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THE ORE DEPOSITS
OF
NICKEL PLATE MOUNTAIN
HEDLEY, B. C.

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I. Introduction.

Nickel Plate Mountain coincides closely with that portion of the Hedley mining district which is of economic interest. From it has come almost the entire past production, and the active mines of the present epoch, Nickel Plate-Sunnyside and Hedley Mascot, lie in a compact group near its summit.

The Hedley district, which is 210 miles due east of Vancouver, is situated in the Okanagan Range of southern British Columbia, where this rather gentle uplift is deeply dissected by the canyons of the Similkameen and its tributaries. The region is essentially part of the Interior Plateau province (Fig. 1) but is adjacent to easterly elements of the Coast Range.

The Similkameen canyon, 4,000 feet in depth and frequently less than 4 miles from rim to rim, traverses the district from northwest to southeast. The deepest and narrowest portion of the canyon lies between Hedley and Keremeos, 18 miles to the southeast. At Hedley an important tributary, Twenty Mile Creek, enters from the north in a bold canyon, making a focus of unusually rugged topography. Nickel Plate Mountain occupies the sector to the east

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of this junction (See Plate 2) and its flanks are ringed by the cliffs of Twenty Mile canyon on the west and by those of the Similkameen canyon on the south. On the east it slopes gently to the hanging valley of Eighteen Mile Creek and on the north with only slight loss of elevation it merges into the moderately hilly surface of the plateau. The elevation at Hedley is 1,700 feet; the summit of Nickel Plate Mountain is 6,200 feet; and the general average of the plateau is about 6,000 feet.

Up to the present time Nickel Plate Mountain has produced two million tons of ore averaging one-half ounce gold from a single system of interrelated orebodies, the Nickel Plate, and one-quarter million tons from half a dozen lesser scattered orebodies, the Sunnyside 1, 2, 3, 4, 4½ and Bulldog. The Nickel Plate system was developed and exploited from its outcrop for 2,000 feet down the dip as a single operation, by the Hedley Gold Mining Co. and its predecessors. Independent ownership of the Mascot Fraction claim necessitated at this point a jump of over 200 feet, beyond which the orebodies were followed for an additional 600 feet of slope distance by the same operators. The Sunnyside 1, 2, 3, and 4 orebodies were also discovered and mined out during these operations.

The Hedley Gold Mining Company properties, discovered between 1898 and 1903, were closed down, permanently as was then believed, in 1930. These have become since 1932 the foundation of the current output of the Kelowna Exploration Company. The Mascot Fraction, with its blocks of ore developed prior to 1930 but intact in 1935, has since that time supplied the Hedley Mascot Company production.

With the dual operation the Nickel Plate system of orebodies, which yielded in the years before 1930 a maximum of 75,000 tons per annum, has now for several years been mined at the rate of 150,000 tons and this rate will be somewhat increased. Both new companies have been aggressive in attacking the geological and metallurgical problems of the deposits, and have pooled information to mutual benefit. As a result the limits of known ore have been extended for hundreds of feet on either flank of the old stoped out strip, with Kelowna taking the lead; and the downward limit of known ore has been pushed from the elevation of 4,800 feet to 4,300 feet, under Hedley Mascot pioneering. These developments have made possible the establishment of ore reserves far greater than were ever in sight before in the Hedley district, and have given assurance of sufficient life to justify a large program of improvements of mines, mills and communities.

While no longer, as in its youth, Canada's largest gold producer, Nickel Plate Mountain is today a more substantial benefit to the people of its dependent communities than it could ever be at that time. Its production of gold is larger and yet has been stabilized at a rate which avoids crowding the mines and which permits orderly exploration in advance of extraction. The Kelowna Exploration Company acceps this balance between pioneering geological study, exploratory workings, blocking out of ore reserves, extraction, milling, camp improvements, and community welfare as the sane and desirable program for a mining operation. It is the evolution of geologic ideas, the contribution made by geology to this mining program, and the techniques which have proved effective, which we shall discuss in this paper.

II. History[1]

1898-1902

The discovery of ore on Nickel Plate Mountain followed the normal course of pioneer prospecting. Gold placers on the Similkameen, although relatively small, led prospectors into the district as early as the 1860's. The first claims on Nickel Plate Mountain were recorded in 1894, but their gossans while gold-bearing, proved low grade. Ore of commercial promise was discovered in 1898 just below and east of the summit, when the prospectors Wollaston and Arundel located the Nickel Plate claim to cover the one surface expression of the Nickel Plate system of orebodies. This outcrop, partially oxidized, could be panned with good results although specimens showed abundantly the characteristic arsenopyrite of the primary ores. Such specimens, seen in Victoria the same year by M. K. Rodgers, while in the field for Marcus Daly of Butte, so attracted him that he went immediately to the prospect, then reached by 30 mile road and horse trail from Penticton.

The senior writer of this paper was privileged as a young geologist in Butte to make a number of mine examinations with M. K. Rodgers. He recalls the general geologic philosophy with which that eminently successful ore hunter approached a prospect. It was not assays alone that guided Rodgers; rather he was influenced by the broad picture as it might show intensity and extent of mineralization. He demanded in a prospect widespread strong alteration, big pervasive mineralization, as well as good values. There is little doubt, therefore, that the great garnet-silica cap

[1] Plates 3 & 4 will assist the reader in following this portion of the paper.

on Nickel Plate Mountain and the ample widths of silicate rock seamed and impregnated with arsenopyrite and pyrrhotite, contributed heavily to his prompt optioning and exploration of the Nickel Plate prospect. It looked like "elephant country". Recognition of this may be considered as Stage I in the evolution of geologic knowledge of Nickel Plate Mountain.

The next geological problem was to convert the two dimensional surface gossan into a three dimensional mass going into the ground in a definite direction. The problem was complicated by the presence, across the gossan, of a strong north-south steep fault, along which the free gold was especially rich, and first efforts were devoted to this, the Rodgers fault. The first deep tunnel, Adit 3, cut it at 150 feet below the outcrop to find it valueless, however, and drifting, raising and sinking on the fault failed to develop ore. Closer observation suggested then that the ore structures might correlate with the obscure west-dipping bedding rather than with the prominent steep fault planes. This hypothesis, applied to exploration, brought early results. Adit 3, extended into the mountain, encountered down the dip of the beds from the outcrop great bodies of ore which, promptly developed by workings and diamond drill holes, justified the immediate inauguration of a program for production; involving the construction during 1902, 3 and 4 of power plant, tramway down 4,000 feet of mountainside, and mill in the valley. This demonstration of bedding control may be taken as Stage II in Nickel Plate geology.

