mt. Stuart region the sandstones are overlain discordantly by the Keechelus andesitic series and intruded by Snoqualmie granodiorite. The sandstones are overlain with angular discordance by the Teanaway basic lavas south of the Mt. Stuart region. The Teanaway lavas dip generally southward at lesser angles than the sandstones and the sandstones crop out in an elongate area ranging from 9 miles wide in the Cle Elum River region to 3 miles wide eastward in the Teanaway River region.

In the Blewett Pass and Swauk Creek regions east of Teanaway River, the Teanaway lava exposures swing southward, then curve back to the east and north, exposing beneath them a large area of continental strata. These strata bear little resemblance to the hard, coarse, arkosic sandstone and conglomerate discussed above, for they are composed of nearly equal amounts of shale and sandstone, and the sandstones, while probably arkosic, are mostly gray and brown, medium and fine grained, and not greatly lithified. The stratigraphic relations of arkosic and shale-sandstone sections are unknown. Both contain abundant plant remains and are largely, if not entirely, of fresh water origin; both lie below the Teanaway lavas; and they form a continuous area of sedimentary rock exposures. Smith (1904) grouped all these strata under the name of Swauk formation. He recognized the lithologic differences of the strata so grouped but considered them lateral gradations such as are commonly observed in continental beds. This conclusion, however, was based on logical inference and was not a matter of observation. The fossil plants upon which an age assignment was made came from the shale-sandstone section of the Swauk Creek region and much of the description of the Swauk appears to have been written with that section foremost in mind, and so when one reads in the Snoqualmie folio (Smith and Calkins, 1906) that the Swauk formation "is characteristically unconsolidated" it must be remembered that this applies to the Swauk sediments of the Swauk Creek region of the Mt. Stuart quadrangle and not to the indurated sandstones that prevail near the iron deposits. The degree of induration of the Swauk Creek-Blewett beds and their location south of the southward-dipping sandstones suggests that they are upper beds of the Swauk formation.

Age.—The uncertainty regarding the stratigraphic position of the shale-sandstone phase of the Swauk formation involves the age assignment proposed by Smith (1904) for the entire formation and the underlying iron beds of the Cle Elum. The fossil plants, upon which the age assignment was based, were collected from the shale-sandstone sequence on Swauk Creek, and the floras of the arkosic sandstone and underlying Cle Elum beds were not represented.

The collection of about 25 species was studied by Knowlton who reported (Smith, 1904, page 5) that one Swauk species was present in the Denver and Laramie floras, that other forms resembled certain Laramie, Denver, and Fort Union species, and that "on this rather insecure basis it is assumed that the age should be regarded as Eocene." Later reports have generally transformed Knowlton's assumption into dogma and have used the term "Eocene" without explaining whether or not it was used in the broad sense advocated by Knowlton. The mention of Laramie, Denver, and Fort Union species shows that Knowlton had in mind a time that was later generally referred to the latest Cretaceous and Paleocene. Considering all these stratigraphic and paleobotanical uncertainties, about all that can be said about the age of the Swauk formation is that the Swauk Creek flora is suggestive of a time near the Mesozoic-Cenozoic boundary and therefore the basal Swauk arkose and the underlying Cle Elum formation are possibly well within the Cretaceous period.

POST-SWAUK HISTORY

Folding and faulting.—The Swauk formation is overlain unconformably by a series of continental sediments and lava flows but these will not be reviewed here because they are not closely related to the iron problem, and, at best, furnish a few clues as to the nature, number, and age of later diastrophic and intrusive events that have modified the Cle Elum beds and overlying Swauk. Folding of more than one episode has caused the Cle Elum beds to dip steeply south and southwest away from the central area of crystalline and metamorphic rocks. Faulting, local crumpling, alteration, and a general advanced degree of lithification are in part related to the folding, in part related to episodes of intrusion and mineralization.

Intrusives.—The Swauk and Cle Elum formations and the basement rocks beneath are cut by numerous dikes and other intrusive bodies which are not involved in the genesis of the Cle Elum formation but have an important bearing on the present structure and occurrence of those beds. Basic dikes, largely of basaltic appearance, are very numerous; acidic intrusives, by comparison, are of very minor number. Smith (1904) found that some of the basic dikes are confluent with basalt flows of the Teanaway lavas which overlie the Swauk formation. He believed, however, that the acidic dikes are older than the Swauk and regarded them as offshoots of the Mt. Stuart granodiorite. Acidic dikes are most abundant in the area of peridotite and metamorphic rock but some of them are now known to cut the Cle Elum beds and overlying Swauk sandstones (F-18, 27). West of Cle Elum River the Swauk was invaded by several stock-like masses of acidic intrusives ranging from porphyry with fine groundmass to normal granodiorite. Some of these were mapped by Smith and Calkins (1906) and referred to the Snoqualmie granodiorite which, in larger bodies, invaded the Swauk of the Snoqualmie Pass region. These intrusives are probably in part responsible for the high degree of induration of the Swauk sediments of Goat Mountain and for a certain degree of alteration shown by the iron deposits of the same region.

Basic dikes are most abundant in the Swauk sandstones near the Cle Elum beds and locally, over areas of several square miles, even greatly exceed the sandstone in volume. They are mostly fairly regular, showing nearly vertical dip and a prevailing northeast trend, but some are complex irregular injections; sills are rare. Many dikes cut regularly across the Cle Elum beds and become discontinuous and irregular in the peridotite. In some places hundreds of closely spaced dikes cut transversely across the Swauk sandstones a few hundred feet above the Cle Elum formation and few continue into the basal Swauk and Cle Elum beds.

"Nickel ledge" veins.—A common rock type along and near the iron zone is generally referred to as "nickel ledge" or "porphyry dike" for the want of more satisfactory appellations than those borrowed from local mining terminology. These rocks are vein- or

dike-like bodies of carbonates and silica, which occur principally in the basement rock below the Cle Elum beds. The "nickel ledges" show prevailing east-west strikes and near-vertical dips; the largest masses are more than 300 feet wide and nearly a mile long. The brilliant yellow, orange, and red colors of their weathered surfaces and the resistant character of the rock make them striking features of the landscape.

Two explanations of the origin of the "nickel ledges" were suggested by Smith (1904):

> The bands or ledges * * * may represent mineralized zones in both the serpentine and the slate, or they may have been originally calcareous beds or lenses belonging to the Peshastin formation, in part included in the intrusive peridotite, in part situated along its contact, and thus subject to alteration by this magnesia-rich rock. The latter hypothesis is the one which is better supported by the relations observed.

Observations along the iron zone show that the nickel ledge there is much younger than both Peshastin formation and peridotite, for the nickel ledge material invades the Cle Elum beds (C-6), the Swauk formation (C-4, 5), and even some of the basic dikes that traverse the Swauk (D-3).

The "nickel ledge" appears to be largely vein material of calcite and other carbonates some of which contain iron and cause the marked coloration of weathered surfaces. The veins are most abundant in the peridotite and here the mineralization commonly was preceded and accompanied by marked brecciation, shearing, and serpentinization of the peridotite adjacent to the veins. Some of the veins are coarsely crystalline white carbonate, others are hard dense material, of pink, brown, and yellow colors, which resembles a dense felsitic igneous rock but is probably finely crystalline siliceous carbonate. Some show the vein material in clean-cut fissures; others show an indefinite zone of brecciated and foliated serpentine, in places somewhat talcose and intricately traversed by small and large veins of carbonate. In few places does the nickel ledge enter the Swauk sandstones as distinct veins but it lies at the base of the Swauk in some places and the vein material permeates and colors the sandstone for distances of more than 100 feet (C-4). The nickel ledge veins show a prevailing east trend at a wide angle to the prevailing trend of the basic dikes. At no place was the vein material found to be traversed by a basalt dike.

Origin of the present land surface.—Late in the Cenozoic era, perhaps as late as the early Pleistocene epoch, the Mt. Stuart region entered the last episode of marked elevation and erosion. Streams that flowed mostly transverse to the westward-trending Cle Elum formation carved a mature topography, and the iron exposures now extend over alternate sharp ridges and narrow intervening canyons with a local relief of 2,000 to 3,500 feet. Alpine glaciation of the late Pleistocene also has left its record upon the topography, and stream alluvium and glacial moraines commonly obscure the bedrock in the canyon bottoms.

Prior to the last glacial record conditions were especially favorable for mass transportation of rock materials by gravity, and extensive slumps, landslides, and mudflows were produced. These features are most abundant in the highly serpentinized zones of the peridotite. The Cle Elum formation, because of its high specific gravity, and the overlying Swauk sandstones, because of their resistant, cliff-forming character, have been extensively incorporated in slumps and landslides.

The mass transportation process is active today but most of the material is so old that it forms well-cemented breccias. Moreover, the land surface has been considerably lowered and reshaped by erosion since much of the material reached present locations. Some of the rock flow is of recent date but much of it lies back of the glacial record. As a consequence, there are well-cemented breccias and landslide remnants containing Cle Elum and Swauk materials that lie upon peridotite hundreds of feet, and even thousands of feet, beyond the present Cle Elum exposures. It is a fairly common occurrence to find sandstone and iron oxide as scattered float, as large blocks, and even as landslide remnants up to more than one acre in area in situations to which they could not have traveled by gravity on the modern topography (E-12).

CLE ELUM FORMATION (Iron-bearing)

The Cle Elum formation lies upon a basement composed largely of peridotite and serpentine and is overlain by the arkosic Swauk sandstones. It is mostly less than 15 feet thick and is absent in some places so that the Swauk lies directly upon the basement rocks. Thus the Cle Elum formation is revealed as a series of restricted exposures that extend from upper Peshastin Creek near Blewett Pass westward for 20 miles to the Cle Elum River canyon along a line that is determined by the steeply inclined basal surface of the Swauk formation.

The Cle Elum beds are composed of iron oxides and other materials derived from peridotite and serpentine. Conglomerates predominate in the east and argillaceous materials predominate in the west. The Cle Elum is not merely a preliminary phase of the Swauk deposition in which local basement materials predominate but a record of an earlier set of environmental conditions which are apparently unrelated to the conditions that initiated the Swauk deposition. There are a few local instances of reworked Cle Elum material in the basal Swauk, but elsewhere the Swauk phase begins abruptly with arkosic sandstones in which there is little material of local derivation. The iron oxide, largely hematite and magnetite, originated through a process involving the transportation, deposition, and concentration of weathering products of peridotite and serpentine; small amounts of residual materials are also present.

DESCRIPTION

The Cle Elum formation is largely conglomerate, breccia, mudstone, and shale; arenaceous deposits are rare. The megascopic materials are almost entirely made up of peridotite and serpentine. The mudstones and shales are commonly composed of greenish-gray or black basic material evidently derived from decomposition products of peridotite and serpentine but as a rule they contain, in addition, various amounts of hematite and magnetite.

Nearly all the Cle Elum formation is assignable to one or the other of two distinct lithologic types. Both types are locally present in the same stratigraphic section but gradations between the two are uncommon. The first type is largely fine grained, comprising mudstones and shales; it predominates in the western part of the iron zone, especially along the upper Cle Elum River. The other is conglomeratic; it characterizes the eastern part of the iron belt, and especially that on Peshastin Creek near the Old Blewett mining district.

The fine-grained phase is largely mudstone and shale composed of hematite, magnetite, and dark-colored clay. Iron oxide commonly constitutes more than 50 percent of the mudstone and shale, and these show colors ranging from red through brown to gray and black. In other phases the iron oxide content is very low and this rock is normally a black, gray, or greenish-gray mudstone which commonly has a wax-like or resinous lustre. Stratification is best developed in the deposits of high iron content.

Though some phases of the fine-grained type are so well stratified that they can be split readily into layers less than one inch thick, there is very little of the fine lamination that is common in shale. Much of the material is crudely stratified, showing only two or three indistinct bedding planes in a thickness of several feet, and it is not uncommon to find sections several feet thick with no apparent bedding planes except those marking the top and bottom of the bed. On many exposures the bed gives a very massive appearance, when in reality it has a thin-bedded or laminated character that is obscured by the uniform drab color, the high degree of induration, and the resistance of the rock to solution effects. Fine-grained clastics composed of other materials but deposited in the same manner probably would show excellent stratification. The existence of hidden stratification is indicated by the fact that beds of massive appearance on fresh surfaces, such as on the walls of exploratory pits, commonly show excellent stratification on adjacent weathered surfaces (F-20).

It is generally difficult to estimate, even roughly, the iron content of the fine-grained type by the general appearance of the rock, though, as a rule, that which is red or brown in color is high in iron oxide and that which has a shiny resinous lustre is largely clay.

The fine-grained type of sediment is very well indurated and generally more resistant to erosion than the Swauk sandstones above and the serpentine and peridotite below. Marked slickensided surfaces, commonly with a film of serpentine, are common features and appear to be related to the alteration process that is responsible for some of the serpentine in the peridotite below. Small-scale crumpling (F-16) is locally present. Fracturing is common, but well-developed joint sets (F-2, 8), while locally present, are rare.

The fine-grained phase of the Cle Elum formation has a well-defined vertical sequence (C-1, 2, F-8, 11, 13, 18, 20, 23) as noted along the Cle Elum River by Zapffe (1944). The base of the bed normally begins with serpentine and peridotite waste, either as mudstone or shale of low iron content or as sandstone, grit, and even coarser fragmental materials. Much of the shearing and readjustment during the folding of the strata has taken place along this basal phase because the high peridotite content makes it weaker than the upper part of the bed (F-8, 11, 12, 18, 20). The shearing often makes it difficult to determine whether the basal phase is residual or transported. Nevertheless, the common occurrence of stratification, sharply-defined basal surfaces, and gradations upward into stratified material generally indicate that transported material is more abundant than residual material. Above the basal phase normally lies a thicker phase of shale and mudstone that contains a high proportion of iron oxide. Megascopically it appears to be entirely a fine-grained clastic. However, it does contain numerous grains of magnetite and plates of specular hematite but these are probably alteration products and not original grains. Stratification is most common and best-developed in this second phase; oölites and pisolites are also common either as closely packed aggregates or sparingly distributed through the iron oxide. The color is commonly red or brown but gray and black is almost equally abundant. The third or uppermost phase, like the basal phase, is of low iron oxide content. It is almost entirely black, dark-gray, or greenish-gray mudstone and shale; arenaceous materials are rare. A wax-like appearance is characteristic of this phase. The composition is that of basic clay with small amounts of iron oxide.

The three phases of the fine-grained type are gradational and the middle phase of high iron oxide content is often recognized only by its high specific gravity, greater hardness, and, where the hematite content is high, by its red streak; the upper and lower clayey phases are recognizable in many cases only by their light weight, green or gray streak, and soft, easily-scratched character. The middle phase, as a rule, constitutes more than half of the total thickness. Though the above sequence is very common in the Cle Elum exposures it is by no means invariable; in some places the middle iron oxide phase is lacking and the lower and upper phases lose their identity; in other places the lower phase is absent and the iron oxide lies upon serpentine or peridotite; but, where the middle iron oxide phase is present, the upper clayey phase is almost invariably present.

The conglomerate type of Cle Elum, as exemplified by the exposures on upper Peshastin Creek (A-5), is composed of pebbles, cobbles, and boulders in a matrix of iron oxide and mudstone. The coarse pieces reach a maximum diameter of well over five feet but the average size is about one foot. Nearly all the pieces, ranging from barely visible grains to large boulders, appear to be composed entirely of peridotite in various stages of alteration to serpentine, though a few are resistant fine- to medium-grained basic rocks, probably complementary dikes of the peridotite intrusive mass, which may be more truly gabbroid or dioritic. The peridotite pieces range from subangular to poorly rounded. The rounding effects probably are not related to movement in streams and currents but may have originated through spheroidal weathering aided by curved fractures and shear planes. All the gabbroid or dioritic pieces noted are well-rounded waterworn cobbles and pebbles.

The matrix is mudstone in which are abundant grains, granules, and pebbles of peridotite. The mudstone is composed of iron oxide and basic clay derived from decomposed peridotite. Some of the mudstone contains a high proportion of iron oxide and, in that case, commonly shows colors ranging from dark red to reddish brown. The peridotite clay phases and some of the iron oxide are gray, greenish gray, and black. The high-iron oxide mudstones, as a rule, contain much magnetite in addition to the dominant hematite. Some of the magnetite grains are barely visible under a hand lens and it is presumed that there are many microscopic grains; some are in coarse grain and granule sizes. The conglomerate matrix differs from the fine-grained Cle Elum type of iron bed only in a greater amount of included grains and small fragments of peridotite and in the absence of even a rude stratification.