1902-1909

The active production period under Daly control lasted from June 1904, to August, 1909. In these five years the mill treated 167,000 tons with an average assay of .696 oz. During this period the bedded ores were extracted from Adit 3 to the surface, making the great Glory Hole stope, and were followed downward by inclines on the footwall, which had proved to be formed by the top of a porphyry sill. A simple guide seemed to have been established whereby the ore beds could be readily projected to and identified on deeper levels. Adit 4, 150 feet below Adit 3, was run in 1908 on this belief, which it rudely dispelled. For the ore was not encountered at the anticipated point, barren porphyry instead persisting for three hundred feet across the ore zone (Fig.2) Simultaneously, the inclines coming down from Adit 3 were losing the ore in steep faults. This seemed to the Daly estate an appropriate time to relinquish the sole ownership, and in the summer of 1909 the control passed into the hands of the newly organized Hedley Gold Mining Company.

Shortly after the reorganization, the crosscuts and drills on Adit 4 level began to encounter ore--rich but in small quantities--wedged into crotches where porphyry on the foot wall met porphyry on the hanging wall. But these narrow crotches proved on development to expand with depth into normal widths of ore formation, and with the discovery of this Stage III in the growth of geological concepts had been reached. At this stage it was realized that ore and porphyry, while in alternate layers, were irregular in that the porphyry might swell and obliterate, locally, the ore-bearing formation. When, thereafter, this phenomenon was encountered, the individual stope might be abandoned but general exploration continued to push forward.

Meanwhile, after studies made in the region and the mine in 1907 and 1908, Charles Camsell published in 1910 his memoir on the geology and ore deposits of the Hedley district. This work at once raised geological knowledge to a new level. The sedimentary formations were described and named, the igneous rocks were mapped and classified, and the structure of Nickel Plate Mountain was worked out within the limits of accuracy appropriate to the scope of the study. All subsequent progress has been built on this solid foundation. In the Nickel Plate mine, Camsell was unfortunate in coming when development downward had been checked by the complexities on the Adit 4 level. He did, however, record one observation of profound significance, not recognized as such at the time or for many years thereafter. Describing the Glory Hole stope, in the vicinity of Adit 3 level, he says:

"In the Nickel Plate mine the orebody does not follow continuously the same stratum of mineralized limestone, but cuts across the beds at a sharp angle, and passes from one bed to another, as it goes downward. This is due to the fact that the intrusive gabbro, which is the footwall of the orebody, has not been injected exactly along one of the bedding planes of the limestone beds, but cuts across them at a sharp angle. The dip of the gabbro is from 25° to 30° while that of the sedimentary rocks is from 16° to 20° . The orebody follows the igneous rock, so that in the mining of it the operations will follow along one bed for some distance, until the ore becomes low grade, then a jog will be made to a lower bed, and that followed until it also passes into low grade rock. The result is that the hanging wall, if it could all be seen, would appear as a series of inverted steps, with wide flat spaces, and short jogs at right angles to the plane of these."

A better description of the essential Nickel Plate structure, in <u>section</u>, has never been penned. For this acutely angling gabbro footwall thus described by Camsell in 1909 is the "Midway Dike" found by Kelowna geologists in 1932-33 to be the backbone of the entire Nickel Plate system of orebodies, (Fig.3), which is in all probability identical with the "Hot Sill" recognized by Hedley-Mascot geologists in 1938-39 as the dominant control of ore in their property. But during the twenty year life of the Hedley Gold Mining Company, there was no recognition that Camsell's observations identified a through-going acute-angled master dike, distinct from the many sills of similar composition which closely parallel the bedding. Parallelism of beds and porphyry was accepted as the normal relationship, except for erratic pinches and swells of no significance. As has so often happened in the application of geology to mining an accurate observation of complex relationships failed to win acceptance over simpler but vague generalizations, or to be followed through in all its implications.

<u>1909-1921</u>

Nevertheless, much ore was discovered by the Hedley Gold Mining Company under the management of Gomer P. Jones, with B. W. Knowles as mining superintendent. The orebodies below Adit 4 proved rich and persistent. Mill capacity was increased to 150 tons per day in 1911 and to 200 tons the next year, and with the larger volume it became possible to treat somewhat lower grade ore, so that the mill feed was brought down to about .55 oz.; an average which was maintained for twelve years, during which 700,000 tons of ore were mined. In exploration the bold step of deep hole drilling from the mountain top, aiming at the projected trend of the ore zone six or seven hundred feet below, was taken and proved successful. (One hole cut 70 feet of .99 oz. ore). Small local inclines within the confines of the orebodies were soon abandoned therefore, and a new inclined shaft, the Dickson, was commenced, well in the footwall of the system of stopes and pointed northwesterly down the long axis as indicated by the drilling. As subsequent developments have proved, this shaft location could not have been improved upon.

The geological problems of this period, from 1912 to 1921, when Dickson Incline and stopes reached the Mascot Fractionclaim line, were concerned chiefly with the so-called Central Fault zone, a system of steep/parallel faults and dikes which, trending westerly, angles across the system of orebodies (which run northwesterly) (Pl.4). Encountered first on Adit 4 level, at the north end, the Central Fault zone was a harassing complication on all levels below. It made a strip 60 feet wide in which no ore was found. South of this the stopes, coming down from the Glory Hole, wedged out above the Dickson level, while north of it no ore was found above the 4th level, though the stopes extended down continuously from there to the Mascot line on the 11th level. Local opinion was content to accept this pattern without interpretation. The orebodies were regarded as spreads raking diagonally down the dip of smoothly tilted bedding, interrupted but otherwise unaffected by the "Central Dike". This, Stage IV of geological thought, remained as the established dogma throughout the remaining life of the Hedley Gold Mining Company.

1922-30.

In 1922, having failed to reach any agreement with the owner of the Mascot Fraction which would permit mining the orebodies known to enter that claim, the Hedley company drove a crosscut on the 12th level across the Mascot and attacked the ore on the farther side. By 1926 these deep stopes had been pushed down from the 12th to the 16th level, while the Dickson Incline, also crossing the Mascot Fraction, reached the 15th level. Below the 15th level, at 4,850 feet elevation, new and disturbing phenomena appeared which stopped the further downward progress of routine development. Strange loose breccias, composed of all varieties of the formations, appeared in the places where firm ore-bearing beds were due. In these breccias values fell off to mere traces of gold.

Meanwhile, it had been found impossible for several years to maintain the average grade of mill feed, despite curtailment of production. The twelve year average of .55 oz. dropped to .40 oz. in 1922, to .37 oz. in 1926 and to .31 oz. in the year following, as mining became concentrated on the lower levels on both sides of the Mascot Fraction. The geologic dogma was modified, therefore, in two ways, to reach Stage V;

(a) The gold content of the orebodies diminished downward, a trend becoming apparent at about the 8th level.

(b) The bottom of ore had been reached on the 16th level. where it ended in breccia.

These modifications, both now known to be erroneous, grew out of misapprehensions. The orebodies proper were not leaner on the lower levels; the over-size stopes had merely been carried into marginal low-grade material under pressure to maintain the mill tonnage. The Nickel Plate system of orebodies did not bottom on the breccia; this material merely interrupted certain individual orebodies, much as did the swollen porphyry on Adit 4. But it has required many years of study, and the correlation of drill and underground data in and adjacent to the Mascot claim, to dispel the illusions of Stage V of the geologic picture.

Special studies by outside geologists became frequent as the orebodies grew harder to find and to follow. Botsford of Arizona in 1926 gave especial attention to the surface of Nickel Plate Mountain, and recommended diamond drilling on a large checkerboard pattern to test the possibilities of other ore systems. This program was carried out during the next few years with no success. The holes, located without reference to structure or possible ore controls, were too widely spaced to be likely to hit ore by the mere law of probability.

Billingsley of Utah in 1927 mapped the mine in detail, with especial attention to folds and crumples in the beds which might correlate with trends of orebodies; and searched also, on the surface, for repetitions of such structures which might carry ore systems. His report to the Hedley Gold Mining Company in 1927 emphasized the importance of these fold axes, especially the Main Nose which coincides with the stopes south of the Central Fault between 7th level and surface, and the adjoining Trough on the north which contains the stopes north of the Central Fault below the 4th level (Pl.4). This fault, in fact, is for a long distance coincident with the common steep limb between Nose and Trough. It was noted that existing stopes in the Nickel Plate mine occupied only portions of the pattern made by these structures. Exploration was recommended in the remaining portions, especially; (See Fig.3a)

(E) In the Trough on and above the 4th level, north of the Central Fault.

(D) On the Nose below the 7th level, down to the Mascot line.

(D) To the south of the breccia on 15th and 16th levels, at greater depth.

Outside of the mine, exploration was recommended (A) on the Nickel Plate nose axis in beds of the Sunnyside ore horizon, to the southeast of the Glory Hole; (B) on the Bulldog anticlinal axis in the same Sunnyside beds; and (C) on the Climax structure, a fault-dike zone which seems to prolong the Bulldog axis toward the northwest.

H. S. Bostock of the Canadian geological survey was studying Nickel Plate Mountain and its ore deposits during these same years, and his report was written in 1929 and published in 1930. He mapped on a large scale (1 to 1200) the summit region of the mountain, expanded and refined Camsell's descriptions of the formations, and brought down to date the account of mining developments and orebodies. The report is full of precise and valuable mineralogical and petrographic data; but its most striking contribution took the form of a beautifully constructed perspective drawing of the stopes and principal openings on the Nickel Plate ore system. Here for the first time the reader could at a glance catch the form of the complex pile of orebodies. Time and development have compelled some modifications in Bostock's correlation of orebodies, for the displacement of the Central Fault and the swing of the beds back from Nose to Trough are greater than he realized, and Nos. 1 and 2 orebodies are successive "shingles" stepping down the Midway Dike, rather than faulted parts of a single ore bed. Nevertheless, this report served, with Billingsley's study, to inaugurate a new Stage VI in the evolution of geologic ideas about Nickel Plate Mountain.

The way was now opened for a trial of exploration under the guidance of structural controls, and a start was in fact made.[1] But the exhaustion of the ore in the Nickel Plate mine in 1930 made impossible the continued persistent exploration which has been subsequently found essential in these highly complex structures. Early in 1931 the Hedley Gold Mining Company was obliged for lack of ore to end its operations, which had been carried on continuously except for short intervals in winter since 1902.

1930-1934

As the clatter of the stamps in the Hedley mill died down, to cease for four years, and the drills stopped their endless gnawing into the depleted orebodies, the opportunity was presented, as at no time in the history of Nickel Plate Mountain, for long,

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[1] A concise account of the operation in this final period of the Hedley Gold Mining Company was written by the staff, and published in these transactions in 1929.

careful geologic study under no pressure of time, and for further evolution of geologic ideas regarding the control and position of the orebodies. For the conclusion that all important ore, except the Mascot block, had been found and mined out seemed out of accord with the evidence. As Billingsley wrote in 1932 to John W. Mercer of the South American Development Company:

"The known commercial orebodies do not adequately fill in the pattern made by structure and alteration..... The Nickel Plate stopes are not central to the alteration blot, but close to its northern edge; and they are tied to no structural feature which is not duplicated elsewhere in the area.... The existing stopes indicate that within the essential mineralized area, orebodies are localized by certain relationships of favorable beds, sills, dikes, and folds or crumples..... It is therefore highly probable that properly coordinated exploration will discover new orebodies within this well defined quadrant of intense alteration."

After personal investigation on the ground, Mercer accepted this interpretation, and in the autumn of 1932 the South American Development Company took an option on the properties of the Hedley Gold Mining Company. The ensuing geological study conducted by Billingsley with assistance from Augustus Locke of California began almost immediately to uncover essential but heretofore neglected elements of the orebody pattern.

(a) The downward angling sheet of porphyry, noted by Camsell in 1908 in the Glory Hole stope, was found to continue down in the same way throughout the mine, and to carry on its back the successive shingle-like orebodies so well shown on Bostock's drawing; that is, all but the lowest one, which clings to its under side. This angling porphyry was christened the Midway Dike (Fig.3).