The general aspect of the conglomerate is somewhat unusual. There is no concrete evidence that it was deposited by water for it lacks such common features of conglomerates as stratification of lenses, and minor beds of differing pebble and boulder content, and orientation of pebbles and boulders. Its unusual character is not entirely a matter of lack of sorting, for the pebbles and boulders are scattered, with rather even spacing, through a clayey matrix that generally equals or exceeds the coarser pieces in volume. Not only is there a lack of lenses and bands of differing concentration of pebbles and boulders, but the pebbles and boulders are largely surrounded by matrix and not in contact with one another. There are, of course, variations in the relative amounts of matrix, pebbles, and boulders so that in some places the matrix is little more than interstitial filling of coarse boulder beds and in others constitutes more than 75 percent of the rock mass, but generally the boulders give the appearance of regular spacing regardless of their abundance. This is especially noticeable on weathered surfaces where the pebbles and boulders, standing in relief, present a characteristic "hobnailed boot" appearance. Any explanation of the mode of deposition of this conglomerate must account for the transportation of clay and large boulders and cannot assume interstitial clay filling in boulder and pebble deposits.

The conglomerate is well lithified and its considerable resistance to erosion is demonstrated by its prominent craggy outcrops. Some of the occasional well-rounded pebbles, because of their smooth surfaces, break cleanly from the matrix on weathered surfaces, and others break away readily because they are bounded by slickensides and sepentinized material, but most pebbles and boulders adhere tightly to the matrix so that joints and fractures cut through them, and they develop rough, etched surfaces as they are gradually freed by weathering of the less resistant matrix. Many pebbles and boulders show a chalky zone of weathered peridotite that extends to a depth of one inch or more from the surface of the fragment. These weathered rinds are seldom seen in freshly broken pieces but are brought out by recent weathering where pebbles and boulders are exposed in cross section upon cross-cutting joint surfaces. This feature may be due to weathering or alteration of the deposit after deposition but, in view of the fact that such features could not be found on pebbles that bore unquestionable marks of stream wear, it leads to the possibility that the boulders and many of the pebbles are spheroidally weathered residual pieces, with weathered rinds, that have been brought to the Cle Elum beds by some agency that did not involve considerable abrasion.

The conglomerate, though jointed to some degree, does not show a well-defined joint system. The matrix, however, is transected by numerous disorderly fractures and the entire mass is cut by many prominent, curved, slickensided breaks which commonly include films and thin layers of blue-green serpentine and, rarely, veins of tremolite.

DISTRIBUTION, ASSOCIATION, AND INTERGRADATIONS OF LITHOLOGIC TYPES

Only the fine-grained type of deposit is present in the westernmost part of the Cle Elum belt. It is exposed along both sides of Cle Elum River, at the east base of Goat Mountain, where it reaches a maximum thickness of 32 feet. Exposures of several thinner lenses continue for nearly two miles east of the river and there the formation enters a region of dense timber and landslides in the basin of upper Boulder Creek. Three and one-half miles east of the Cle Elum River, on the east side of the canyon of the Middle Fork of Teanaway River, a basal Swauk breccia lies upon Peshastin and Hawkins metamorphics for a distance of one and one-half miles. Landslides and timber conceal the Cle Elum zone between the Middle and North forks of Teanaway River, a distance of two miles. Between the North Fork and Peshastin Creek, a distance of more than 13 miles, both fine-grained and conglomeratic types are locally developed and occasionally exposed.

At some places along the North Fork-Peshastin section only one type or the other is present, but in other places the two occur together. In the latter case the fine-grained type occurs only as thin lenses associated with greater thicknesses of the conglomeratic type. These conditions are best shown on upper Nigger Creek. One exposure (B-1) shows lenticular bodies of mudstone, less than three feet thick, at the base of a conglomeratic bed that is about 100 feet thick. The contact of conglomerate and mudstone is gradational. About 10 feet above the basal mudstone lies another mudstone zone which reaches a maximum thickness of four feet and pinches out in a distance of 30 feet. Other exposures on Nigger Creek (B-2, 3, 4) show layers of fine-grained type a few feet thick interbedded with conglomerate type and with conglomerate that contains rounded pebbles.

Lateral changes from conglomerate to mudstone are evident between Peshastin Creek and North Fork of Teanaway River, for some exposed sections are entirely mudstone and others entirely conglomerate. Lateral intergradation, though probable in view of observed vertical gradations, has not been seen because of discontinuous exposures.

Lithologic types intermediate between the conglomerate and fine-grained types are surprisingly rare. One occurrence was noted on upper Nigger Creek (B-2) where eight feet of mudstone with occasional rounded pebbles and angular pieces of peridotite is overlain by 12 feet of mudstone in which are numerous well-rounded pebbles and occasional angular pebbles and boulders. A similar condition is present in the conglomerate bed on the west side of Peshastin Creek (A-4) where a bed of mudstone, which is about 30 feet thick and high in iron oxide, lies within the thick Blewett type conglomerate. The mudstone is like the mudstones of high iron content on the Cle Elum River in all respects except the presence of occasional boulders and pebbles of peridotite. Boulders and pebbles increase in number at the base of the mudstone and the contact with the underlying conglomerate is gradational; the upper contact is gradational in some places and in others it is an abrupt transition to coarse boulder conglomerate.

STRATIGRAPHIC RELATIONS OF CLE ELUM FORMATION AND BASEMENT ROCKS

The Cle Elum beds lie upon peridotite and serpentine. Altered sedimentary rocks of the Peshastin formation and altered basic lavas, breccias, and tuffs of the Hawkins formation are present in nearby areas. Southwest of the iron belt the Easton schist was present and is now exposed only a few miles southwest of the iron belt. The Mt. Stuart granodiorite is now widely exposed a few miles north of the iron belt and possibly it was present during the deposition of the Cle Elum beds. However, the schist and granodiorite, as well as unknown rock types buried beneath the extensive cover of Tertiary formations and those lying some distance away, have left no record of their presence in the Cle Elum sediments. Those sediments are composed largely of peridotite waste and iron oxide thus indicating a strictly local derivation of the Cle Elum materials.

In view of the local origin of the Cle Elum it becomes necessary to give particular attention to those details which will decide the relative importance of residual and transported materials in the belt. Some of the pertinent evidence such as the lithologic character and stratification of the beds already have been discussed, and the primary object here will be to pay especial attention to the Cle Elum-basement rock contact zone.

Smith (1904) believed that the Swauk formation, of which the iron-bearing beds were considered a basal phase, was deposited in the rising waters of a large lake and that the "rugged topography caused the coast line to be extremely irregular." The concept of a rugged topography prior to the Cle Elum was emphasized by Smith and Calkins (1906) and by some later writers. Concrete evidence of a rugged pre-Cle Elum topography is lacking along the iron belt. The presence of boulder conglomerates in the eastern iron zone is perhaps indicative of considerable relief, but, as pointed out on a previous page, the conglomerate is primarily a mudstone through which are scattered many boulders and smaller pieces.

The fine-grained type of iron bed deposit, on the other hand, is strongly suggestive of low relief in the pre-Cle Elum surface. In the Cle Elum region it is almost entirely mudstone and shale in which even small pebbles are absent. Sandy, granular, and pebbly materials are locally present but they are restricted to a thickness of a few inches or a few feet at the base of the Cle Elum formation, and much of these materials is residually weathered peridotite. East of the Teanaway River these fine-grained deposits are locally interbedded with conglomerate and even lie at the base of the conglomerate. The lithologic character of the Cle Elum beds, therefore, furnishes no conclusive evidence of a rugged topography and gives some strong evidence against it. The basal Swauk beds, to be discussed on a later page, emphatically discount the rugged topography concept because of their fine grain and general lack of local materials.

The Cle Elum-basement contact shows no prominent channels or ridges suggestive of considerable relief. Several marked deviations (C-7) in the generally regular trend of the contact were noted but these are of later structural origin. Small-scale relief is indicated by the lenticular character of the Cle Elum beds, but little relief is required to cause local stratigraphic failure of a bed that, in most places, is less than 25 feet thick. At some places the peridotite surface beneath the iron bed is hummocky and irregular with a local relief of less than 20 feet (B-1, E-9, 11, F-8, 9, 13).

The general impression of the pre-Cle Elum topography gained during the investigation is that the surface in the western end of the iron belt was one of very low relief, perhaps of less than 100 feet, but that in the east, where conglomerates are predominant, the relief may have been on the order of several hundred feet.

It is perhaps to be expected that the contact zone of the Cle Elum and underlying rocks would normally show deeply weathered basement rock and residually weathered material that might not be clearly distinguishable from the transported fine materials, for the high proportion of clay and iron oxide in the Cle Elum beds suggests conditions favoring advanced chemical weathering of the peridotite. Pronounced weathering effects are not uncommon in the peridotite below the Cle Elum beds but residual soil layers and gradational contacts of clayey material and bedrock are surprisingly rare. As a rule the basal Cle Elum contact is abrupt and definite; gradational contacts were noted at some places (B-2, F-10, 11, 12, 13) but in some of these a residual character of the Cle Elum beds could be ruled out for all except a few inches or a few feet of basal material because of stratification or other features indicating transported material. As a rule the basal part of the Cle Elum is made up of greenish-gray or black clay or of granular peridotite waste in which may be angular fragments as much as six inches in diameter. This basal zone commonly lies below mudstone or shale of high iron oxide content and so superficially resembles either a gradation from concentrated iron oxide to basement rock or a zone of weathered peridotite beneath transported clay and iron oxide. It is apparently this basal zone that led Zapffe (1944) to conclude that the Cle Elum belt is a residual laterite that grades downward into peridotite. Most of these occurrences, however, reveal a transported character either by stratification within the material or by a regular abrupt contact with unweathered peridotite below. The residual or transported character of the basal Cle Elum formation could not be decided in some places because much of the adjustment to folding has taken place in the basal zone which was less competent than strata above and the massive peridotite below, and in the presence of extensive foliation (B-2, 3, D-1, F-8, 11, 18, 25) it is difficult to differentiate between sheared peridotite waste and sheared peridotite and serpentine. The considerable serpentinization of the peridotite that has taken place since the Cle Elum beds were deposited also affects the reworked peridotite materials and obscures their original sedimentary character. Some of the exposures show mudstone or shale of high iron content lying directly upon basement rock.

The upper part of the peridotite beneath the Cle Elum beds and beneath questionable residual zones is commonly made up of a black dense soft material of glossy or wax-like lustre (B-2, C-2, E-11). It is usually cut by numerous curved shear planes like those characteristic of serpentine, and, in fact, the material resembles a black serpentine. It is so similar to the black, wax-like, serpentinized mudstones of the Cle Elum that hand specimens of the two materials can seldom be differentiated, and it appears certain that the material represents the weathered zone of the peridotite basement rock. At the time of the Cle Elum deposition the black material probably included much basic residual clay that was similar to the transported clays of the Cle Elum formation. Post-Cle Elum alteration, which was responsible for some of the serpentine deep in the peridotite mass, also developed the serpentine characters of the basic clays. In some places the weathered rock is restricted to a thickness of a few inches or a few feet and extends irregularly into the peridotite mass along joints and shear zones to depths of as much as 50 feet; in other places it reaches thicknesses of 10 to 20 feet but generally shows irregular branches penetrating the joint planes to even greater depths. The weathered rock normally shows a gradational contact with peridotite or with the normal type of green serpentine.

A second type of alteration effect along the upper part of the peridotite basement is very common. Instead of the black wax-like type of altered clay it shows much iron oxide stain (C-2, E-4, 5, 11, F-6, 8, 11). The weathered zones when viewed from some distance give the false impression of a thick Cle Elum exposure, but at close range one finds that the colors, ranging from yellow and orange to dark red, are but iron oxide stain upon very rough, pitted, and intricately etched surfaces which traverse the peridotite in all directions. A film or thin zone of light green chalky altered material generally lies immediately beneath the iron stain. The effect is such as one would expect if alteration of peridotite and serpentine had taken place along all the joint surfaces, fractures, and shear planes so that the rock was softened and stained to a depth of a few millimeters or a few inches along every avenue that could be reached by percolating solutions; then upon exposure on the present land surface, much of the altered nonresistant material was carried away, leaving a rough iron-stained surface that is suggestive of solution effects upon calcareous rocks. These rough, stained surfaces contrast markedly with the blocky, somewhat smooth surfaces of peridotite and serpentine at some distance from the contact. The stained surfaces commonly extend to depths of less than 50 feet, but locally in the Cle Elum region reach depths of more than 200 feet below the Cle Elum formation.

Associated with the stained and altered peridotite zone are numerous seams or veins of iron oxide (E-9, F-6, 8, 12, 14, 17, 21) which extend to the same depth as the alteration. The seams are mostly less than four inches wide though some are more than a foot wide. They are extremely variable in width and in the course that they follow, so that it is difficult to trace many of them for more than 10 or 20 feet, but because they are wider and more numerous immediately below the Cle Elum formation and trend generally normal to the contact, it is believed that the seams are iron oxide-filled fissures that extend into the peridotite basement rocks to maximum depths of more than 200 feet (F-11). The iron oxide filling does not differ materially from the iron oxide phases of the Cle Elum; red hematite and invisible clay of lighter weight prevails but magnetite is also present locally in such amounts as to develop natural lodestone, as on Magnetic Point east of Cle Elum River. The iron oxide shows no banding or other structures that might indicate chemical deposition but is solid and massive except where it has been crushed or sheared by later earth movements. A combination of brecciation, foliation, and serpentinization is very common along the iron oxide seams. It produces fine-grained breccia of serpentine and iron oxide fragments, sheared iron oxide layers, and markedly foliated serpentine and iron oxide. This later type commonly produces a ruby red or carmine serpentine in which the iron oxide content, judging from the light weight, is probably less than 20 percent. Much of this type is well exposed in the region because the brilliant red shear surfaces have remarkable stimulative effects upon prospectors and miners; the two largest tunnels of the region, the Balfour-Guthrie mine (F-14) of the Cle Elum region and the Skookum mine on the Middle Fork of the Teanaway, were driven through serpentine in which were many seams of red serpentine. The crushing and serpentinization have left some seams untouched, but their effects extend into the Cle Elum beds and residually weathered peridotite beneath; therefore they are evidently related to the post-Cle Elum deformation and are in no way involved in the origin of the iron oxide seams.

The localization of the stained and etched surfaces, the altered peridotite, and the iron oxide seams in a zone immediately below the pre-Cle Elum land surface is strongly suggestive of agencies operating beneath that surface prior to or during the Cle Elum deposition. It is difficult to account for these phenomena by decomposition in the aerated zone of the earth because that would require the water table to be at a depth of more than 200 feet in a region of deposition, of low relief, and of moist climate. The possibility of solution and decomposition of the peridotite below the water table cannot be ruled out. The iron oxide seams are possibly the result only of subsurface processes, but the iron oxide resembles the high-iron oxide phases of the Cle Elum so closely as to suggest that they were carried from the surface into open solution fissures. The seams cannot be related unquestionably to the transported iron oxide of the Cle Elum formation, but such an origin is suggested by the fact that all gradations exist from a jagged Cle Elum-peridotite contact through broad short iron oxide seams obviously confluent with the Cle Elum (F-9) to narrow deep seams whose connection with the Cle Elum cannot be traced.

STRATIGRAPHIC RELATIONS OF CLE ELUM AND SWAUK FORMATIONS

Smith and Calkins (1904, 1906) regarded the iron-bearing beds as a preliminary phase of locally derived materials in the basal beds of the Swauk formation. The present investigation revealed local materials in the basal Swauk only in a few places and indicated that the iron oxide deposits herein referred to as the Cle Elum beds are stratigraphically and genetically distinct from the overlying Swauk formation. The Cle Elum beds are of local origin; the composition reflects accurately the basement rocks that are immediately beneath it; they constitute record of low relief, nearly inactive erosion, and quiescent diastrophism. The Swauk formation shows an abrupt change to rock materials of distant origin; it is a record of diastrophic activity and of renewed, active erosion and deposition. The inclusion of local materials in the basal Swauk took place locally, notably on Iron Peak, but resulted largely from the reworking of Cle Elum sediments.

The Cle Elum is composed almost entirely of peridotite and serpentine pieces, basic clays evidently derived from peridotite and serpentine, and iron oxide which, in the form of magnetite, is abundant in the peridotite. Occasional pebbles of basaltic rock, probably derived from nearby Hawkins rocks, were locally noted, but in the entire course of the field studies not one granitic rock fragment was found in the Cle Elum conglomerates.

The Swauk formation, by contrast, is composed largely of granitoid rock waste. Though shales are abundant in the Swauk Creek section which has been included with the Swauk formation, the strata lying above the Cle Elum and constituting a thickness of more than 5,000 feet are composed largely of arkosic sandstone. Beds of conglomerate and pebbly sandstone are present in some parts of the section but probably amount to less than 15 percent of the total thickness; shale was rarely seen and then only as beds a few inches or a few feet thick. The arkosic sandstones are mostly of coarse grain in which the feldspar and quartz is readily seen. Though there may be ample reason to question the statement of Smith and Calkins (1904, 1906) that the arkosic beds are "plainly derived from the Mt. Stuart granodiorite" there can be no question that they were derived from granitoid rocks.