(b) The fold pattern--Main Nose and Trough, as reported in 1927, was now seen to be emphasized by minor sharp crumplings, which correlated with "rich cores" of the orebodies.

(c) The "Central Dike", 60 feet wide, was resolved into a pair of faults followed by two or three narrow "brown" dikes. Within this zone, and between these dikes lay segments of the orebodies, turned back 200 feet eastward from the Main Nose and dipping steeply northward into the Trough (Fig.4). Discovery of these segments permitted correlation of the ore beds across the fault zone. As this proved the former correlations by the Hedley company to be incorrect, the old system of numbers for the ore beds was replaced by a color scheme, in which the beds were called Purple, Red, Orange, and Yellow, from the top down. The upper three beds are above the Midway dike; the Yellow Bed is beneath it.

(d) The orebodies, Nickel Plate and Sunnyside alike, were found to correlate in a general way with the "marble line"; that is, with the no-man's land which separates the highly altered (garnet, epidote, calcite) portion of the beds from the fresh unaltered sediments into which this passes on north, east and south. This correlation explained the shift southward of the successive lower orebodies in the Nickel Plate system, and also the distribution of the Sunnyside and Bulldog orebodies along the top of a flattish fresh limestone floor beneath the mass of garnetized rock (Pl.4).

(e) The northwest trend of the Nickel Plate system proved to coincide with the course of a transverse steep dike, the Flange, which in turn follows the southern limb of the Main Nose. The concept was thus expressed in May, 1933:-

"The three upper ore beds (all but the Yellow) are at the same time on the nose of the anticline and within a trough formed by the Flange and the Midway dikes. The largest stopes of the mine are in this structure; the others are either in the Yellow bed on the nose below the Midway, or in the Orange bed along the south side of the Flange." (Fig.5)

The addition of these elements brought the geologic picture up to Stage VII. Exploration was carried on throughout 1933 and 1934 by the Kelowna Exploration Co., a subsidiary of the South American Development Co., on the basis of Billingsley's 1927 recommendations, sharpened to incorporate the above concepts. By December, 1934, newly developed ore reserves were sufficient to permit resumption of mining and milling on the old scale. By this time, also, the price of gold had increased from $20 to $34 per ounce. Since the new ore was of approximately the average grade taken out by the Hedley Gold Mining Company, the new price provided a substantial additional margin of profit, which permitted increased exploration and development expenditures. Without such large current expenditures the geological program of subsequent years could hardly have been carried out; since the search for ore on Nickel Plate Mountain requires intense and costly coordination of workings and drill holes.

1935-1940

The autumn of 1934, which witnessed the resumption of production at the Nickel Plate mine under the management of W. C. Douglass, saw also the awakening of the Mascot Fraction from its long hibernation. Using by agreement the workings and facilities of the Nickel Plate, a Vancouver syndicate under the geological guidance of Victor Dolmage drilled and measured the known orebodies of that claim and found them sufficient to justify a self-sustained mining operation. During 1935, while the Nickel Plate was making its first year's run and pushing its exploration into the Sunnyside beds on the Main Nose axis, the Hedley-Mascot was establishing its camp on the western cliffs of the mountain, driving a 3,000 foot tunnel into the orebodies, building a mill in the valley, and connecting tunnel mouth and mill with a steep aerial tram. Production started in April, 1936.

From that date up to the present (September, 1940) Hedley has had two continuous operations, Hedley Mascot maintaining a production of about 60,000 tons per year, while Kelowna, synchronizing mine developments with expansion and improvement of the mill, has steadily stepped up its tonnage, the figures being:

64,800 in 1936
78,000 in 1937
88,600 in 1938
90,200 in 1939
100,000 in 1940 (at present rate)

The output of new ore in the current revival of Hedley has amounted to 725,000 tons, of which Kelowna has supplied 450,000 and Hedlay Mascot 275,000.

The geological picture has been steadily enlarged during these operations, with competent local staffs in both properties closely mapping the advancing cross-cuts, drifts and stopes. The daily scrutiny of fresh faces of ore, for which there is in mining geology no substitute, has brought to light detailed relationships between the ore and its environment which materially tighten the control of exploration.

In the Kelowna mines the chief results have been as follows: (See Pl.4 and 5) Nickel Plate System;

(a) Development of Red and Purple orebodies in Trough north of Central Fault from 4th level up to Adit 4.

(b) Discovery of new ore bed, the Upper Purple, above the Purple, from which it is separated by a unique "chert breccia" sheet; and development of this bed from above Adit 4 down to Mascot line.

(c) Discovery, to the northeast of the Trough, of a second anticline, the North Nose, which carries ore shoots in the Red, Purple, and Upper Purple beds, along an axial dike, the North Flange.

(d) Development of Orange and Yellow orebodies on Main Nose south of Central Fault from 7th to 12th levels (latter reaches Mascot line); and still farther southwest into an adjoining syncline. In this area the orebodies in the lower beds are increasingly focussed at the intersection of the angling Midway and the steep Flange dikes; with Orange ore above the Midway on either side of the Flange, and Yellow ore beneath the Midway in similar position.

(e) Discovery in this southwestern region of productive beds below the Yellow.

Sunnyside System:

(a) Development of the high grade Sunnyside ore discovered on the Main Nose in 1935, by a long crosscut into the footwall of the Nickel Plate stopes. The local staff under Hume has been especially concerned with determining the shape and course of this system of rich orebodies, and its control by the combination of anticline, axial dikes and sills (Fig.6).

(b) Development of an orebody at shallow depth on the Bulldog crumple, an orebody represented on the surface by low grade pyrrhotite only.

In the Hedley-Mascot property the most significant results have been obtained in depth.

(a) Yellow and Lower Yellow ore have been followed down from the elevation of the Kelowna 12th level into virgin ground in the southern part of the Mascot Fraction. The close association with Midway (Hot Sill) and Flange persists.

(b) Bold deep drilling along the western line of the Mascot, from the tunnel level at 4800 ft. elevation, has found entirely new deep ore in and south of the confusing breccia region which seemed to bottom the Nickel Plate system. This new ore, which lies between 4500 and 4300 feet elevation, is being vigorously explored in both Mascot and Kelowna ground to the westward. The best interpretation at present is that it is made up of several new ore "shingles" with interleaved sills stepping down the Hot Sill, which steepens to 60 degrees or more at these depths. The important Flange dike continues on into this region and here, as above, seems to be medial to the most productive strip. The orebodies in detail appear to conform to the control pattern established by Hume in the Sunnyside area. To reach this ore Hedley-Mascot has driven a new low tunnel at 4300 ft. elevation, while Kelowna has begun to sink an incline shaft below the 15th level.