The pebbles in the Swauk sandstones and conglomerates give more exact information on the sources of the Swauk formation. They are characteristically well-rounded and imbedded in a matrix of arkose. The advanced degree of rounding casts doubt on the derivation of the pebbles from a nearby source, and if they came from the Mt. Stuart granodiorite it would appear that they came from more distant portions of the Mt. Stuart mass than that mapped by Smith and Calkins (1904) a few miles north of the Swauk exposures. This inference is borne out also by the composition of the pebbles, for they are mostly quartz and medium- and fine-grained acid rocks which are very hard and resistant to wear. Normal granitoid rocks are very rare in some beds and only locally are predominant. The pebbles, therefore, are largely the minor resistant rock types such as would be present as veins and dikes in a granitoid mass, and their concentration in the Swauk conglomerates strongly suggests that the normal granitoid types have been reduced in amount through extensive transportation. Other rock types almost invariably represented in the conglomerates but of very minor number are basalt, quartzite, and quartz-mica schist. The basalt is similar to that in the Hawkins lavas and breccias and is probably from that source. The quartz-mica schist is similar to some phases of the Easton schist as described by Smith and Calkins. Though the Swauk, for a distance of many miles, lies upon peridotite or is separated from it only by the thin Cle Elum beds, peridotite pebbles in it are extremely rare in the main body of the formation. In a few places, however, minor sandstone beds near the base of the formation contain numerous dark grains which are in part basalt but also include peridotite, and, in the localities noted below, local materials have been included in the basal beds of the Swauk.

The lowermost Swauk beds are mostly sandstone which, in large part, are of markedly finer grain than the coarse, granite-like, arkosic sandstone that one comes to regard as "typical" Swauk sandstone. Conglomerates are present in the lower part of the Swauk formation but they lie mostly from 20 to 800 feet above the base of the formation and only in a few places (E-3, F-6, 9) do they come down to the base of the formation. The conglomerates appear to mark a well-defined and widespread lithologic facies of the Swauk, for they were noted in section after section from the vicinity of the westernmost Cle Elum outcrops near Cle Elum River eastward for 15 miles to upper Nigger Creek. As a rule they do not constitute a definite bed but appear as a series of beds including conglomerate, pebbly sandstone, and coarse sandstone. The thickness ranges from 20 feet to more than 300 feet.

The Swauk-Cle Elum contact is nearly everywhere very sharply defined. The usual condition is one in which the light-gray arkosic sandstone lies upon a flat well-defined smooth upper surface of the Cle Elum beds with no visible mixing of the two very unlike sediments. A similar situation exists where the Cle Elum beds are absent and the Swauk sediments lie upon peridotite and serpentine.

The principal exception to the rule that the basal Swauk contains little material from nearby basement rocks is found on the west side of Middle Fork of Teanaway River where breccia and mudstone lie between the arkosic Swauk sandstones and the basement. The basement rock of this region is largely a complex mass of various kinds of Hawkins and Peshastin rocks as well as minor amounts of serpentine. The Hawkins rocks are largely well-lithified red and green tuffs and breccias. The Peshastin is composed of gray and nearly white siliceous schist in which are quartz veins and pods of quartz and cherty material. Green chloritic schists are also present and may be a part of the Peshastin. The basement rocks here were mapped by Smith (1906) as Peshastin, probably because of the difficulty of separating the several types.

The breccia bed ranges in thickness from 10 to 80 feet. At the southeast it is largely a fine-grained breccia composed of a tumbled mass of sharply angular fragments of quartzose material derived from the Peshastin, and of angular Hawkins rocks. The matrix, in some places less than 25 percent of the rock, is green and brown clayey material such as could have come from the weathering products of either Hawkins formation or peridotite. Northeastward the bed increases in thickness for a distance of one-half mile and includes layers of green and brown mudstone with little fragmental material and layers of coarse or fine breccia. Northwestward to Jolly Mountain ridge the thickness decreases somewhat, fragmental material is less abundant, and the bed is largely a gritty and sandy mudstone with scattered angular pieces of Hawkins and Peshastin rocks. The contact of the breccia-mudstone with the overlying arkosic Swauk sandstones is sharply defined in some places but in others it is gradational and on the east side of the Jolly Mountain ridge light gray arkosic sandstone layers are interbedded with the breccia and mudstone.

The breccia-mudstone bed resembles the Cle Elum beds only in being composed of locally derived material. The lack of appreciable amounts of iron oxide, gradations with Swauk sandstones, and interbedded arkosic sandstones indicates that the deposit is a locally derived facies of the basal Swauk beds.

Four exceptions to the general rule that the basal Swauk and Cle Elum beds are lithologically distinct and do not intergrade have been found. On the south side of Camp Creek (F-27) several feet of green basic sandstone and mudstone overlying the Cle Elum are apparently basal Swauk beds. An exposure on the east slope of Goat Mountain (F-16), shows a thickness of about 40 feet of gray and black mudstone composed of peridotite waste and materials reworked from the Cle Elum. In a small exposure high up on the east side of the Cle Elum canyon (F-10) fine sandstone and mudstone, for a thickness of 12 inches above the Cle Elum beds, contain enough iron oxide to color them a brick-red. Ferruginous mudstones, sandstones, and conglomerates grading into and interbedded with arkosic sandstones and black shales of the basal Swauk formation are well-developed high up on the south side of Iron Peak (E-1 to E-11).

It is believed that these apparently gradational contacts are due to reworking of the Cle Elum beds during the initial phase of the Swauk deposition. The Cle Elum occurrences were seen only in small exposures and revealed nothing conclusive, but the Iron Peak occurrence is widely and cleanly exposed, and there the evidence for reworking appears conclusive.

Conglomerate is abundant in the ferruginous beds of Iron Peak. Some of the conglomerate is the normal conglomeratic type which has numerous pieces of peridotite well spaced through a matrix of iron oxide and clay, and this type lies upon peridotite, does not intergrade with Swauk beds, and is not interbedded with them. A second type of conglomerate, more abundant than that of the Cle Elum formation, contains the usual scattered pebbles and boulders, but the matrix is composed of sandstone, grit, and fine pebbly materials wholly unlike the matrix of the Cle Elum conglomerate. Many of the larger pebbles are well rounded, and many of the pieces of granule and small pebble size, ranging from angular to well rounded, are composed of red iron oxide mudstone characteristic of the fine-grained beds in the Cle Elum. Small round pellets of pea size are abundant; some of these are peridotite in small pieces, but, significantly, many of the pellets are reworked iron oxide oölites. The sandstone phase of the matrix is like that which occurs abundantly on Iron Peak as distinct ferruginous sandstone beds. The sandstone bears no resemblance to the arkosic Swauk sandstones; it is mostly red and brown and contains much iron oxide. Superficially it resembles the mudstones and shales of the fine-grained beds of the Cle Elum which are high in iron oxide but it is an arenaceous rock made up of hematite, magnetite, and peridotite grains. The grained character is best revealed by black magnetite grains which commonly occur as sharply defined laminae and thin layers of black sand but also are scattered among grains of hematite. The arenaceous character is evident even where the black sands are absent. Where the sandstones, either in distinct beds or as matrix of conglomerate, contain granules and small pebbles, oölites are almost invariably present.

The abundance of oölites in the conglomerate matrix and in pebbly sandstone, the abundant pebbles of iron oxide and mudstone of which some are well rounded and evidently waterworn, and the unusual arenaceous character of much of the ferruginous strata indicate extensive reworking of Cle Elum materials that were sufficiently lithified to permit their shaping into well-rounded pebbles. This thesis is supported by the presence of abundant and well-preserved fossil plants in the red ferruginous beds (E-4, 7, 8), for fossil plants are very common in basal beds of the Swauk and almost wholly lacking in the Cle Elum formation.

Mudstone and shale resembling the fine-grained beds of the Cle Elum are present also. Some are black or greenish-gray and obviously composed of basic clay derived from peridotite, and others contain so much red iron oxide that they resemble hematite. Reworking is difficult or impossible to detect in these argillaceous beds. However, they show much better stratification than the usual Cle Elum beds of fine grain. This condition extends to the sandstones and conglomerates as well, and it is a striking feature when contrasted with the massive character of the normal conglomerate of the Cle Elum formation. The high development of stratification, therefore, may be a reliable guide for identification of reworked Cle Elum materials of fine grain.

The ferruginous conglomerates in no place were found above arkosic sandstones and shales of the Swauk type. They lie upon a hummocky surface of peridotite or upon massive peridotite-iron oxide mudstone which fill the irregularities of the peridotite surface, extend into fissures, and form a flat surface upon which the coarse beds lie (E-9). The shales and mudstones of the Cle Elum type are in places (E-7, 10) interbedded with gray and brown arkosic sandstone layers and with black shale and mudstone of the Swauk type. Moreover some very micaceous sandstones, which are probably arkosic as well, are much iron-stained and contain oölites of iron oxide. Vertical gradations from Swauk to Cle Elum types are common and one locality (E-2) shows a fine-grained ferruginous bed seven feet thick which in a distance of 75 feet grades laterally into fine conglomerate that is composed of both peridotite and siliceous pebbles in a matrix of peridotite waste and iron oxide. Mixing, interbedding, and intergradation of Swauk and Cle Elum probably do not extend through a greater thickness than 50 feet.

The impression gained from the Iron Peak locality is that both conglomeratic and fine-grained types of the Cle Elum were present here at the beginning of Swauk deposition and, because of some unusual local condition, perhaps of land relief or of drainage, much of the Cle Elum was eroded and entered the basal Swauk beds as (1) reworked conglomerates, sandstones, mudstones, and shale of essentially the same composition as the original Cle Elum, and (2) as Cle Elum materials mixed with arkosic sandstone and shale of the Swauk type. Most of the iron-bearing beds of the Iron Peak region, therefore, are classed by the writer as a part of the Swauk formation.

The prevailing stratigraphic relations of Swauk and Cle Elum, as presented on earlier pages, repeatedly emphasize the marked differences of Swauk and Cle Elum materials in composition, source, and environmental conditions indicated, and these conditions are not transitional as they should be if local materials were extensively included in the basal Swauk beds, but remarkably abrupt. The Iron Peak occurrence is an exception to the rule that Swauk and Cle Elum beds are composed of radically different materials but it is not a contradiction of the thesis that the two are chronologically and genetically distinct. In fact the iron oxide sands and well-rounded iron oxide pebbles in the Iron Peak deposit add much to the evidence of a time difference.

STRUCTURE

Structures relating to folding.—The Swauk formation and the Cle Elum beds are concordant in structure. The diastrophic activity which initiated the Swauk deposition apparently had little effect upon the Cle Elum formation of the Mt. Stuart region. The great section of arkosic sandstone in the Swauk, perhaps amounting to a thickness of 10,000 feet, necessarily indicates long continued subsidence in the area of Swauk deposits and corresponding elevation of the regions that furnished the sediments, but the initial stage of diastrophism that affected the Cle Elum formation before it was covered by arkosic sands may have been one of slight relative subsidence and gentle local warping. Some evidence of local relief and active erosion is present in the Iron Peak and Goat Mountain occurrences of reworked Cle Elum materials, and other occurrences may be present in some places where the iron zone is concealed by alluvium and soil, but the wide distribution of the thin Cle Elum formation, the lack of local materials in the Swauk, and the general absence of scour on the upper surface of the Cle Elum shows the lack of local erosion preceding Swauk deposition and therefore, by inference, the lack of marked local diastrophism. Available evidence indicates that the discontinuous nature of the Cle Elum beds is largely an original depositional feature and not one related to post-Cle Elum erosion.

Post-Swauk deformation of more than one episode has produced broad folds in the Swauk formation, but in the vicinity of the iron belt one sees only steeply inclined Swauk and Cle Elum beds which dip away from the crystalline and metamorphic rocks of the Mt. Stuart region. From Peshastin Creek westward to Middle Fork of Teanaway River the strata dip southward mostly at angles exceeding 50 degrees; dips of 80 to 90 degrees are very common, and slight overturning is locally present. West of the Middle Fork dips of less than 30 degrees are common and, one and one-half miles east of Cle Elum River the Cle Elum beds are horizontal or dip less than 30 degrees for a distance of one-half mile. Near the Cle Elum River the dip increases and ranges between 45 and 90 degrees for more than two miles along the river. The strike is surprisingly regular, showing only three minor deflections from the prevailing westward trend in a distance of 20 miles from Peshastin Creek to Cle Elum River (pl. 1). In the Cle Elum canyon, however, the strike swings from west to northwest and then to northeast in a distance of one-half mile, producing a steeply pitching anticline with widely divergent limbs. Cle Elum River follows the west limb of the anticline north of Boulder Creek, enters the peridotite near Boulder Creek, and again enters the Swauk section approximately on the axis of the fold. Between Boulder Creek and Camp Creek two shallow synclines plunge steeply westward with the dip of the major structures and the exposures of the Cle Elum formation follow a somewhat sinuous course along the bottom of the Cle Elum canyon.

The structure of the Cle Elum formation is commonly not closely reflected by the Swauk strata for more than several hundred or a thousand feet above it. In the Teanaway region most of the Swauk strata dip southward at angles of 50 to 60 degrees or even less so that the strata show considerable topographic deflection of outcrops in this rugged ridge and canyon country. The dip steepens in the basal beds, and the nearly vertical Cle Elum beds or basal Swauk contact continue regularly westward with little deflection of outcrops by the rugged topography. Between the Middle Fork and the Cle Elum River quite the reverse situation is present, for the Swauk strata a few hundred or a thousand feet stratigraphically above the Cle Elum are vertical or dip very steeply, but the basal Swauk and Cle Elum beds show a low dip. This condition is best developed on the ridge between Boulder Creek and Little Boulder Creek where the Cle Elum is horizontal (F-2) but the Swauk sandstones less than 2,500 feet above are vertical.

The reasons for the condition of high dip of the Swauk and low dip of the Cle Elum are unknown. It does not appear to be related to location relative to a synclinal axis, for the transition generally takes place in a distance of less than 2,000 feet whereas the thick succession of Swauk strata above maintain their steep dip for a distance of more than two miles across the strike. Great quantities of dike materials lie along the transition zone and their intrusion may account for the change of structure in the Swauk.

The condition of low dip on the Cle Elum beds and high dip on nearby Swauk strata appears to be related to relative distance from a region of low dip on a broad structural terrace or flat-topped anticline. On Iron Peak, for example, the line of Cle Elum outcrops trends regularly westward across the flanks of the mountain and shows dips generally greater than 60 degrees. Higher up on the mountain, however, numerous remnants of the Cle Elum and lowermost Swauk strata are preserved on the ridge tops showing the excellent exposures of reworked Cle Elum materials described on an earlier page. These remnants show low dips, some as little as five degrees, and, of course, the remnants are there because the dip of the Swauk and Cle Elum beds is so low that it conforms closely to the upper ridge level of this broad-topped mountain. North of the remnants of low dip many ancient landslide blocks of basal Swauk and Cle Elum show that the original base of the Swauk once lay only a short distance above the present ridge tops. The distribution of these outliers and landslide material seems to require a structural terrace, or zone of gentle south dip, immediately north of the main Swauk and Cle Elum sections that traverse the lower slopes of the mountain with high angle dip.

Essentially the same situation is repeated east of Cle Elum River. As described above, the dip of the Swauk decreases 80 or 90 degrees to zero in a horizontal distance of less than 2,500 feet. This could be nothing more than an abrupt minor wrinkle or local terrace on the major structure so far as the evidence preserved in the Swauk beds is concerned, but more than one mile north of the main iron belt, on the ridge north of Boulder Creek, the peridotite contains seams of iron oxide (F-28) like those common below the Cle Elum beds, and lying on the peridotite are small remnants of the Cle Elum formation. The seams and iron oxide remnants, therefore, show that the Cle Elum was once present here at nearly the same level as on the opposite side of Boulder Creek Canyon more than a mile away. The nature of the original structure cannot be determined here as certainly as on Iron Peak because the outliers are fewer and more localized, and the possibility of faulting cannot be entirely discounted, but the similarity to the Iron Peak conditions is certainly suggestive of a repetition or westward continuation of the terrace structure.

Faults.—The Cle Elum formation is offset in a number of places by small transverse faults but in only two localities were displacements of more than 200 feet noted. One major fault is located one and three-fourths miles east of the Cle Elum River where the strata, striking regularly eastward and dipping gently southward, end abruptly on the east against peridotite. The relations are very much obscured by dense timber and landslides, but the distribution of occasional peridotite and nickel ledge outcrops indicates that the continuation of the Cle Elum beds east of the fault has been offset about 2,000 feet to the south. The relative values of horizontal and vertical components are unknown.

The second locality is one of more complex major faults; it lies at the easternmost end of the iron belt (pl. 1). On the north side of the Shaser Creek canyon the Swauk sandstones and conglomerates dip steeply northward toward a major east-west fault that has brought the Swauk down against peridotite. The Cle Elum beds are necessarily cut off by the fault, but a thick section of Cle Elum conglomerate with interbedded fine-grained type (A-5) is preserved between the fault and peridotite for a distance of 1,600 feet. The dip is not evident in the massive conglomerate but the included layer of fine-grained type dips southward at 65-70 degrees, thus suggesting that the Cle Elum lies upon the peridotite in the usual structural relation. However, the peridotite-Cle Elum contact is not exposed and it was not possible to determine whether this Cle Elum occurrence lies between two faults or between a fault and a depositional contact.