These recent and current developments have carried the evolution of the geologic ideas into Stage VIII. This represents our present concepts, but we know that even this eighth stage is not final. In this paper we have deliberately followed through the evolution of geologic ideas in this long lived district from the beginning, for the purpose of emphasizing the value of time and the necessity of change and growth. If geology is to become an instrument of precision, fitted to cope with theproblems of ore discovery, the geologist must be free to observe, to interpret objectively without slavery to dogmas or to the published word, and especially without emotional defense of his own former ideas, whether published or not. For the observations of one year cannot, in a growing science, be mere repetitions of those of the years past. Closer or larger scale mapping, attention to obscure features formerly ignored (like internal structure in granite), emphasis on new relationships, will bring different conclusions even in identical places.

So we pass on to describe the geology of Nickel Plate Mountain and its ore deposits as it appears in the light of the present stage of evolution of ideas.

III. Regional Geologic Framework.

It will have become apparent, from the above narration of the mining history of Nickel Plate Mountain, that geological understanding of these orebodies has grown principally as a result of recognition of their close dependence upon the enveloping structures. Orebodies here, as elsewhere, exist not in a vacuum nor in a homogenous matrix, but in the midst of formations crumpled, recrystallized, faulted and flooded with melts and other fluids. And these processes in turn are not the result of local forces and energies, special to Nickel Plate Mountain. They are creations of fields of force which permeate the region and produce regional motions and regional structure patterns in which Nickel Plate Mountain takes its proper place. It is important therefore to orient the Hedley district in respect to those regional forces and patterns.

Plate 1 shows the general geologic pattern of the Northwest Boundary region in which Hedley lies. Despite the many blank areas in which information is lacking, the large features of the pattern are clear. These are on the east: the Northern Rocky Mountain thrust system and the Selkirk-Purcell-Cabinet mountain system, separated by the Rocky Mountain Trench. On the west: the thrust slices of Vancouver Island, the Coast-Cascade Range plutons, and the thrust slices of the eastern Coast Range. And in the center, occupying the Interior Plateau, a shield-like complex made up of the Shuswap and Nelson plutons and intercalated flattish septa of sediments and volcanics. To the south of the Cascade Range and of the Shyswap-Nelson complex is the Columbia River lava in a Pacific embayment. The plutonic systems are apparently deflected eastward around this embayment, resuming a southward course in the Idaho pluton and thence swinging back southwesterly across Oregon toward the Sierra Nevadas. (Fig.7)

In this great bulge of plutons, the major structural feature of the North American Cordillera, the Hedley region occupies a significant place. Together with the Tulameen platinum belt and Copper Mountain, it is in a crotch caught between the southeast trending front of the Coast Range and the northeast trending "crust" of the Shuswap shield, a major reentrant or "syntaxis" of the Cordilleran plutonic arc. This reentrant we may call the Kamloops-Similkameen wedge. It is 100 miles wide north of Okanagan Lake, tapering to 50 miles at the international boundary and to a final point near the junction of the Okanagan with the Columbia River, (Pl.2) It is occupied in part by Carboniferous, Permian and Mesozoic (mainly Triassic) sediments and volcanics, essentially the same formations as are found to the eastward entangled in the Shuswap system. They are here folded rather steeply on westerly, southwesterly and southerly axes.

The other parts are filled with huge masses of granite. Where well studied these masses are found to be compound, that is, of several "ages" (or stages, as we now prefer to say). Along the boundary, for example, W. A. Daly finds the Remmel and Osoyoos gneissoid granitic bodies with about 63 percent silica to be followed successively, by these types:

1.	Similkameen, older phase	66% silica
2.	Similkameen, younger phase	67-70% silica
3.	Cathedral, older phase	71% silica
4.	Cathedral, younger phase	76% silica

The femic elements diminish in the granite masses as the silica increases, but each "batholith" is bordered and in part-roofed by excessively femic complex bodies which appear to be sediments recrystallized and enriched in these elements. In other words, the salic elements stay behind in the nodes of granitization, while the femics, more mobile, have been carried to the margins. Sedimentary formations of medium composition have thus been split during the process of recrystallization by hot gases and fluids into highly salic and highly femic parts (like the bands in pegmatized schist or injection gneiss) which are ultimately separated geographically by the outward migration of the femic carriers.

No doubt the salic fluids travel also to some extent; farther, however, as aqueous pegmatite than as granite melt. While "intrusive" granite contacts are known, cross-cutting the formation, we have seen none that demand invasion by melt from remote "deep seated sources". For these great granite masses cannot always have crystallized at great depth. Many are shown by their contacts to be so recent (Remmel, post-Cretaceous to Otter and Cathedral, post-Oligocene) that no great thickness of cover could have existed. In no case is great depth of cover demonstrated. But whether the accepted interpretation be one emphasizing recrystallization or one emphasizing intrusion by mobile melts, there can be no doubt that this Kamloops-Similkameen wedge has been the seat of widespread and emphatic heat effects, which vary from granite bodies 2000 square miles in surface area, like the Okanagan batholith, down to granite and pegmatite "cores" in close folds, like Copper Mountain, and even to alteration pipes, funnels and spreads of silicate minerals such as augite, epidote and garnet, as at Nickel Plate Mountain. And these effects are in large part as recent as post-Oligocene.

IV. Geology of the District.

The geology of Nickel Plate Mountain has been described in print by Camsell (1910) and Bostock (1930). Camsell published a map of the entire mountain on a scale of one inch to 1000 feet, and Bostock one of the productive area only on a scale of one inch to 500 feet. The Hedley district is included also on Bostock's map of the Penticton quadrangle, on a scale of one inch to 2 miles, and the recently published Hedley, Keremeos and Wolf Creek quadrangles on a scale of one inch to 1 mile. The general features are thus well known, and can be summarized very briefly here (Pl.2).

Triassic formations, argillites with minor limestone, and volcanics, lie in rather close folds which trend across the district from northeast to southwest and south. These folds, a mile or so north of Nickel Plate Mountain, are flanked by the southern front of the huge Okanagan granitic mass, while twenty miles to the south they plunge end on into the Similkameen batholith.

The Similkameen canyon from Hedley to Keremeos gives a cross section of this belt of folds. At Hedley is the west flank of an anticline, with beds dipping 25 to 30 degrees northwest. Four miles below, at Sixteen Mile Creek, the east flank turns down on a vertical limb. A second anticline crosses at the mouth of . Ashnola Creek, and a third just west of Keremeos. The east limbs of these are also steep, and the system ends at Keremeos in a north-south belt of steep dips, close or overturned folds and faults, beyond which lie metamorphosed schistose Carboniferous argillites. The section is one of assymmetrical folds showing push to the eastward, with close crumpling (and thrust faulting) against the crystalline Paleozoic mass.

Just beyond Hedley, on the western edge of the section, the beds also turn up into a zone of steep and overturned dips, through which passes the Bradshaw fault. The Triassic belt as a whole, therefore, appears to be a corrugated slice eighteen miles wide caught between eastward thrust zones at either edge. The slice, between northern and southern granites, is twenty-five to thirty miles long. The beds in the eastern half are mainly meta-volcanics; those in the western half, mainly argillites. Limestones are found on the two limbs of the most westerly anticline, at Hedley and Sixteen Mile Creek respectively; and on Apex Mountain, a few miles to the eastward.

In addition to the andesites and basalts which are integral parts of the Triassic series, the Similkameen district is rich in post-Triassic crystalline rocks. These include serpentine, hornblendite and pyroxenite, as recrystallized contact phases of the Triassic beds close to the great granites; augite syenite, etc., as alkali-rich rims of these granites; the granites themselves; diorites and hornblende-andesites in multiple bedded sheets and cross-cutting dikes; augite-andesites and gabbros in stocks and angling sheets; and acidic and basic porphries in a boxwork of thin dikes. These heat effects are most pronounced on the ends of the slice. On the southern end, marginal to or within the Similkameen granite mass, are the augite syenites of Kruger Mountain, the hornblendite of Richter Mountain, the gabbro of upper Ashnola Creek, and the basic complex of Snowy and Chopaka Mountains. On the northwestern flank, close alongside the Okanagan granite, are the andesite-diorites, the gabbros, the granodiorite and the late acidic and basic dikes. These varied igneous rocks are clustered in especial abundance along the Bradshaw thrust zone, with the strongest concentration at Hedley and Nickel Plate Mountain.

V. Geology of Nickel Plate Mountain.

Introduction.

Seen from a distance, as from the southwestern slopes of the Similkameen Valley near Hedley, Nickel Plate Mountain presents the aspect which won its native name, Kyisk-ming, or Striped Mountain; a name used also by Dawson in 1877 in the first geological description of the region.

It is striped because the steep cliffs on the Similkameen face expose 2000 feet of west dipping light lime argillites interbanded with innumerable rusty dark sills; this tilted pile resting on cliffs of granite. The upper edge of the granite dips westerly also, but more gently than the overlying formation, the layers of which are truncated by the contact. All observers since the time of Dawson have correctly appraised this general pattern. But there has been a steady evolution of ideas regarding its relationship to its surroundings and the nature of its limiting structures, and also regarding the character of its rock layers and the details of their deformation and alteration.

<u>Limiting Structures</u> (Pl.3)

The striped formation of Nickel Plate Mountain is floored by granite and capped by breccias. On the southeast, as it rises toward the axis of the Hedley anticline, it is eroded away by Eighteen Mile Creek; on the northwest it dips down, breccia cap and all, against the Bradshaw fault zone, which is also west-dipping but steeper than the Nickel Plate beds. Thus, between the flatter granite floor and the steeper Bradshaw fault the striped beds must ultimately wedge out not far below the valley level.

The breccias are in two sheets which converge downward toward the Bradshaw fault and with it outline two subsidiary slices in the upper part of the wedge. The lower of the three slices, then, consists of the banded argillites between granite and lower or Climax breccia; it composes the great mass of Nickel Plate Mountain. The middle slice, consisting of argillite with a large lobe of gabbro, occupies the summit ridge, Climax Bluff, and the northwestern slopes as far as Windfall Canyon. The upper slice rests on the Copperfield breccia, which angles across the north end of

Nickel Plate Mountain and down the northern cliffs of Windfall Canyon. It composes the mass of Red Mountain, which is made up like Nickel Plate Mountain of thin bedded sediments and tuffs banded with dark sills. Fig. 8 shows the general relation of these slices in plan and section. The nature of the structure, the character of the breccias, the detail of drag-folding, and the apparent repetition of identical formations above the breccia and to the west of the Bradshaw fault zone, suggest that the Climax and Copperfield breccias and the Bradshaw fault are common members of a thrust zone, which converge northwestward like leaves of a book to a single steep structure in depth. The granite floor has the attitude of a still flatter leaf out of the same book.

This summary statement involves concepts which have not appeared in the published descriptions of the mountain. Camsell recognized the thrust nature of easterly elements of the Bradshaw fault zone, but regarded the general displacement as normal; i.e., down on the northwest side. He did, however, note the strong resemblance between the "Aberdeen" formation, west of the fault, and the "Redtop" formation, lowest member of the series on the east side. This resemblance in a large way is apparent to any observer who from the Similkameen valley combines in a single view the Redtop cliffs on the southern face of Nickel Plate Mountain and the crumpled Aberdeen beds on the rugged face of Stemwinder Mountain.

The breccias of Climax Bluff and Windfall Canyon were well described by Camsell. The lowest, or Climax breccia, he regarded as a phase of the "Kingston limestone", which he considered the uppermost member of the Nickel Plate series (Recent more detailed mapping places it much lower.) Concerning the Kingston limestone

Camsell says:-

"A satisfactory description.....is hardly possible.....from the fact that there is no portion of the whole Cache Creek group of the Hedley district that has suffered so much alteration and deformation as this limestone..... It has been folded, faulted, brecciated, or thoroughly silicified, so that its recognition depends almost wholly on its position..... A few hundred feet to the south of Climax Bluff a very highly altered band of rock occupies the horizon equivalent to the Kingston limestone. This rock was undoubtedly originally a limestone, but has been metamorphosed and silicified.....in the form of a recrystallization, with the formation of large crystals of quartz, garnet, epidote and some tourmaline and axinite..... On large outcrops, there is strong evidence of brecciation..... This brecciation probably took place before the alteration.....and is consequently now somewhat obscured by it.