East of the main Cle Elum exposures at Shaser Creek other faults with different orientation have brought the Swauk beds down against the peridotite and the Cle Elum formation is absent except as small remnants preserved between large basalt dikes in the peridotite area. The fault relations of Swauk and peridotite are maintained northeast across Peshastin Creek, lower Tronsen Creek, and into the hills beyond. This Shaser Creek-Peshastin Creek-Tronsen Creek area appears to be a zone of major faulting in which three or more major faults, or fault zones, converge toward the junction of Shaser Creek and Peshastin Creek. In addition to the westward- and northeastward-trending dislocations which have brought the Swauk down against the peridotite, a third major dislocation extends southeastward along Scotty Creek into the Swauk area and separates two unlike masses of Swauk strata. Northeast of the fault arkosic sandstones and conglomerates, like those overlying the Cle Elum beds, dip gently southeast; southwest of the fault shales and sandstone like those of the Swauk Creek area dip steeply northward. The relations of the three lines of dislocation are obscured by soil and alluvium in the region of their intersection; it is possible that two of these three major lines are a part of a single fault which changes strike abruptly.

Small faults, with stratigraphic throw of less than 200 feet, are common along the basal Swauk and Cle Elum beds (C-3, F-15, 21, 23, 24). They will not be individually described. Shear planes or foliation in the basal part of the Cle Elum formation in the upper part of the peridotite basement rock are so marked in some places as to indicate appreciable displacement parallel to the Cle Elum-peridotite contact, but the displacements are not measurable. Extensive development of nickel ledges at the Swauk-peridotite or Cle Elum-peridotite contact in the Teanaway country are likewise suggestive of fault displacements because the nickel ledge material is so generally associated with pronounced shear zones.

Dikes and veins.—The numerous basic dikes and the less numerous though abundant "nickel ledge" veins are the record of at least two episodes of marked fracturing and fissuring. Both episodes had important effects upon the Cle Elum strata but that of dike intrusion is by far the more important, not only because of the great number of dikes but also because they trend generally northeast and intersect the westward-trending Cle Elum at wide angles. The nickel ledges are not only less numerous but also generally trend nearly parallel to the Cle Elum formation and so are only locally in contact with it. The basic dikes are more abundant in the Swauk area, less abundant in the peridotite and older rocks; the nickel ledge veins are abundant in the peridotite, locally highly developed immediately beneath the Swauk and Cle Elum beds, and rare within the Swauk area.

The basic dikes are described at some length by Smith (1904). The present discussion will be restricted largely to additional details noted along the iron belt. The most striking features of the dikes are their number, the great volume of intrusive material represented by them, and the extensive rupturing of the older rocks that accompanied their intrusion. Measurements which would permit an accurate analysis of the volume of dike material are not available, but estimates of the approximate volumes were made a number of places and they indicate that, along a line parallel to the strike of the Swauk and 500 feet above the base of the formation, the average ratio of intrusive to sedimentary rock may be on the order of 1 to 4 throughout the length of the iron belt; that for a distance of more than 8 miles the intrusive exceeds the sedimentary rock; and that locally, for distances of about one mile, the volume of intrusive rock is eight or nine times that of sedimentary rock. The volume of intrusive rock differs greatly from place to place. In the Cle Elum region it is very low and dike rocks probably constitute less than one-tenth of the total rock volume. They are more abundant in the Peshastin Creek region at the opposite end of the iron belt, but it is in the eastern part of the Teanaway drainage area that they reach their greatest development. From the east side of Miller Peak west to the west side of Iron Peak, a distance of more than eight miles, the intrusions are so numerous as to reduce the Swauk to a series of thin sandstone slabs lying between large complex dike masses. The ridge between Standup and Bean creeks is probably more than 90 percent basic dike material and the Swauk sandstones are preserved as occasional thin layers or lenses a few feet or a few tens of feet thick. Sandstone layers are somewhat more numerous between Standup and Stafford creeks and on Miller Peak, but in a distance of more than eight miles the volume of basalt is considerably greater than that of Swauk rocks.

These estimates, showing great amounts of dike material, are given for a stratigraphic horizon about 500 feet above the base of the Swauk formation. They do not apply in the same high degree to the upper beds of the Swauk, the basal beds, Cle Elum beds, and the basement rocks below, for the intrusions are most numerous along an indefinite zone that lies some distance above the base of the Swauk and many dikes fail to cross the Cle Elum beds or enter the basement rocks beyond. This zone of dike concentration was not seen in the Cle Elum area but it may be present, for the Swauk area is densely timbered and was not closely observed; a number of basic dikes and a few acidic dikes were seen along the basal contact and many of these cut across the Cle Elum formation. Similar conditions were indicated eastward to the Teanaway River, though much of the iron belt is concealed by landslides, soil, alluvium, and dense timber. Along the south slopes of Iron Peak the zone of excessive intrusion begins and continues eastward to and beyond Miller Peak. On Iron Peak great numbers of dikes cut across the iron-bearing beds and divide them into a series of short sections, but on the eastern part of the mountain it is already evident that there are fewer dikes in the immediate region of the Cle Elum section than in the Swauk section or in the peridotite 100 feet or more from the Cle Elum beds. East of Beverly Creek intrusives make up fully 50 percent of the rock in the lower Swauk zone but few of them continue into the basal beds and there is an irregular strip of sandstone, ranging in width from 20 feet to more than 200 feet, lying between the zone of heavy intrusion and the peridotite. This condition is maintained eastward across the two forks of Bean Creek, Standup Creek, and Stafford Creek, showing a zone of few intrusions in the lower 50 to 500 feet of the Swauk formation and a stratigraphically higher zone of numerous intrusions. Even on the Bean-Standup ridge, where the basic intrusions are estimated at 90 percent of the lower Swauk section, a zone of sandstones with relatively few dikes persists near the Swauk-peridotite contact.

The upper part of the zone of numerous intrusions is not as clearly defined as the lower part, but it is generally evident at a point 2,000 or 3,000 feet above the base of the Swauk that the dikes are less numerous than lower in the section. On Miller Peak, however, dikes are extremely abundant in beds that may be fully 4,000 feet above the base of the Swauk.

In the Peshastin Creek area the dikes are numerous but less abundant than in the Teanaway country. They are regular and well defined in the Swauk area and are cut off by the fault at the Swauk-peridotite contact. Though this region as a whole conforms to the general rule that dikes are less abundant in the peridotite than in the Swauk, there are some large complex dikes in the peridotite on the west side of the Peshastin Creek canyon and these have no counterpart in the local Swauk section.

The basic dikes are of two kinds. One kind is of fairly constant width and these maintain fairly uniform strike and dip for considerable distances where they occur in the Swauk formation but are shorter and more variable in width, strike, and dip in the peridotite. Some of these dikes are more than 100 feet wide but the average width is probably about 30 or 40 feet. In the zone of numerous dikes it is commonly difficult to distinguish individual dikes, for they stand side by side without intervening sandstone slabs and make up multiple or compound dikes several hundred feet or even 1,000 feet wide. The second kind is one of irregular and commonly very complex injections. In extreme cases these are short, broad, and as irregularly shaped as an amoeba, suggesting what one might expect if a large amount of fluid material were suddenly and forcibly injected into the rock along a small pipe-like conduit. Others are more regular masses of wedge-like or ovoid outline.

Dikes of the first type are composed largely of solid basaltic material. The second type, however, includes much brecciated and even highly vesicular material, indicating that early materials of the intrusive episode were broken up and included in later injections. Also present is a soft, brown, massive basalt type which resembles a weathered basalt.

Though the dikes are largely intrusive phenomena, they and the forces that produced them have an important bearing on structure of the iron-bearing beds, for their continuity is interrupted in many places by cross-cutting dikes. From the economic standpoint it is fortunate that the regions of most numerous dikes are mostly those in which the Cle Elum is absent or poorly developed. Along most of the zones of extensive intrusions in the Teanaway region the Cle Elum is absent beneath the Swauk and where present it is mostly so thin and of such low grade as to be of doubtful economic importance even if unaffected by dikes. The thickest and most continuous sections of "high grade" iron oxide in the Cle Elum region are likewise little affected by dikes, and a zone of numerous dikes there coincides with a zone of thin, discontinuous deposits of iron oxide. On Iron Peak, however, the iron oxide deposits of the basal Swauk and Cle Elum beds are commonly more than eight feet thick and appear to have considerable lateral dimensions though there is much uncertainty on this point because of the poor exposures; and here many dikes cut across the iron oxide deposits and divide them into a series of short sections. Likewise the thick section of Cle Elum on the west side of Peshastin Creek is cut off on the west by a series of large dikes and does not reappear beyond the dike mass. Small remnants of Cle Elum and of peridotite are preserved here and there between dikes, and this condition is repeated east of the main Cle Elum exposures where large multiple dikes in the peridotite hold narrow slabs of peridotite and Cle Elum strata between them.

The volume of dike material in the lower Swauk, estimated at 20 percent of the total volume of rock, appears to require a marked northwest-southeast distension of the Swauk as the dike fissures formed. The horizontal distension could not have been equally distributed because the dikes are more numerous and generally larger in the Swauk than in the peridotite, and, within the zone of extensive intrusion in the Teanaway region, the concentration of dikes some distance above the basal Swauk beds must have produced considerable differential movements within the Swauk. The effects of this differential distension are evident in the basal beds of the Swauk, for they are disrupted by numerous small faults and locally crumpled and overturned. Some of the small faults extend across the Swauk-peridotite contact and cause small offsets. The Cle Elum formation is only locally involved in this disturbed zone because it is generally absent, though it is possible that the absence of the Cle Elum is in part due to faulting.

The "nickel ledge" veins represent an episode of fissuring and fracturing that was similar in some respects to the basic dike episode. However, the nickel ledge fissures were filled with vein materials rather than igneous rock, shearing and fracturing and even marked foliation and brecciation was a common accompaniment of the fissuring, and the veins show a prevailing east-west strike at a wide angle to the basic dikes. Because their strike is mostly nearly parallel to the strike of the Cle Elum formation, and because they are common only in the peridotite area, they are seldom found in contact with the Cle Elum. On the east side of the Little Boulder Creek canyon (F-7) a nickel ledge vein about 10 feet wide lies near the middle of the Cle Elum formation and divides it into two parts. On the east side of Bean Creek canyon (C-5) of the Teanaway region, nickel ledge material is present above and below some of the Cle Elum strata and the Cle Elum extends into and ends abruptly in the nickel ledge vein. At this locality the nickel ledge vein material, lying along the Cle Elum between the Swauk and the peridotite, increases abruptly to a thickness of about 200 feet (C-7) where the basal Swauk and Cle Elum turn abruptly southward and show a deflection of about one-fourth mile from their prevailing westward trend (fig. 1.). This suggests that the nickel ledge fissures are related to an episode of deformation that caused folding in the Swauk as well as fissuring of the peridotite. Further indication of the association of the nickel ledges with deformation of the Swauk is found in the abundance of nickel ledge veins along the Swauk-peridotite contact between Beverly Creek and Stafford Creek. In some places the ledge is nearly 200 feet thick and other smaller veins parallel the Swauk contact a short distance within the peridotite mass. Some of the ledge material is solid carbonate and silica, commonly in multiple veins lying in parallel position, and the presence of this type of material at the contact might mean nothing more than that the contact was a surface of easy separation along which fissures were formed. However, the common association of shearing, foliation, and brecciation with the nickel ledge suggests some dislocation parallel to the base of the Swauk.

Landslides and slumps.—Pleistocene and Recent landslides and slumps have caused marked surficial modifications of the older Cle Elum structures. The Cle Elum enters mass dislocations readily because it is heavy and normally lies upon partly serpentinized peridotite, and it holds together well during movement because of its strong, massive character. Therefore it is not unusual to find scattered float and even large blocks of iron oxide, Cle Elum formation materials, and Swauk sandstones lying upon the peridotite for a thousand or even several thousand feet from the main Cle Elum exposures. Some of the materials have recently come down steep slopes but some lie in places that they could not have reached on the modern topography and represent ancient landslides, slumps, and other products of mass-wastage that were left behind during the erosional recession of the inclined Swauk and Cle Elum beds. A number of mining claims have been located on these local and surficial materials where they include heavy iron oxide phases of the Cle Elum formation. As the peridotite characteristically supports little vegetation whereas the Swauk sandstone is normally heavily timbered, the large outlying landslide masses of Swauk are marked by dense groves of Douglas fir surrounded by the sparse timber characteristic of peridotite.

Outlying landslide masses of iron oxide beds are best developed on the upper slopes of Iron Peak (E-4 to 10). Another, associated with a block of arkosic Swauk sandstone and conglomerate, lies about one-fourth mile north of the basal Swauk contact on the east side of the canyon of the North Fork of Teanaway River (E-12). The small masses of iron oxide exposed in prospect holes on the ridge north of Boulder Creek (F-29) may be landslide materials though they lie at or near the former position of the Cle Elum strata and may represent a small outlier. Landslide material of Swauk sandstone and conglomerate without Cle Elum formation materials are present in the peridotite area on the two spurs that lie south of Boulder Creek and east of Cle Elum River. The small area of Swauk shown by Smith and Calkins (1906) in the bottom of Boulder Creek Canyon appears to be one of these ancient landslide blocks left during the erosional recession of the Swauk beds. Landslides affecting basal Swauk are evident between the Middle Fork and North Fork of Teanaway River; one mass of Swauk sandstone is crossed by the De Roux Creek-Middle Fork trail on the south side of De Roux Creek canyon one mile north of the nearest Swauk exposures which do not now lie in the De Roux Creek drainage area. The large exposure of conglomerate of the Cle Elum formation on the high ridge immediately west of Peshastin Creek (pl. 1) is flanked by much landslide and slump material and many large rolled blocks.

ORIGIN

Two major problems are involved in the genesis of the Cle Elum formation. One is concerned with the nature of source rock or rocks and the other with the manner in which the source rock was incorporated in the Cle Elum strata. The first is readily answered, for there is abundant evidence to show that the source rock was peridotite. The second problem is more difficult because peridotite also underlies the Cle Elum and requires differentiation of residual and transported materials. Under this condition in which deposits derived from peridotite lie upon peridotite it seems very improbable that the deposits would be either entirely residual or entirely transported. The thesis presented here is that the Cle Elum beds are composed largely of transported peridotite waste of local origin but may include a small amount of residual material.

Previous interpretations.—Kimball (1898) believed that the iron oxide deposits in the Cle Elum canyon are residual concentration of the iron oxide from pyroxene in moist places of the present topography. Smith and Willis (1901) in discussing the "Clealum iron ores"—the Cle Elum formation of the Cle Elum region, pointed out the similarity of the iron oxide and clay to the weathering products of peridotite and serpentine:

> In the facts of its position and association there is no evidence to show that it is a deposit brought in from any more or less remote extraneous source. There is much, on the contrary, to connect it with the serpentine. In its field-relations the ore lies on the serpentine, contains serpentine waste, and grades into shale derived from serpentine.
>
> The analyses of the ore and serpentine show that they both contain in addition to the usual rock constituents such occasional ones as chromium and nickel. Magnesia, an important constituent of serpentine, is also found in the ore. It is therefore reasonable to suppose that the iron ore is a result of concentration from serpentine. * * *

They apparently regard the iron-bearing beds as a transported rather than a residual deposit though they are somewhat vague on this point. They believed that the Cle Elum strata and the first arkosic sands of the Swauk formation were deposited contemporaneously, and this concept introduces various complications in harmonizing the somewhat different environments required by the two very different kinds of deposits. They recognize that the fine-grained Cle Elum beds require a land surface of low relief but hold to the belief that, as a whole, the land surface was one of bold relief. This leads to the conclusion that serpentine corresponded with the lowlands and, by implication, that other rocks, especially the granodiorites, corresponded with bold relief. In connection with the iron-bearing beds they state that "the residual mantle was deep. The climate was sub-tropic and vegetation was abundant," but, in connection with the supposedly contemporaneous arkosic sands, they state that "The climate became favorable to very rapid disintegration of granite * * * without marked chemical change." The marked lithologic differences between the Cle Elum beds and the arkose leads to the belief that entire watersheds were restricted to serpentine areas and did not reach into the source of the arkosic sands, or that, by some means, "the localities where serpentine was weathering were for a time protected from the widespreading arkose," even though serpentine is correlated with lowlands in a region of "bold relief." The interpretation is further complicated by the assumption that iron-bearing beds and arkose were deposited in the waters of a rising lake. They state that granite waste was delivered by streams at certain points along the coast and was built into beaches, spits, and bars.

> Behind the beaches and spits, lagoons were enclosed and, in some instances, such lagoons correspond to shallow bays which received the drainage from areas of serpentine. That drainage was charged with iron and decaying plants. The conditions were thus favorable for precipitation of iron either as ferrous carbonate or as a hydrate of the sesqui-oxide in the shallow water of the lagoon. As the shore line of the slowly rising water-body advanced upon the land, the several conditions advanced with it, and in favorable localities a deposit of iron was a characteristic, and more or less extensive, basal deposit of the sediments.

"Iron ore" is not specifically mentioned in the Mt. Stuart folio (Smith, 1904, p. 5), but the conglomerate on the east side of the valley of the North Fork of Teanaway River, apparently the upper Iron Peak occurrences, and those on upper Nigger Creek are mentioned as basal Swauk conglomerate. "In the first of these occurrences (Iron Peak) the conglomerate is associated with a shale composed of serpentine and magnetite, representing residual material from the rock directly beneath this Swauk outlier." This description, including the part quoted, is repeated almost verbatim in the Snoqualmie folio (Smith and Calkins, 1906, p. 4) but attributed to an occurrence in "the valley of the North Fork of Clealum River". The reference was surely intended for the North Fork of Teanaway River.

The Cle Elum iron deposits also were described by Smith and Calkins (1906) but the remarks relating to genesis of the iron are largely a rewording of the earlier material by Smith and Willis (1901).

> The ore bodies occur as lenses at the basal contact of the Swauk sandstone on the serpentine. The field relations as well as the character of the ore indicate that it is of sedimentary origin, being a peculiar basal phase of the Swauk formation.
>
> These ferruginous bodies originated as residual deposits on the surface of the serpentine, which were exposed to weathering before the Swauk epoch. Conglomerates of either granodiorite or serpentine boulders occur elsewhere at the base of the Swauk formation and represent simply local phases that are somewhat coarser than these deposits. Where inclosed basins were formed in serpentine rocks, the residual material covering the surface would receive drainage charged with iron and decaying vegetation, thus furnishing solutions of such character that the work of concentration may have begun early in the Eocene epoch.
>
> The analysis given above supports this explanation of the ore as the product of decay of the serpentine. On comparing the analysis of the ore with the analysis of the serpentine of this area it is found that the ore is simply a rearranged but chemically little modified residual product. The presence of chromium and nickel shows its relationship to the serpentine.

Reports by Shedd (1902) and by Shedd, Jenkins, and Cooper (1922) contribute little information on genesis except as extensive quotations from Smith and Willis (1901). The Cle Elum occurrences on upper Peshastin Creek are discussed briefly by Shedd, Jenkins, and Cooper (1922, pp. 70-72) who suggested that the iron oxide originated through segregation from peridotite. However, their observations on these occurrences are scant and inaccurate. Broughton (1943) states that the Blewett deposits are of sedimentary origin and Zapffe (1944) states that the fine-grained deposits near the Cle Elum River are residual deposits that grade into peridotite.

Source rock.—There appears to be little reason to question the derivation of the Cle Elum material from serpentine or from the original peridotite. A large part of the formation is basic clayey material, pebbles, and boulders obviously derived from the peridotite. The iron oxide is mixed with the peridotite waste and, in the form of magnetite, it is abundantly represented in the original peridotite. According to Smith and Willis (1900) additional iron oxide is formed as peridotite alters to serpentine and as serpentine and peridotite decompose under weathering action. The importance of iron oxide derived from serpentinization may be open to question because of the uncertainty regarding the amount of serpentinization prior to the deposition of iron-bearing beds, but the peridotite is nevertheless an entirely adequate source of the iron oxide. The evidence does not rest entirely upon the fact that the peridotite contained iron oxide which might have been incorporated in the iron-bearing beds; observations of peridotite and serpentine in other parts of the world show that iron oxide is not only released but also concentrated by the weathering process.

Other interpretations advanced here agree with Smith and Willis only in emphasizing the importance of transported material over residual material; the elaborate set of postulated conditions attending the deposition of the iron-bearing bed, such as lagoons, lowlands on serpentine protected from arkosic sands, and especially bold relief and contemporaneity of iron-bearing beds and basal Swauk, is discounted here. The evidence for noncontemporaneity of Swauk and Cle Elum was presented on an earlier page.

Nature of the pre-Cle Elum land surface.—Evidence for low relief during the time of Cle Elum deposition was also presented on earlier pages. The Smith-Willis concept of bold relief apparently was influenced by the belief that both Swauk and Cle Elum represented the same epoch of deposition. It may be suspected that the present investigation did not reach the regions of bold relief because it was confined to the region in which Swauk and Cle Elum lie mostly above peridotite, a region that Smith and Willis stated was lowland. However, most of the "basal Swauk" of Smith and Willis lies upon peridotite throughout the area mapped by them, and where the "basal contact of the Swauk with the older formations is exceedingly uneven" (Smith and Willis, 1901) is not recorded in any published reports. Certainly there is little evidence of a bold relief in the early Swauk deposits, for they are so largely fine- and medium-grained arkosic sandstone, and the conglomeratic beds, lying mostly some distance above the base of the formation, are made up of the well-worn concentrates of granitic waste that apparently have traveled a considerable distance. The coarse sandstone and conglomerates in the higher beds of the Swauk cannot be considered evidence for bold relief in the Cle Elum history for two reasons: (1) The Cle Elum and the Swauk formations are not contemporaneous, and (2) the elevated regions that furnished the coarse sediments lie outside the Cle Elum region.

"Basal Swauk" conglomerates are mentioned in the Mt. Stuart and Snoqualmie folios and may have been considered as evidence for bold relief, but, with the exception of a conglomerate of uncertain stratigraphic position on lower Peshastin Creek about five miles north of the iron belt, the supposed basal Swauk conglomerates are mostly the peculiar conglomeratic type of Cle Elum which could have been formed on a surface of moderate or low relief. The concept of low or very moderate relief in the region of the iron bed deposits seems justified by the evidence at hand.

Residual and transportational processes.—With the above modifications of previous concepts, the origin of the Cle Elum beds becomes the question of how deposits of iron oxide, clay, and conglomerate, derived from peridotite and possibly serpentine, accumulated upon a surface of low or very moderate relief prior to the diastrophic activity that caused streams to bring in the weathering products of distant exposures of granodiorites and other crystalline rocks. The problem involves the relative importance of residual and transportational agencies. Though there is little direct evidence on the matter, there seems to be little reason to doubt that residual deposits were common, because the composition of the Cle Elum material is so generally that which is characteristically developed by residual weathering of serpentine and peridotite. Deep weathering of the peridotite is common beneath the Cle Elum, but there are few if any places where a residual origin of some of the Cle Elum materials can be demonstrated. Zapffe (1944) states that the fine-grained iron oxide deposits near Cle Elum River are residual deposits and grade into peridotite beneath, but the writer's observations, in the area studied by Zapffe and in the Cle Elum belt as a whole, do not agree. Transported Cle Elum formation materials, on the other hand, can be proved in many places throughout the length of the Cle Elum exposures by stratification, by waterworn pebbles, by interbedding of conglomerates and mudstones, and by the presence of rock fragments not present in the subjacent basement rock. Even where these direct evidences of transportation are not present or are confined to the upper positions of the Cle Elum a transported origin of the entire formation is generally at least indicated by a sharp basal contact with the underlying peridotite even where the peridotite basement is deeply weathered. In some places fragmental serpentine and peridotite mixed with clay and iron oxide are present at the base of the Cle Elum but these basal zones are so generally crushed and sheared by adjustment to folding that no decision could be reached. Therefore the assumption that the Cle Elum formation includes some residual material in place rests only upon the probability that, as the Cle Elum contains so much reworked residual material of local derivation, it should include at least a small amount of the residual mantle.

The mode, or modes, of transportation and deposition of the Cle Elum materials cannot be determined satisfactorily though certain inferences may be justified. The stratification and fine grain of part of the Cle Elum indicates that it was deposited in ponded or sluggish water. The discontinuous character of the deposits may be due in part to erosion at the beginning of the Swauk episode, but the common occurrence of a clayey upper lithologic phase of the Cle Elum type and the general lack of reworked Cle Elum materials in the Swauk indicates that the discontinuous character is in some part an original one. Therefore it seems most probable that the fine-grained type was not deposited in a large deep lake but in smaller bodies of water that occupied the shallow depressions of a land surface of very low relief. Some of these may have been nothing more than ponds or small lakes; some may have been arms or inlets of more extensive lakes of irregular outline and similar to the "lagoons" postulated by Smith and Willis (1901); some were probably sluggish streams.

In most places the Cle Elum formation is exposed only as occasional lenticular cross sections of bodies whose third dimension cannot be determined, and even the linear extent of some sections cannot be traced because of later deposits or poor exposures. Prediction of the underground extensions of discontinuous bodies of iron is, therefore, very difficult. The lenticular exposures on the sides of the two ridges east of Cle Elum River (F-1 to 13) may be cross sections of elongate bodies that continue through the ridges along former shallow channels or they may be nothing more than sections of nearly equidimensional lenses. In the bottom of Cle Elum canyon above the mouth of Boulder Creek a cross section of fine-grained Cle Elum beds appears to be continuous for a distance of about one mile and its southward continuation is obscured by talus and vegetation. In view of the discontinuity of the Cle Elum strata elsewhere it is possible that this long section is cut nearly parallel to an elongate channel deposit.

The conglomeratic type of Cle Elum contains a small amount of material in which well-rounded pebbles (B-2, 3, 4) are so abundant and so well-sorted as to indicate clearly some kind of current deposition but it is not clear as to whether lake shore or stream currents were responsible. In most of the conglomerate, pebbles and boulders are scattered through a fine-grained matrix of clay and iron oxide. Though occasional waterworn pebbles show that some of the material passed through a stage involving considerable movement in streams or on lake shores, there is nothing to indicate that the material reached its present location by streams or lake deposition. The unsorted character of the deposits, the extreme range of grain size from clay to large boulders, lack of stratification, and spacing of boulders in clay all suggest some form of soil and rock flow conditions.

The deposit is similar in some respects to the mudflow and landslide materials formed on and below serpentine areas of the Mt. Stuart region in the Pleistocene and still forming today. Some of these young deposits are breccias with little fine material and others are largely clayey serpentine waste and include many fragments of serpentine ranging up to one foot or more in diameter. Though soil creep, talus, and landslide movements are in part responsible for the fragmental deposits, the latter type has been observed in transit as very liquid mud flows during heavy rainstorms. Though the Cle Elum conglomerate contains large boulders of peridotite and has a dark-colored matrix of iron oxide and clay, whereas the Recent material has smaller boulders and pebbles of serpentine and a light-gray clayey and granular matrix, the difference may be accounted for by the more rugged topography and more rigorous climate of the present in which abundant loose materials can be developed only in the completely serpentinized and therefore highly fractured facies of the peridotite.

Considering the fact that materials are made available for mudflows under present conditions it is to be expected that in the past, when advanced chemical weathering produced clayey material heavy with iron oxide, various forms of mass wastage would operate upon a land surface of relatively low relief. Deep weathering seems adequate to account for the release of small and large blocks of peridotite from the bedrock and their incorporation in clayey waste as angular and spheroidally weathered pieces. The amount of relief necessary to cause soil and rock flow is open to question, but probably a local relief of no more than 200 feet is essential, though the thickness of Cle Elum conglomerate on Peshastin Creek apparently requires a relief of more than 400 feet. The occasional stream-worn pebbles in the conglomerate type of Cle Elum could be explained as older stream deposits that were incorporated in the flow. The well-defined thin beds of the fine-grained Cle Elum beneath and within the conglomerate may mean that local water bodies were present, but the presence of occasional cobbles and boulders within the fine-grained beds (A-5) does not harmonize with deposition in quiet waters.

It is possible that the relative amounts of iron oxide and clay in the Cle Elum formation may have been increased after deposition by concentration or decreased by leaching. It is difficult to account for the common occurrence of a clayey upper phase above the phase of highest iron oxide content except by concentration in the iron oxide phase. However it is perhaps possible that leaching of iron oxide from the upper zone was accomplished after the manner described by Frasché (1941) but it would require a long halt in deposition.

The iron oxide deposits in the basal Swauk on Iron Peak apparently are not in the same category as the Cle Elum deposits for they appear to be reworked in the basal beds of the younger Swauk formation. Whether the reworked Cle Elum material is lake shore or stream deposits, or both, could not be determined.

Summary of conclusions.—In summary, it can be said that the Cle Elum belt is largely a transported deposit originating from residual weathering of peridotite and possibly of local serpentine facies. The fine-grained type of deposit was deposited by water on a surface of low relief where residual materials may have been present. The rest of the story deals with probabilities. The fine-grained type was probably deposited in shallow waterways of sluggish or ponded water. The conglomeratic type is probably soil and rock flow material formed on a surface of greater relief than that beneath the fine-grained type.

LITHIFICATION AND ALTERATION OF THE CLE ELUM BEDS

The Cle Elum formation was buried, during the Tertiary period, beneath many thousands of feet of sedimentary strata and lava flows. In addition it has undergone at least three diastrophic episodes in which it was tilted steeply away from the crystalline rock area around Mt. Stuart; it has been intruded by basic and acidic dikes, affected by the nickel ledge episode, and subjected to processes that formed much serpentine.

As a consequence of these later events the Cle Elum is well lithified and generally more resistant to erosion than any other rock in the region. There are, however, effects other than lithification. Serpentinization subsequent to the Cle Elum deposition is especially noticeable and makes it difficult to estimate the composition of the peridotite mass at the time of the Cle Elum deposition. Within the Cle Elum the serpentinization has had little effect upon the high-iron oxide deposits but it has transformed the basic clays of the Cle Elum, and the weathered peridotite below the Cle Elum, into material that is difficult to distinguish from normal serpentine except by the prevalence of dark gray and black over green colors. The conglomerates, especially in the Peshastin Creek area, commonly show sheared serpentine on the surfaces of boulders and in vein-like films along cross-cutting shear planes. In some places veins of tremolite were noted in the Cle Elum strata. Below the Cle Elum formation serpentine is highly developed along the seams of iron oxide that penetrate the peridotite mass, and also along the nickel ledge veins which are later than the Cle Elum. The cause of this late development of serpentine is unknown; it may have been related to the intrusion of Mt. Stuart granodiorite.

Some of the magnetite in the Cle Elum appears to be of post-depositional origin. Field tests, made with a magnet, suggest that there is a close correlation between the amount of magnetite in the Cle Elum and the degree of crushing, shearing, and dynamic and contact metamorphism suffered by different parts of the formation. The foliated zones of ruby-red serpentine developed along seams of iron oxide in the peridotite below the Cle Elum are commonly of low iron content but highly magnetic, as on Magnetic Point east of the Cle Elum River (F-8) and on the ridge north of Boulder Creek (F-28). Much of the adjustment to folding has taken place in fragmental peridotite at the base of the Cle Elum, and this zone, now markedly crushed and sheared, is mostly more magnetic than the massive, unsheared iron oxide and clay in the middle and upper part of the formation. A higher content of magnetite is indicated near the borders of cross-cutting dikes than in other parts of the formation.

The numerous basic dikes that cut the Cle Elum formation gave no appreciable metamorphic effects other than development of magnetite. In the Cle Elum region the Cle Elum beds and overlying Swauk sandstones were cut by acidic dikes similar to those which Smith (1904) believed were contemporaneous with the Mt. Stuart granodiorite. These dikes apparently caused the deposition of streaks and scattered crystals of pyrite in adjacent rocks. The pyrite in the Cle Elum on the west side of Cle Elum River (F-18) probably has this origin.

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APPENDIX OF REPRESENTATIVE SECTIONS

Here are described a number of Cle Elum and Swauk occurrences that best illustrate stratigraphic and structural conditions described in the foregoing text. It is essentially a condensation of field notes on critical occurrences. The arrangement is geographic; it presents the occurrences in order from east to west insofar as possible. Summary statements on large general localities are lettered consecutively in capital letters; small localities under each general location are numbered. Locations of these representative sections are shown in plate 1.

The iron-bearing strata of the Blewett and Cle Elum regions have received considerable attention by earlier writers; therefore the writer's data from these regions are greatly condensed and the less accessible and little-known intermediate sections are emphasized.

A. BLEWETT AREA

This area includes one large exposure of the Cle Elum formation and several small ones. The accompanying geologic map (pl. 2), made with tape and compass, shows the major geologic features and permits considerable condensation of field notes.

A-1. *Swauk conglomerate on Tronsen Creek one-fourth mile above its mouth.*

Thickness—50 ft.; strike is N. 20° E.; dip is 25°-30° E.; matrix 40-50%; pebbles mostly well rounded, none angular, only a few subangular; average size—2-3 in., maximum—12 in., less than 10% are less than 6 in.; massive; little orientation of flat pebbles.

Composition:

	Percent
Granodiorite and related rocks	60
About one-third normal granodiorite, and two-thirds medium-grained dike rocks, aplite, and pegmatite.	
Basaltic rocks and greenstone, probably derived from Hawkins formation	20
Dark fine-grained schists, probably Easton or Peshastin	10
Miscellaneous; dark-gray chert, quartzites, etc.	10

This conglomerate is somewhat higher in granodiorite than most of the conglomerates on the ridge south of Tronsen Creek.

A-2. *Cle Elum formation near mouth of Tronsen Creek.* (See pl. 1.)