"Continuing northward from Climax Bluff.....we find a peculiar brecciated limestone.....made up of angular limestone fragments, varying in size from a few inches to several feet in diameter. These are cemented together with an igneous cement, which, however, forms a very small proportion of the whole rock.....

"Following the breccia bed along the ridge to the north, the cementing material changes from andesitic to calcareous, and we find remnants of a small band of fine grained conglomerate..... generally, though not always, parallel to the bedding planes of the limestone. The whole occurrence is peculiar and difficult to account for....."

The Windfall Canyon breccias, which we now call the Copperfield breccia, are discussed as follows:

"From Windfall Ridge.....limestone breccia forms a well marked bed, lying on top of and below beds of volcanic material, which can be traced right across Red Mountain into Bradshaw Canyon. The volcanic beds both above and below it are not brecciated, and it is probable that the brecciation of the limestone was effected by hot volcanic rocks alongside it, or the compression and sinking of the loose volcanic tuffs on which it rests. Beyond and to the west of Bradshaw Canyon.....the Kingston limestone..... is seen to have resumed its normal massive character, and no brecciation is apparent in it. The overlying volcanic materials have also pinched out..... On account of the absence of brecciation to the west of Bradshaw Canyon, the belief is strengthened that the brecciation was due to the.....volcanic rocks."

This explanation leaves unexplained the strangely inconsistent stratigraphic relationships:

(a) At the Kingston mine the "limestone" is a thin-bedded series overlain by normal Nickel Plate argillites and underlain by banded lime argillites and dark cherts in thin layers.

(b) On Climax bluff the limestone breccia is overlain by highly silicified argillites of the upper Nickel Plate series, and is underlain by normal Nickel Plate argillites, heavily garnetized.

(c) In Windfall Canyon the limestone breccia rests on silicified argillites and is overlain by the tuffaceous argillites of the Red Mountain formation.

(d) West of Bradshaw Canyon the "Kingston limestone" is overlain by "Aberdeen" argillites, which as Camsell says "are very similar to those of the Redtop formation".

It seems impossible to account for these inconsistencies, as did Camsell, by variations in primary deposition within such a close range; for these places are all within a one mile radius of Climax Bluff. Nor do the breccias look like slump or volcanic breccias. In 1927, when Billingsley first mapped some of the area on a large scale, he encountered this difficulty, and discussed it with Bostock, who generously spared a day from his own work for a joint visit to critical outcrops. No conclusion was then reached, and in his publication in 1930 Bostock did not depart definitely from the Camsell hypothesis.

His descriptions are as follows:-

"At the top of the upper siliceous beds (of the Nickel Plate formation), quantities of coarse breccia occur intercalated with banded quartzite beds..... The proportion of breccia reaches a maximum of 50 per cent in the vicinity of Climax Bluff. It decreases to the northeast..... The breccias are of two varieties, one similar to that described in the paragraph above (i.e., composed of angular fragments of light colored, fine-grained, banded rock, variously oriented and surrounded by smaller fragments of the same rock, all of which are cemented into a solid mass of uniform strength and hardness), though sometimes containing blocks as large as 2 feet long. The other is conspicuous for the quantity of metamorphic silicates and coarse calcite present in it..... A thickness of 90 feet of coarse breccia of this second variety occurs.

"Red Mountain Formation: The lower strata.....consists predominately of coarse breccias. The base of the formation...... consists of a vaguely stratified mass of angular fragments embedded in a matrix.....composed of fine, sandy, and tuffaceous particles with scattered grains of coarser sand and chert pebbles. The cement is partly calcareous. The fragments are chiefly of limestone, but also of the banded siliceous rocks. The maximum dimension is generally from 3 to 6 inches, but occasional blocks 2 to 3 feet long occur."

Bostock does not attempt an explanation for these strange formations.

With the advent of leisurely detailed mapping in 1932, it became evident that these breccias are functions of motion, alteration and recrystallization rather than vagaries of original sedimentation. Their thickest expansions were found along sharp folds in the beds; flattish planes of movement proved to be persistent along their extent; and microscopic study showed the groundmass to be largely made up of crushed and finely broken country rock. The concept held at present by the writers, therefore, is as stated above that the breccias were made fundamentally on thrust planes; that they divide the rock pile of Nickel Plate and Red Mountain into slices, each of which has independent bedding attitudes approximating but not identical with the strike and dip of the bounding thrusts.

At the base of the mountain is the granodiorite. As was shown by Camsell, the top of this is flatter than the overlying beds and truncates them with a drag to the westward; and the contact thus made is a locus of aplite, which sends tongues upward along bedding planes and acutely angling shears. (Fig.9) A large dike of granodiorite also rises above the contact, following a steep northwest fracture across the southern slopes of the mountain. The aplite, in our present concept, is a product of recrystallization, by means of fluids which were guided in general by the contact but which pressed out also along tributary channels. May not the granodiorite itself be an earlier product of a similar process? Recent mapping shows it to be full of internal structures parallel to the contact, and to be split a few hundred feet below the top by a sedimentary septum of the same flattish attitude; both features which may be regarded as indicative of fundamental flattish control. We suggest, therefore, that a lower element of the Bradshaw book of thrusts provided such a control, along which sheets of granodiorite first built up, to be followed by lesser aplite sheets along the margins. An interesting illustration of this type of structure is found near Nickel Plate Lake, six miles east of the mountain, where successive sheets of granodiorite about 20 feet thick are parted by equal thicknesses of sediments; the whole pile dipping gently to the northwest.

Internal Structure

The orebearing portion of Nickel Plate Mountain is limited, so far as is now known, to the lowest slice of the three, i.e., that one with a granodiorite floor and a roof of Climax breccia. It is composed of westerly dipping sediments which have been subdivided as follows:

Camsell	Bostock
Nickel Plate Formation	Nickel Plate Formation
Kingston limestone	Summit beds 300 ft.
	Upper siliceous beds 180 ft.
Middle division 500 ft.	Productive beds 200 ft.
alternating bands of limestone and quartzite	Lower siliceous beds 170 ft.
	Sunnyside productive beds 200 ft
Sunnyside Limestone 300 ft.	Sunnyside limestone 100 ft.
Redtop formation	

While there has been in recent years no important revision of this stratigraphy, there is a tendency now to lay greater stress on alteration and recrystallization, which are believed to have converted beds originally very similar into such widely diversified end products as marble, chert, "quartzite", skarn (garnet-epidote-augite-calcite); and possibly, where the rocks have previously been broken, even to skarn-porphyry breccia, chert breccia, chert porphyry breccia and by gradual transition to porphyry itself.