A nearly vertical slab of highly ferruginous mudstone, about 180 ft. long and 30 ft. thick, lying between basic dikes; dark brown, dark gray, and black in large part, but some is red-brown. Near southwest end of outcrop are two or more lenses of conglomerate with well-rounded pebbles and cobbles of peridotite and hard greenish-gray dike rock. This occurrence is apparently a slab of the Cle Elum formation that was split off and preserved in a series of basic dikes. It may be at or near the former location of the Cle Elum formation, but only this remnant remains in the dike series.

A-3. *West side of Peshastin Creek one-fourth mile above mouth of Tronsen Creek.*

Fine-grained Cle Elum beds and serpentine in lens between dikes.

Lens is 8 ft. wide and 20 ft. long; vertical. Serpentine and Cle Elum are crushed and sheared. Cle Elum material observed only in loose blocks; relation to serpentine uncertain and obscured by dump from open pit. Probably serpentine and iron oxide were independent lenses broken off from the wall of the fissure by intrusion of several parallel dikes. Other slabs of serpentine between dikes north of this point.

A-4. *Cle Elum remnant 400 ft. west of Peshastin Creek and 150 ft. north of Shaser Creek.*

A small body of fine-grained type exposed by pits and caved tunnels. Brown and black; high in iron oxide. Some serpentine exposed; may be a boulder of Cle Elum conglomerate. No bedrock exposed nearby and tunnels and pits apparently penetrate only loose rock. This occurrence may be a small block in a fault zone, but depth of loose material around it indicates that it has come to present location by creep, rolling, or slumping, probably when topography was somewhat different from what it is today.

A-5. *Large exposure on the ridge west of Peshastin Creek.*

Largely conglomerate of Cle Elum formation. The description of this type, given on an earlier page, was based on this section and will not be repeated.

Stratigraphic section, on a N-S line extending through large open cut at end of road and about midway in the length of the mass, as follows:

	Feet
1. Conglomerate	360
Angular to poorly rounded pebbles, cobbles, and boulders of peridotite in matrix of ferruginous mudstone contains occasional well-rounded pebbles of hard, medium- to fine-grained basic dike rocks.	
2. Coarse conglomerate	20
An indefinite zone of boulders 2-8 ft. in diameter; matrix only interstitial filling between closely packed boulders.	

3. Fine-grained deposit with occasional pebbles and boulders of periodotite and serpentine............ 13
   Estimated composition: iron oxide and clay, 75%; boulders and cobbles, 15%; pebbles and smaller pieces, 10%.
   Most of the pebbles, cobbles, and boulders are subangular to poorly rounded; a few are angular; and a few pebbles are fairly well rounded. The clay-iron oxide mixture is mostly brown and red-brown.
4. Shear zone along basalt sill........................ 4
5. Fine-grained iron oxide and basic clay.............. 7
   About 95% iron oxide-clay; 5% serpentine fragments in angular to subangular pieces mostly less than 1 in. in diameter. Brown, reddish-brown to dark red; dense; contains flakes and grains of metallic mineral (magnetite?). Much jointed and fractured; also slickensided.
6. Conglomerate 15
   Pebbly clay-iron oxide above grading down into bouldery conglomerate. Boulders as much as 42 in. in diameter; angular to poorly rounded; matrix speckled with angular fragments of serpentine and peridotite. Many fractures, joints, and slickensides.
7. Bouldery conglomerate gradation from 6............ 25
   Largely boulders of serpentine and peridotite ranging in diameter from 1 to 4 ft.; matrix as in 6.
8. Base of Cle Elum concealed by talus and slope wash. Concealed thickness unknown.

   Total 444

A-6. *Dikes west of A-5.*

Cle Elum of A-5 is cut off on west by a series of northward-trending dikes. Dikes are largely basaltic; a few are greenish and gray, perhaps andesitic; and one is granitic; some are of variable width and discontinuous. Slabs of peridotite, serpentine, and Cle Elum formation lie between dikes.

B. NIGGER CREEK

The iron bed is exposed at several places along the north side of upper Nigger Creek where tributary gullies have reached the bedrock beneath a mantle of terrace alluvium, mudflow breccias, and soil. The deposits are largely of the conglomerate type, but there is a minor amount of fine-grained type and fine conglomerate with well-rounded pebbles. The Cle Elum is present in each good exposure seen at the base of the Swauk, suggesting that it is continuous for a distance of more than one mile.

The basal Swauk is made up of fine- and medium-grained arkosic sandstone but a conglomeratic zone lies about 200 ft. above the base of the formation. Basic dikes are fairly common in and near the Cle Elum but are not nearly so numerous as on the Miller Peak ridge south of Nigger Creek.

B-1. *N. 2°-3° W. of Miller Peak, on interstream ridge between Nigger Creek and northwestern tributary.*

Cle Elum about 100 ft. thick exposed for about 300 ft. along strike. Strike is east, dip is 50°-60° S. Composition: Largely conglomerate; contains several lenses up to 4 ft. thick, of fairly well rounded pebbles and cobbles. Contains also two lenses of fine-grained type; one lens, or rather a series of pods or lenses, lies at the base of conglomerate and in a thickness of 2-3 ft. grades into the conglomerate; the other lens is 10-15 ft. above base of conglomerate; it is 4 ft. thick in one place but pinches out in distance of 30 feet.

Prevalent type of boulder in conglomerate is angular to poorly rounded rough-surfaced pieces of peridotite ranging up to 3 ft. in diameter but mostly about 1 ft. in diameter. Matrix is basic mudstone, low in iron oxide. As at A-5 (Blewett area), boulders are scattered through matrix and mostly not in contact with one another.

Base of Cle Elum lies on hummocky peridotite surface with relief of 3 ft. or more. Pods of fine-grained type fill depressions and grade into conglomerate above. Contact of fine-grained beds and underlying peridotite sharp; no straining or weathering of peridotite at contact except recent action; none of orange-yellow stained and etched joint surfaces such as are common west of Nigger Creek.

Cle Elum overlain with sharp contact by arkosic Swauk sandstone.

B-2. *Cle Elum and basal Swauk in small gully about one-fourth mile west of B-1.*

Strike is N. 70° W., dip is 90° to 85° N. (slight overturning).

Section:

Basal Swauk	Feet
1. Swauk conglomerate and sandstone................	50
Lenses of well-rounded pebbles and cobbles interbedded with lenses of arkosic sandstone.	
Pebbles and cobbles are largely granitic and siliceous; also a number of Hawkins basaltic types and a few schists.	
2. Medium- and fine-grained sandstone................	100
3. Concealed. Probably soft sandstone................	50
Cle Elum	
4. Clay-iron mudstone with numerous well-rounded peridotite pebbles and occasional rough peridotite blocks	12
Black; massive; somewhat sandy in places; soft; very little iron oxide.	

5. Clay-iron mudstone with occasional rounded pebbles and occasional angular pieces.................... 8

Basalt

6. Basalt dike.. 12
   Apparently parallel to base of sedimentary section.

Peridotite

7. Foliated weathered peridotite (?).................. 1-2
   May be a mudstone but no pebbles were found, and it is the resinous black serpentine such as found below Cle Elum elsewhere.
8. Serpentinized, weathered zone of peridotite........ 15+

B-3. *Cle Elum in gully about one-fourth mile west of B-2.*
Strike is east, dip is 90°.

Section:

Feet

1. Dark greenish-gray basic sandstone................ 3
   Overlain by fine, gray, bedded Swauk sandstone; grades downward into 2.
2. Pebble conglomerate 12
   Well-rounded peridotite pebbles up to 3 or 4 inches in diameter in unsorted sandy and muddy mixture of peridotite waste.
3. Iron oxide... 4
   Black, dark-brown, and red; heavy; massive and much fractured; somewhat siliceous and hard in spots. Grades into 4.
4. Grit, sandstone, and mudstone...................... 2
   Greenish-gray; composed of peridotite waste; contains angular pieces of small pebble size.
5. Sheared and crushed zone at contact with underlying serpentine.

B-4. *West side of gully about one-eighth mile west of B-3.*

Block of Cle Elum faulted down into peridotite; exposed section largely surrounded by basalt dikes. Peridotite for at least 300 ft. to south instead of usual basal Swauk beds.

Section from south to north, probably in descending stratigraphic order:

Feet

1. Grit and sandstone................................. 25
   An unsorted mixture of grit and small pebbles, sand, and mud, all of peridotite waste.
2. Conglomerate with many well-rounded cobbles of peridotite 3

3. Conglomerate 75
   Matrix of mudstone and sandstone from peridotite waste; low in iron oxide even though color is commonly red and brown. One 2- to 4-ft. bed of fine-grained clay-iron oxide near the top.

C. STAFFORD CREEK TO BEAN CREEK

The Cle Elum formation is absent in most places where the basal Swauk zone is exposed in this region, but alluvium, soil, and timber conceal the bedrock for nearly one-third of the distance. Three small occurrences of fine-grained type of Cle Elum were seen in the eastern part of this section where the bedrock is largely concealed, so the formation may be more widespread there than the number of exposures might suggest. Exposures are good on upper Standup Creek and on the Bean-Standup ridge but only two small Cle Elum occurrences were seen.

The lowermost Swauk is made up largely of arkosic sandstones ranging in grain size from fine to coarse but mostly medium and fine. A prominent zone of conglomerate and pebbly arkosic sandstone lies about 400 ft. stratigraphically above the base of the Swauk. Basalt dikes are numerous in and near the conglomerate zone and locally make up about 90% of the rock mass, but they are much fewer in number in the basal Swauk zone.

C-1. *Cle Elum exposure 225 ft. above level of Stafford Creek, at mouth of western tributary canyon.*

Clay-iron mudstone and sandstone 12 ft. thick, exposed by trench. Well stratified and sandy at the base; mudstone above. Contact with serpentine sharp; no Swauk sandstone exposed above. Two small blocks of Cle Elum here; one or both are slump blocks; another exposed about 300 ft. S. 55° E. of this point.

C-2. *Cle Elum exposure on sharp ridge between cirque basin that lies in headwaters of Stafford Creek and head of tributary that flows east to C-1.*

Strike is N. 70° W., dip is 85° S.; thickness—2-4 ft. Largely mudstone with some low-grade iron oxide in middle of bed. Weathering of peridotite below is shown only by brown-black resinous serpentine along joints and the usual yellow-orange etched peridotite for 15 ft. below the Cle Elum. Upper contact with Swauk sandstone is abrupt.

C-3. *South base of Earl Peak in head of upper Standup Creek Canyon.*

Cle Elum absent. In some places the fine- and medium-grained Swauk sandstones lie upon peridotite with sharp contact; in other places nickel ledge veins, a few feet up to 50 ft. wide, lie along contact. Dip of Swauk and nickel ledge mostly near 90°. Sandstone near contact is crushed, traversed by numerous small faults, and locally overturned. Many dikes of basalt and irregular injections of soft, brown and greenish-brown basic rock in lower sandstone. Irregular dikes in peridotite.

C-4. *East side of Bean Creek Canyon at altitude of 5,440 ft.*

Vertical nickel ledge vein, 15 ft. thick, lies between basal Swauk sandstone and peridotite. Vein is brecciated and crisscrossed by later veins of carbonate; sandstone is crushed and colored orange and pink by nickel ledge stain for 30 ft. above its base; peridotite is foliated and serpentinized to a depth of 15 ft. adjacent to nickel ledge; foliae are parallel to vein.

C-5. *East side of Bean Creek Canyon at altitude of 5,270 ft.*

Nickel ledge 100 ft. thick at base of Swauk sandstone. Forks of ledge run out into peridotite, which in places is foliated and brecciated. Lenses of brecciated serpentine in ledge. Foliation vertical, parallel to base of Swauk. Some irregular apophyses of ledge invade the sandstone, and sandstone is yellow, orange, pink, and purple with nickel ledge stain.

C-6. *East side of Bean Creek Canyon at altitude of 5,160 ft.*

Cle Elum exposed for distance of about 75 ft.; it is crushed and probably faulted; apparent thickness of 12 ft. is exposed but upper part is buried by soil mantle. A nickel ledge vein lies between Cle Elum beds and peridotite; at upper end of exposure the vein cuts across the beds and invests a tongue-like projection of iron oxide. Upper part is red and chocolate colored low-grade iron oxide; middle part is greenish-black clay-iron oxide mudstone with spots of fairly heavy black iron oxide; basal part is green grit and sandstone derived from peridotite. All three types with gradational contact; all fairly well stratified; middle and upper part is somewhat oölitic. Dip variable, mostly 60°-80° S.

C-7. *From C-6 southwest to Bean Creek.*

The base of the Swauk is deflected from its prevailing westerly strike and swings southward for about 600 ft. and there curves to southwest and passes beneath terrace alluvium near the bottom of Bean Creek Canyon. The nickel ledge vein of C-6, lying between peridotite and sandstone, increases in width to nearly 200 ft. One small exposure of Cle Elum noted between sandstone and vein.

D. BEAN CREEK TO BEVERLY CREEK

Only two small Cle Elum occurrences were found on the two steep and narrow ridges that lie between Bean and Beverly creeks. The iron belt is partly concealed in some places and considerably invaded by basic intrusions and nickel ledge veins.

The lower Swauk here is very similar to that of C, showing a prominent conglomeratic zone about 500 ft. above the base and fine- and medium-grained sandstones below the conglomerate.

Faulting, crushing, and crumpling of lower sandstones are pronounced. Basic intrusions are abundant but show less concentration in the conglomeratic zone than east of Bean Creek.

D-1. *Cle Elum exposure in deep narrow gulch 1,000 ft. northwest of Bean Creek.*

Cle Elum about 6 ft. thick; weathered zone in peridotite below is 10 ft. deep. Basal 1-2 ft. of Cle Elum is stratified sandstone composed of peridotite waste; grades up into fairly good iron oxide; upper 1 ft. of Cle Elum shows usual gradation to basic mudstone. Overlain with sharp contact by 1 ft. of greenish-gray soft fine sandstone, and this followed by lighter greenish-gray arkosic sandstone.

D-2. *Cle Elum exposure 1,585 ft. northwest of Bean Creek, near top of canyonside.*

A small exposure of fine-grained type beneath talus. Mostly basic mudstone; low in iron oxide; chocolate brown to black and resinous; massive; somewhat oölitic. Thickness less than 15 ft.

West of this point arkosic Swauk sandstone lies upon peridotite.

D-3. *Conglomeratic zone of Swauk on west fork of Bean Creek about 500 ft. stratigraphically above base of the formation.*

Strike is W.; dip is 55° S. in upper part, increasing to 65° in lower part. Largely sandstone; medium- to coarse-grained; less feldspathic and quartzose than usual Swauk; contains many dark grains of which some are probably Hawkins type, others are greenish and appear to be serpentine and peridotite, though much of greenish color is stain on feldspar. Pebbles are mostly 2-4 in. in diameter, some are more than 8 in.; about 50% of pebbles are granitic and quartzose types; 25-35% are Hawkins-type basalt; remainder is largely quartz and mica schist; occasional pebbles resemble silicified serpentine and peridotite but none can be certainly identified as such. Pebbles are arranged in streaks and lenses. Basalt dike 2-4 ft. wide traverses conglomerate. A lens of nickel ledge vein, 1 ft. wide, lies alongside the dike, and small veins of nickel ledge penetrate joint cracks in dike. Here is evidence that nickel ledge is later than basalt dikes.

E. IRON PEAK

The Cle Elum, and reworked Cle Elum materials in the basal Swauk, are exposed in several places along the south and southwest flanks of Iron Peak but soil, talus, vegetation, and Pleistocene mudflow breccias conceal the bedrock for most of the distance. The Swauk and Cle Elum beds show the usual steep southerly dip and regular strike. The conglomeratic Swauk zone of C and D continues but comes down nearly to the base of the formation near the

Teanaway River. Many basic dikes traverse the Cle Elum beds on the south side of the mountain but are less numerous near the Teanaway River.

Outliers of the basal Swauk and Cle Elum and recemented ancient landslide and slump material from the Swauk and Cle Elum formations cap the sharp ridges of upper Iron Peak to an altitude of about 800 ft. above the main line of exposures. The dip of the Swauk in the outliers is low except where involved in landslides, indicating a terrace structure.

The locality numbers proceed from east to west along the main line of exposures then double back to the outliers.

E-1. *Basal Swauk on head of west fork of first canyon west of Beverly Creek.*

Peridotite overlain by thickness of several feet of conglomeratic mudstone and sandstone composed of peridotite waste; contains reworked oölites and fragments of clay-iron oxide. Above the conglomerate is 8-10 ft. of gray, brown, and black mudstone composed largely of basic clay and a small amount of iron oxide. Above basic and ferruginous zone lies a conglomerate about 150 ft. thick. Pebbles are usual Swauk type of granitic waste and Hawkins type of basaltic pebbles in an arkosic matrix; matrix is speckled with black grains, probably peridotite.

E-2. *Basal Swauk. East side of east fork of third canyon west of Beverly Creek.*

A lateral gradation from iron oxide and basic clay to Swauk conglomerate. Exposure about 75 ft. long; cut off by dike on the west and by a fault on the east. East end of exposure is iron oxide and basic clay derived from peridotite. This grades west into a fine-grained conglomerate which is a mixture of well-rounded siliceous pebbles of the normal Swauk type and peridotite pebbles. Matrix is coarse sand and grit composed largely of peridotite waste and iron oxide. The conglomerate phase grades upward into normal, gray, fine Swauk conglomerate but clay-iron phase is overlain with sharp contact by fine gray conglomerate which grades upward into pebbly sandstone.

E-3. *Basal Swauk conglomerate and Cle Elum on east side of North Fork of Teanaway River at altitude of 4,850 ft.*

Strike is N. 80° E., dip is 90°. Conglomeratic bed 50 ft. thick at base of Swauk; grades upward into arkosic sandstone. It is largely medium- to coarse-grained arkosic sandstone with granitic and siliceous pebbles, also many basaltic "Hawkins type" pebbles, a few of schist, and a few of peridotite (?).

Cle Elum formation possibly represented by 18 ft. thickness of peridotite fragments, iron oxide, and basic mudstone. It is a fragmental deposit, largely peridotite in small pebble to sand and mud sizes; angular in megascopic pieces; brown and black; heavy; magnetic; hard and somewhat sheared. Iron content highest in middle; grades to clayey mudstone at top. Evidently a transported deposit; probably reworked Cle Elum. Contact with Swauk sandstone and conglomerate is sharp. A zone of resinous serpentine, as much as 3 ft. thick, underlies the ferruginous bed in some places; probably weathered zone of peridotite.

E-4. *Uppermost exposure of slump blocks on Iron Peak.*

Well-stratified iron oxide and peridotite waste, about 3 ft. thick, grades upward into black, heavy, well-stratified iron oxide. Stratification shown by lamination and thin layers of black (magnetite?) sands, also by flakes in micaceous zones; contains fossil reed imprints; lies upon yellowish-red etched peridotite surface. It is apparently reworked material from the Cle Elum in basal Swauk.

E-5. *75 ft. east of E-4. Another slump block showing reworked Cle Elum material in basal Swauk.*

Section (incomplete):	Feet
1. Very black low-grade iron oxide-clay	3
2. Conglomerate	4
Angular to poorly rounded peridotite pebbles; matrix is resinous clay-iron mudstone; oölites, apparently reworked, abundant at base; grades into 1 above and 3 below.	
3. Black stratified clay-iron mudstone	3
Lies upon peridotite with sharp contact; peridotite etched and stained yellow along joints to depth of 6 ft.	

E-6. *70 ft. east of E-5. Slump block showing probable reworked Cle Elum materials.*

Section (incomplete):	Feet
1. Basic mudstone and sandstone with iron oxide	3
2. Black well-stratified iron oxide	3
3. Well-stratified peridotite mudstone, sandstone, and resinous iron oxide	3

E-7. *75 ft. southeast of E-6. Slump block showing higher strata of basal Swauk than E-4, E-5, and E-6.*

Section (incomplete):	Feet	Inches
1. Dark gray Swauk sandstone with reworked iron oxide, approximately	2	
Medium-grained, very micaceous, stratified; contains fossil leaves; grades into 2.		
2. Fine sandstone and shale	1	
Black, micaceous, well-stratified; contains much iron oxide.		

3. Sandstone and grit.......................... 1
   Poorly sorted sand with granules of serpentine and iron oxide, and iron oxide oölites. Some laminae are micaceous.
4. Argillaceous sandstone grading down into black shale 3
   Heavy; contains much iron oxide.
5. Greenish gray sandstone gradation at base of 4 8
6. Black shale and fine argillaceous sandstone.. 1
   Lower strata obscured by rubble but principal iron oxide beds are beneath this section.

E-8. *Top of sharp ridge about 600 ft. east of E-7.*

The ridge top preserves a complex mass of landslide and slump material showing mudstone, sandstone, and shale composed largely of peridotite waste and mostly high in iron oxide, also basalt dikes, serpentine, and peridotite. One block shows vertical strata of shale, mudstone, and sandstone, of high iron oxide content, with apparent thickness of 60 ft. but probably including much repetition by slumping. Another block of mudstone and shale composed of iron oxide and peridotite waste shows low-angle dip surfaces upon which are plant stem imprints as much as 6 ft. long and 5 in. wide. Another block shows conglomerate about 20 ft. thick. Probably in part original Cle Elum and in part basal Swauk.

E-9. *Ridge top about 600 ft. southeast of E-4.*

An excellent exposure of nearly horizontal strata in slump block. Probably in large part basal Swauk but possibly includes some original Cle Elum at base.

Section: Feet

1. High-grade iron oxide and peridotite waste........ 10
   Black; bedded; mostly grains and granules of peridotite; also lenses, 1-2 in. thick, of sandy material with reworked oölites.
2. Conglomerate 5
   Occasional boulders of peridotite up to 2 ft. in diameter; angular to poorly rounded. Numerous pebbles; mostly less than 6 in. in diameter; many well rounded. Matrix is largely grit and sandstone composed largely of peridotite grains of which many are well rounded; also a number of round pellets of iron oxide that are probably reworked oölites. Thickness increases to 12 ft. on north cirque wall. Grades into 3 below.
3. Largely massive peridotite-iron mudstone and sandstone 6
   Contains a few pebbles and boulders of peridotite and reworked oölites. Lateral gradation to conglomerate in nearby cirque wall.

4. Deeply weathered irregular peridotite surface with relief of more than 6 ft. Massive iron oxide and clay-iron oxide reach down into peridotite in fissures which are as much as 18 in. wide and 5 ft. deep. Perhaps a residual soil or some of original Cle Elum formation preserved in these fissures.

E-10. *Basal Swauk 200 ft. southwest of E4, on main south spur of Iron Peak.*

Vertical strata in large slump block. Apparently the block is all one piece, but there is so much faulting and slumping nearby that one cannot be sure that strata are not cut out or repeated here.

Section:	Feet	Inches
1. Black shale which ends against dike on upper (north) side	50	
2. Medium- to fine-grained massive gray sandstone	9	
3. Black shale with iron oxide. Base grades into 4.	12	
4. Bedded iron oxide and basic clay mixture. Fairly high grade iron oxide at base; much basic clayey material in middle and upper part; black to dark brown.	12	
5. Black shale with 8 in. layer of clay-iron oxide. Overlies peridotite with sharp contact. Peridotite weathered to depth of 22 ft.; no fissures or iron oxide seen along joints, though rock is largely concealed by talus.	8	6

E-11. *Basal Swauk on south spur of Iron Peak from E-10 southward for a distance of about 1,000 feet.*

The top of the spur, which is flat topped and 300 ft. wide in one place, conforms closely to a dip surface at or slightly above the base of the Swauk formation. The surface dips southward at about 10° in its upper part, nearly 25° in its lower part.

For 600 ft. south of E-10 the ridge top preserves the sub-Swauk surface of weathered peridotite. It is a hummocky, irregular surface which shows much of the orange-red-brown etched peridotite. Surfaces extending down irregularly on joint surfaces. Dark brown wax-like serpentine, a metamorphic product from weathered peridotite, extends to a depth of 20 ft.; a few fissures, 2-3 in. wide, are filled with iron oxide; relief of exhumed surface of peridotite beneath Swauk about 4 ft. Many patches of basal Swauk preserved on lower part of this area. Basal part of Swauk, about 2 ft. in thickness, is largely conglomeratic with angular to poorly rounded pieces of peridotite ranging from about 2 in. in diameter down to tiny fragments. Some of the pebbles are composed of brown fine-grained type of Cle Elum and some of these are as much as 2 in. in diameter and well rounded. Matrix is mudstone, sandstone, and grit composed of reworked clay and iron oxide from the Cle Elum. Reworked oölites are abundant in grit and sandstone. Above conglomerate comes 2-3 ft. of poorly bedded clay-iron oxide of fine grain.

At south end of this outlier the basal conglomerate is 20 ft. thick; it contains poorly rounded to angular blocks of peridotite as much as 4 ft. in diameter. Resembles conglomerate type of Cle Elum but contains much sand and grit in matrix and contains some pebbly sandstone and fine conglomerate with well-rounded pebbles. The conglomerate grades upward into poorly sorted grits and sandstones composed largely of peridotite but including also many fragments of clay-iron oxide and many oölites from the Cle Elum. Next above are basic mudstones and sandstones with some variations to low-grade iron oxides.

E-12. *Cle Elum and Swauk in slump blocks at altitude of 4,100 ft. on east side of North Fork of Teanaway canyon and one-fourth mile north of iron zone.*

Arkosic Swauk sandstone and conglomerate exposed for about 500 ft. along bottom of deep gulch; cemented mudflow breccia of serpentine at least 100 ft. deep to north and east, peridotite and serpentine to south. This block could not have come down from Swauk-Cle Elum outcrops on present topography; is Pleistocene landslide or slump material. Small block of Cle Elum at upper end of Swauk exposures; is overturned and dips steeply southward. Peridotite-Cle Elum contact is sharp; overlain by 6 ft. of heavy clay-iron oxide which grades into 18 in. of black basic mudstone at top. Coarse, light gray arkosic sandstone of Swauk begins abruptly above Cle Elum beds.

F. CLE ELUM REGION

The Cle Elum beds of this region are composed almost entirely of fine-grained iron oxide-clay gradations and described in some detail on earlier pages as the fine-grained type of Cle Elum formation. The conglomerate type, so common in the Blewett area, is absent. The deposits are higher in iron oxide, thicker, and more continuous along the outcrop than in the Teanaway region. On the two steep ridges east of Cle Elum River the Cle Elum beds are not continuous and the Swauk beds lie upon the peridotite in several places. The eastern ridge, lying between Little Boulder Creek and Boulder Creek, will be termed Boulder Ridge. The western ridge, lying between Little Boulder Creek and Cle Elum River, will be termed Magnetic Ridge because a part of the ridge is known locally as Magnetic Point. In the bottom of Cle Elum Canyon and north to Camp Creek, the Cle Elum beds are present wherever there are exposures of the iron zone. However, only three exposures were found in a distance of one and one-half miles south of Boulder

Creek where the Cle Elum formation is largely concealed by talus from Goat Mountain, dense vegetation, soil, and river alluvium. North of Boulder Creek the Cle Elum is exposed in many places for a distance of more than one mile though covered by alluvium for a distance of 1,200 ft. about midway in this section.

F-1. *Pit in Cle Elum beds 66 ft. west of easternmost exposure on northeast side of Boulder Ridge.*

Thickness is 6 ft.; upper part heavy with iron oxide but basal portion, one foot thick, is mostly clay. Weathered peridotite surface beneath.

F-2. *184 ft. west of F-1. Pit in horizontal Cle Elum formation.*

Thickness is 10 ft. Lower part is platy black iron oxide; fine-grained; platy structure may be stratification; very hard; 3 or 4 sets of joints develop "razor edges" on acute angles. Upper part is more massive, oölitic, dark brown and black.

F-3. *300 ft. west of F-2.*

Thickness is 1-2 ft. Top of Cle Elum is high in clay and overlain, with sharp contact, by fine-grained pebble conglomerate of Swauk; lower 2-3 ft. of conglomerate is black and iron-stained. Contact with peridotite also sharp; only about 1 ft. of weathered peridotite.

F-4. *Cle Elum concealed by timber and landslides for 1,000 ft. west of F-3.*

F-5. *Westernmost exposures on northeast side of Boulder Ridge, 1,000 ft. west of F-3.*

Thickness is 2-4 ft.; dip is south at 20°. Fairly high-grade iron oxide in large part but grades into black ferruginous mudstone at the top. Color is black and dark brown; stratification is present. Basal contact with peridotite is abrupt; overlain by medium- to coarse-grained arkosic sandstone and conglomerate of Swauk.

F-6. *Top and upper west side of Boulder Ridge.*

Cle Elum formation absent but the peridotite is weathered and shows red, brown, and orange colors; etched joint surfaces and sheared and brecciated zones of peridotite and iron oxide to a depth of about 100 ft. Swauk is largely arkosic sandstone with a few pebbly zones; it dips southward at 20°-30°.

F-7. *West side of Boulder Ridge.*

Cle Elum beds exposed for distance of 100 ft. above timber and alluvium of Little Boulder Canyon. Apparent thickness is more than 50 ft. but it may be partly repeated by faulting. Nickel ledge vein material, perhaps more than 10 ft. thick, appears to lie within the Cle Elum formation but relations are obscured by soil and timber. It is mostly black iron oxide, some is dark brown and reddish brown, rather massive, oölitic and pisolitic. A tunnel, now caved, was driven about 50 ft. below the exposures to intersect the beds at depth.

F-8. *Top of Magnetic Ridge.*

Basal Swauk is arkosic sandstone with minor amount of fine-grained conglomerate. Contact with Cle Elum not well exposed, but the Cle Elum, standing in relief, shows undulating or hummocky upper surface which is suggestive of an eroded surface caused by pre-Swauk erosion. Cle Elum is about 12 ft. thick; bedding indistinct; mostly brownish black to dark reddish brown; fine-grained and high in iron oxide; some oölitic and pisolitic bands with pellets as much as one-half inch in diameter. Closely spaced joints produce smooth-faced polyhedrons, some with razor-sharp edges.

At the top of the peridotite comes an indefinite zone, about 6 ft. thick, of bright red iron oxide, serpentine, and peridotite which is considerably sheared and brecciated. Apparently a considerably weathered surficial zone of peridotite which has undergone later shearing, brecciation, and serpentinization. It does not appear gradational with the Cle Elum formation but below it grades into more solid peridotite in which the iron-stained and serpentinized weathered zones reach down along the joints as large zones of altered material separating rounded blocks of unweathered peridotite which shows many etched and stained surfaces. At a depth of 100 ft. the weathered material is restricted to seams of bright red serpentinized material in which there is much magnetite as well as hematite. Natural lodestone in the seams, as much as 150 ft. below the Cle Elum formation, gives the name of "Magnetic Point" to this locality.

F-9. *West side of Magnetic Ridge for 800 ft. southeast of F-8.*

Cle Elum is not continuous; it is a series of lenses or pods of fine-grained clay-iron oxide lying in depressions of a hummocky peridotite surface. No lens is more than 15 ft. thick and 50 ft. long; some are only about 2 ft. thick and 8 ft. long. Contact with peridotite is sharp; some stratification in Cle Elum.

Swauk conglomerate with siliceous pebbles overlies the Cle Elum; dip is southward at 30° near ridge top, increasing to 50°-60° farther down.

F-10. *About 800 ft. west of top of Magnetic Ridge.*

Small exposure showing iron oxide in basal Swauk. Strike is N. 30° E.; dip is southeast at 45°.

Section:	Feet	Inches
1. Well-bedded fine sandstone..................	1	
2. Fine- to medium-grained arkosic sandstone; massive and light gray....................	2	6

3. Well-bedded, fine, gray sandstone above, grading down to reddish-brown, hematite-stained fine sandstone and shale..................	1	
4. Gray-black and reddish-gray mudstone with iron oxide .... This is basal stratum of Swauk.		6
5. Oölitic red-brown iron oxide and clay of Cle Elum formation		7
6. Dirt and rubble suggesting that 1-5 are in a slump block.		
7. A few feet below 5, red-brown to black iron oxide outcrop shows thickness of.......... Contact with peridotite is gradational.	8	

F-11. *About 1,400 ft. southwest of top of Magnetic Ridge.*

Cle Elum exposed for 172 ft. and probably continues westward for a considerable distance. Thickness is 3-8 ft.; strike is N. 70° E., dip is south at 28°. Peridotite is red and iron-stained, and weathered along joints to a depth of more than 200 ft. below Cle Elum. Peridotite-Cle Elum contact is gradational. Solid peridotite grades to Cle Elum through about 1 ft. of sheared fragmental peridotite mixed with iron oxide and clay. This grades into red, fine-grained, highly magnetic iron oxide-clay in lower 1-2 ft. of Cle Elum beds. Above, the Cle Elum is largely fine-grained, black, hard and much jointed. Some parts of the bed are high in iron oxide; others are mostly clayey products. At the top is the usual lightweight mudstone gradation and this is overlain with sharp contact by fine, gray well-bedded Swauk sandstones. Stratification cannot be certainly identified in the Cle Elum but there is some alternation of layers, or rather indefinite phases of high and low iron oxide material, that suggests bedding. The deposit may be residual but such origin cannot be proved.

F-12. *94 ft. southwest of F-11.*

Cle Elum exposed for distance of 300 ft. Average thickness is 6-7 ft. Upper part, averaging about 5 ft. in thickness, is heavy "high-grade" iron oxide-clay. Basal zone of 1½ to 3 feet is heavy sheared iron oxide with metallic streaks and fragments of peridotite. Below the sheared zone is a weathered surface of peridotite with red iron oxide and clay encircling weathered blocks of peridotite and passing downward into the peridotite mass. The basal transition zone contains irregular seams of tremolite. This occurrence resembles F-11 in showing an apparent gradation from Cle Elum to peridotite suggestive of a residual character, but most of the Cle Elum above the basal gradation shows distinct lamination which is surely stratification.

F-13. *From F-12 southwest for 1,000 ft. to timber and alluvium in lower part of canyon.*

The Cle Elum is very thin, discontinuous, and much obscured by soil. Maximum thickness seen is 3 ft. The bed is little more than a ferruginous clay layer lying upon and in depressions of an irregular surface of residually weathered peridotite blocks. Contact with Swauk is regular and sharp.

F-14. *Balfour-Guthrie mine one mile south of Boulder Creek and one-half mile east of Cle Elum River.*

The dump shows very little rock except serpentine; no Swauk sandstone, and only a few small pieces of Cle Elum material. The serpentine contains seams of red iron oxide and sheared and brecciated zones containing the bright red serpentine and iron oxide combination that is so characteristic of the serpentine basement beneath the Cle Elum. So far as can be told by the surface material on the dump, the tunnel penetrated only the zone of weathering and of iron oxide seams beneath the Cle Elum formation.

F-15. *Gorge of Cle Elum River about 1½ miles below Boulder Creek.*

The bottom of Cle Elum Canyon contains much alluvium and timber but the river has cut a narrow gorge through the alluvium and exposed the Cle Elum formation on both sides of the stream. The Cle Elum beds are offset by small faults, somewhat crushed and sheared, and intruded by a dense dike rock of andesitic or felsitic composition.

Thickness of Cle Elum ranges from 15 in. to 12 ft., probably because of faulting and shearing at a very acute angle to the strike of the bed.

F-16. *Basal Swauk and Cle Elum (?) on Goat Mountain; 460 ft. higher than the river and in a gully that comes down to the river about one-fourth mile south of Boulder Springs Forest Camp.*

Dip is west at 45°-60°; much irregularity and some minor faulting. Dark-gray to black mudstone and fine sandstone, 5 ft. thick, underlie the normal arkosic Swauk sandstones; they are very carbonaceous and contain fossil leaves and reeds. Next below is conglomerate and sandstone, about 20 ft. thick and composed of peridotite waste and iron oxide; the upper part is high in iron oxide, which is apparently reworked, for it is a mass of pisolites, fragments of iron oxide and peridotite, and finer basic material. Below the ferruginous phase is a sheared and crushed mass of serpentine-like material about 15 ft. thick, which resembles the serpentinized weathered material common in peridotite beneath the Cle Elum, but it contains a number of well-rounded waterworn cobbles of peridotite. The contact with peridotite beneath is not well exposed. These beds are apparently basal Swauk beds containing reworked Cle Elum material and peridotite waste.

F-17. *South end of exposures on west bank of Cle Elum River.*

Beginning 300 ft. north of the mouth of Boulder Creek, the Cle Elum is exposed for a distance of 480 ft. northeast to the point where it crosses to the east side of the river. F-17 includes several pits and trenches, and one shaft in the southern 350 feet of this west side exposure. Strike is N. 55° E., dip is northwest at 50°; thickness is 13 ft. (minimum). Gray and black; heavy and high in iron oxide; fine-grained; well-stratified in some places and even lamellar; also shows a scaly structure parallel to bedding. Upper and lower contacts not clearly exposed but it is overlain by light-gray arkosic Swauk sandstone. Weathering in peridotite beneath is less marked than on ridges east of river but seams of iron oxide in peridotite are well exposed along water's edge fully 100 ft. below the Cle Elum. One seam is 2 ft. thick and composed of red-brown iron oxide and clay; it appears to be a fissure that has been filled with Cle Elum materials.

F-18. *Trench across Cle Elum near north end of west-side exposures.*

Section somewhat obscured by soil and rubble and complicated by pod-like dikes of a light-gray dense basaltic or andesitic rock and a pink, hard felsite.

Approximate section, exclusive of dikes:

	Feet	Inches
1. Black, carbonaceous fine sandstone and shale of lower Swauk.		
2. Sandstone (?)	4	
A crushed and foliated grayish-black rock apparently composed of peridotite waste with a small amount of iron oxide. Probably upper part of Cle Elum formation.		
3. Mudstone	6	
Largely basic clay with a small amount of iron oxide; black and very hard.		
4. Heavy iron oxide phase.....................	7	6
Exposure shows well-stratified gray and black iron oxide throughout. Stratification shown by gray and black bands less than one-half inch in thickness. Prominent shearing along bedding; a scaly structure parallel to bedding may be due to shearing; some pronounced but small-scale crumpling; streaks of pyrite present along some bedding planes.		
5. Foliated zone in fragmental peridotite at base of Cle Elum..........................		8
May be weathered zone of peridotite but deep seaming and staining of basement is not present here.		

F-19. *East bank of river, opposite F-18.*

Iron bed is 10 ft. thick; overlain by well-bedded Swauk sandstone.

F-20. *310 ft. southeast of F-19.*

Cle Elum well-exposed by cross-trench, open cut, and shaft; thickness is 32 ft.

Section:	Feet
1. Fine-grained poorly stratified high-grade iron oxide..	20
2. Fine-grained well-stratified high-grade iron oxide.... Stratification shown by lamination which is indistinct on fresh surfaces but becomes very distinct on weathered surface. Color dark brown and black; stratification most pronounced at the base.	10
3. Sheared fragmental peridotite containing much heavy red iron oxide.......... Stratified; highly magnetic; apparently a transported deposit of iron oxide, clay, sand, and larger fragments of peridotite.	2
4. Residual soil (?).......... Crushed and sheared peridotite waste; low in iron oxide.	1
5. Residual boulder of peridotite..........	2
6. Peridotite with irregular weathered zones that are red-streaked with iron oxide..........	6
7. Peridotite with sheared seams of iron oxide and clay. Approximately	10

F-21. *Cle Elum formation for 790 ft. north of F-20.*

The formation forms a fairly continuous ridge that is glacially rounded and rises 5-20 feet above adjacent soil and alluvium; thickness ranges from 12 to 20 feet. Lithology like that of fine-grained iron oxide of F-20. Upper part rather massive or indistinctly stratified, somewhat oölitic, lower part well-stratified, even lamellar; lower fragmental zone and peridotite concealed. Strike is north; dip is high and to west. Two small faults offset line of exposures.

F-22. *1,100 ft. north of F-21.*

Cle Elum concealed by deep alluvium for 1,100 ft. north of F-21. On east bank of river at F-22, it dips west at 23° and therefore is broadly exposed on east bank of river for a north-south distance of 300 ft. Base not exposed and thickness uncertain.

F-23. *South side of prominent knoll about 300 ft. northeast of F-22.*

Strike is N. 35° E.; dip is northwest at 50°. Cle Elum has apparent thickness of more than 50 feet but is surely repeated by faulting; true thickness probably less than 25 feet. The Cle Elum shows normal gradation from basic mudstone above to heavy iron oxide-clay in middle and fragmental peridotite and iron oxide at the base. Repetition of basal fragmental zone near middle of exposures indicates fault repetition, and this fault, with downthrow to the south, is well shown west of F-23. Cle Elum is overlain by coarse arkosic sandstone with conglomeratic beds containing siliceous pebbles.

F-24. *Northward continuation of exposures from F-23 around the east and northeast sides of the knoll.*

Strike of Cle Elum and Swauk sandstone-conglomerate section above swings to north then to N. 10°-20° W.; dip is westward at 45°-70°. The Cle Elum beds are not well exposed, but a series of pits has been dug, showing a thickness of only 12 ft. on the east side of the knoll and 3-6 ft. on the northeast side; a greater thickness may be concealed beneath soil and glacial drift. A pit on northeast side of knoll shows a section of Cle Elum about 6 ft. thick and apparently beneath it is a coarse pebbly sandstone and pebble conglomerate in which are pebbles and grains of peridotite and serpentine; only a few feet of conglomerate exposed; contact of conglomerate and Cle Elum shows much gouge and breccia. Evidently some of the Swauk conglomeratic zone, which lies a few feet above the Cle Elum in this region, has been faulted down so that it appears below the Cle Elum. Cle Elum material in these pits is fine-grained, black to dark brown, somewhat sheared, and bedded or banded, in conformity with the overlying sandstone and conglomerate.

F-25. *North-northeast slope of knoll.*

A pit 8 ft. deep shows a minimum thickness of 4 ft. of Cle Elum. The bed is overlain by coarse sandstone and pebble conglomerate similar to that which appears to underlie the Cle Elum at F-24. The sandstone and conglomerate are arkosic and contain siliceous pebbles, but they show also many dark grains that were probably derived from peridotite. The Cle Elum and sandstone are separated by a layer of gouge 2 in. thick; no evidence of a gradational contact, though there has been much shearing parallel to the bedding.

F-26. *The long north slope of the knoll.*

Cle Elum is exposed by trenches and pits almost to the bottom of the dry tributary gully of Cle Elum River which runs between this knoll of F-23-26 and the next knoll to the north (F-27). Average thickness is between 8 ft. and 10 ft.; maximum thickness seen is 20 ft.; apparently a continuous layer. About 60 ft. south of gully bottom the beds are so well stratified that they break up into slabs only one-fourth to one-half inch thick. Dip is westward at about 20°.

F-27. *Northeast side of low knoll which rises from the south side of Camp Creek between Cle Elum River and the road.*

Cle Elum beds exposed in pits for a distance of about 200 ft. Thickness ranges from 3 to 12 feet but they are largely peridotite waste. Green sandstone and mudstone along the contact of the Cle Elum and the overlying arkoses of the Swauk range in thickness from 1 to 3 feet; suggest that Cle Elum and peridotite was incorporated in basal Swauk. Strike is N. 45° W., dip is southwest at 60°. Large dikes of acidic porphyry and basalt intrude the Swauk sandstones on the top of the knoll and appear to continue into the peridotite area east of the knoll; absence of Cle Elum exposures on east side of knoll is probably due to interruption by these dikes.

High Ridge North of Boulder Creek and East of Cle Elum River.

This ridge is made up of peridotite and serpentine lying within the curve described by the Swauk and Cle Elum outcrops as they trend westward along the south side of Boulder Creek and turn northward along Cle Elum River. The western part of the ridge is not far below the original basal Swauk and Cle Elum zone, for seams of iron oxide are present in the peridotite and a small remnant of Cle Elum, perhaps a slump block, lies upon the serpentine. It is believed that these occurrences were made possible by a nearly horizontal terrace in the Swauk and Cle Elum structure, for the upward projection of the high dips prevailing in the Swauk would carry the formation high above the top of this ridge. A beginning of this terrace is evident south of Boulder Creek where the prevailing high dips in the Swauk formation abruptly decrease to less than 10 degrees along the margin of the peridotite area.

F-28. *Pits in iron oxide and serpentine seams on the south side of the ridge, about one-half mile north and 600 feet above Denny's cabin on Boulder Creek.*

Three small pits are dug about 150 ft. east of the top of the spur that descends steeply toward the mouth of Boulder Creek. This is another occurrence of iron oxide in a serpentinized shear zone of the peridotite. The iron oxide is nearly all a vivid red or carmine hematite, dull in massive pieces and glossy on slickensides. Adjacent rock is peridotite but the iron oxide occurs in a serpentinized zone of shearing and brecciation. Zone is about 15 ft. wide in largest pit, but it can be traced for at least 200 ft. to the northwest where it appears to be lenticular and discontinuous. In places the red iron oxide shows up in a band 5 ft. wide, and in others it pinches out to a few thin red seams. Iron oxide and green serpentine are intimately intermixed as (1) bands parallel to slickensides, (2) brecciated iron oxide and serpentine or peridotite, (3) iron oxide with spots and streaks of serpentine,

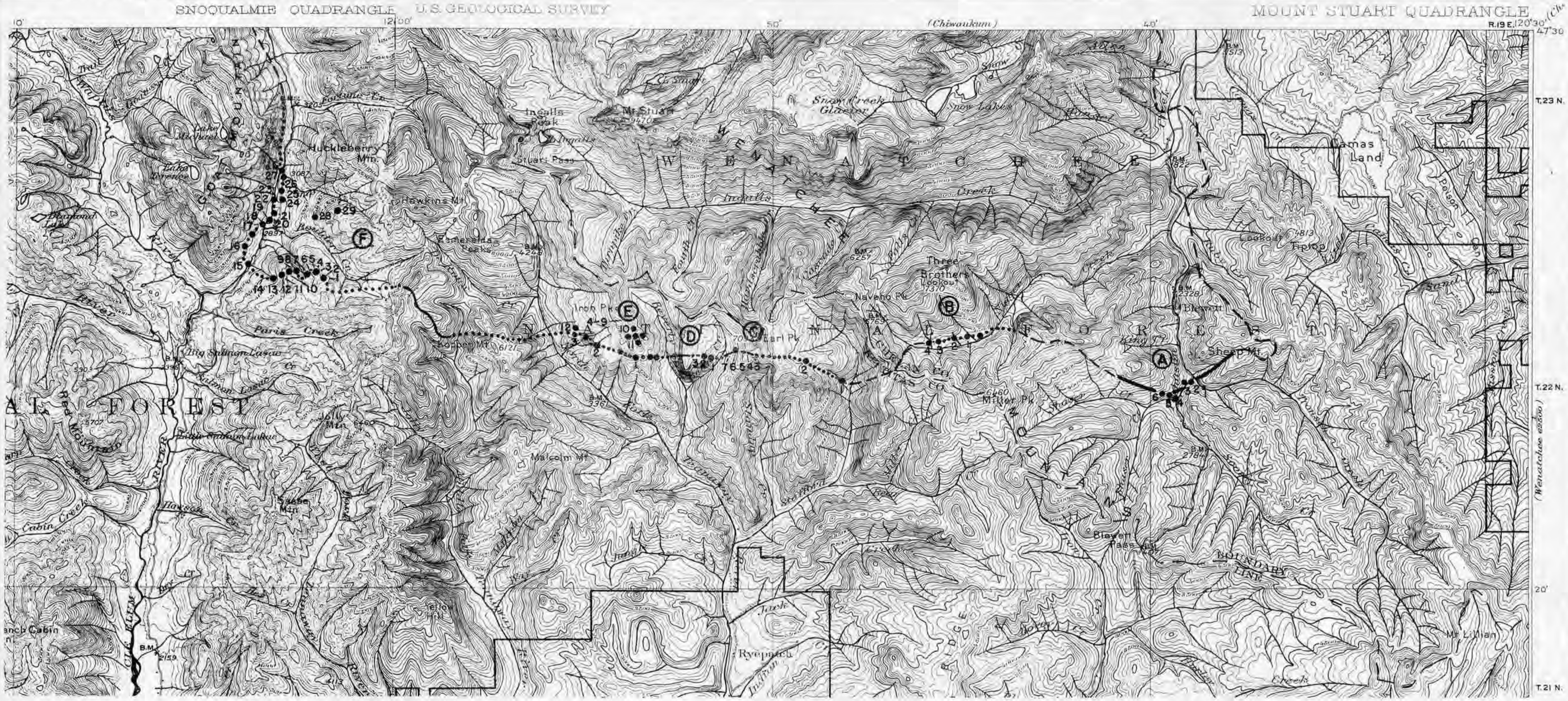
(4) serpentine with faint to pronounced spots of red iron oxide, and (5) glistening films of iron oxide on slickensides. Most of the red "oxide" is not noticeably heavier than serpentine; it is probably largely serpentine colored with iron oxide. There is a very strong magnetic attraction along the iron oxide zone but the most magnetic rock noted was not iron oxide but peridotite from near the shear zone.

F-29. *Open pits on the top of the ridge at an altitude of more than 5,000 feet.*

A few small blocks of iron oxide have been dug out of what appears to be serpentine landslide material. The iron oxide resembles that which is common in the fine-grained type of the Cle Elum formation. It is mostly brown, gray, and black; some is sheared and has a metallic lustre; some is pisolitic; some is black and granular.

STATE OF WASHINGTON
DEPARTMENT OF CONSERVATION AND DEVELOPMENT
DIVISION OF GEOLOGY
HAROLD E. CULVER SUPERVISOR

REPORT OF INVESTIGATIONS
NUMBER 11 PLATE I
1944



EXPLANATION

- IRON OXIDE DEPOSITS OF THE CLE ELUM AND BASAL SWAUK FORMATIONS
- CLE ELUM ABSENT. SWAUK FORMATION LIES UPON BASEMENT ROCKS
- SWAUK–PERIDOTITE BOUNDARY NOT INVESTIGATED. LOCATION FROM SMITH AND CALKINS
- CLE ELUM HORIZON CONCEALED BY QUATERNARY DEPOSITS
- FAULTS

Scale: 1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.

DISTRIBUTION OF THE CLE ELUM FORMATION AND KEY FOR REPRESENTATIVE SECTIONS

CHELAN AND KITTITAS COUNTIES WASHINGTON

GEOLOGIC MAP OF THE CLE ELUM FORMATION OF THE BLEWETT DISTRICT, CHELAN COUNTY, WASHINGTON