Just as alteration has grown in significance at the expense of original sedimentation, so has deformation grown at the expense of original bedding. It is recognized, now, that many of the most conspicuous lineaments of the mountain are not bedding planes, although close to these in attitude, but are superimposed shears and thrust surfaces. Even the porphyry "sills" so abundant throughout the stratigraphic column, are to a great extent controlled by these shears. A close scrutiny from the valley of the cliffs above the granite base will establish this fact. Thus it is that the sills so frequently break across beds or fork to enclose wedges of argillites of varying thicknesses. In general (and this is corroborated in detail in the stopes) the true bedding is more contorted than the contacts of the sills. Often the contacts will coincide with the bedding on the gentle limb of a fold, but will cut out across the bedding on a steep limb. This is the behavior of thrust shears in compressed weak formations, where beds both crumple and slide one over the other. A few of these angling lineaments are more persistently cross-cutting in nature than others. These are the loci of breccias and of certain porphyry apreads or dikes. They are miniatures of the Climax and Copperfield breccia thrusts themselves.

As a consequence of this pervasive motion the argillites of the orebearing slice are full of crumples of greater or lesser amplitude. Some are limited to the confines of a single stratum; others are sharpest in one stratum but persist with dininishing intensity into upper or lower horizons. The cliffs of Stemwinder Mountain show typical examples of both. A few affect the entire series of beds in the slice. These last are developed on northwest axes, transverse therefore to the major Hedley anticline. They angle down its westerly limb toward the Bradshaw fault zone, and reflect a shortening of the ore-bearing slice in a northeast-southwest direction. Across the mountain five folds of this order have been mapped; Red Eagle, Kingston, Tipple, Bulldog, and Nickel Plate (Pl.3). Of these the Red Eagle crumple is southwest of the large northwest granodiorite dike and is in fresh unaltered formations, but the others occupy the main focus of intrusion, alteration and ore. Each is accompanied by northwest axial faults, some of which are followed by dikes of both pre-ore and post-ore porphyry.

The Kingston crumple lies immediately northeast of the granodiorite dike. It is a broad fold with axis trending west-northwest; and the south limb, with dips up to 70 degrees, is the steeper. The axis is occupied by a diorite mass several hundred feet in width. The Kingston prospect lies astride of this, the croppings on the Kingston claim following its southern margin (Fig.10) while those of the Metropolitan are on its northern edge. The strong skarn alteration of the productive area lies to the north. Farther to the eastward the Kingston diorite dike flares out in a series of intercalated sills and sheets, which occupy about thirty per cent of the stratigraphic column on the southeast flank of Nickel Plate Mountain.

The Tipple crumple is conspicuous on the southeastern spur of the mountain, passing near the tipple at the head of the inclined tramway. It has not been traced farther to the northwest. This crumple also is steepest on the southwest limb, so that the combined effect of the Kingston and Tipple folds is to appreciably raise the panel of ground to the northwest. This high panel has a breadth of 5000 feet, extends through the Bulldog and Nickel Plate crumples with intervening minor flexures, and turns downwards steeply again into the Nickel Plate trough. The trough marks roughly the northern limit of skarn alteration. Thus the high panel is the seat of the funnel of alteration in which lie the orebodies of Nickel Plate Mountain; and it is also the focus of maximum development of intercalated sills and of gabbro intrusions. It is the ore-bearing structural unit of the mountain.

Porphyries.

Porphyry sills, sheets and dikes are prevalent throughout the entire formation of Nickel Plate Mountain above the granite floor, but they are particularly numerous within the high panel, where they make up from 20 to 50 per cent of the total thickness.

Apart from the post-ore dikes, which will be discussed later, these porphyries appear superficially to fall into two groups; a dark hornblende-rich group which can be described as diorite, diorite-porphyry, or andesite-porphyry, and a light colored group, rich in pale augite, which has the composition of gabbro. Camsell in 1910 made this basic distinction.

In 1927 Billingsley, in connection with surface mapping, sent a collection of rock types to Norman Smith of Boston, petrographer. Smith reported that only one rock type was present, namely, diorite, and that the pale rock was an alteration product of this, made by the addition of seconday augite. The evidence seemed convincing in many cases, but not in all.

Bostock, in 1930, followed Camsell in recognizing a southern parent stock from which spread apophyses of diorite porphyry and a northern parent stock with apophyses of gabbro. He noted the fact however, that diorite appears again "on the north side of the area containing the gabbro porphyry. No sharp line can be drawn between the areas of gabbro porphyry and those of diorite porphyry, since transitional gradations occur between them." For purposes of mapping he made an arbitrary division, calling all the porphyries gabbro in the area between the Bulldog and Nickel Plate crumples, inclusive. This means practically the high panel in which the argillites contain the maximum alteration.

The Kelowna examination in 1932 took as a major problem the nature of these porphyries and their relationship to the ore. Several hundred rock specimens were collected and about half were studied microscopically by Harrison Schmitt of Hanover, New Mexico. This investigation went far toward clarifying the puzzle. Schmitt concluded:

1. The general porphyry type, including almost all the sills in the high panel itself, is dioritic, properly called hornblende diorite porphyry or hornblende andesite porphyry. The primary phenocrysts are hornblende and labradorite.

2. Gabbro is also present, making up the holocrystalline Climax stock and certain porphyritic low-angle sheets in the high panel, which are apophyses from that stock. The primary phenocrysts are augite and labradorite.

3. Within the high panel all rocks are highly altered, the chief change being the replacement of hornblende and occasionally feldspar by secondary pale augite (leucaugite). The only distinction left therefore is the presence of primary augite in the gabbros in addition to the universal secondary leucaugite. But this is a vital distinction, for it identifies the latest pre-ore porphyry and correlates this with a late stage of deformation characterized by low-angle thrusts. The Climax stock itself rests on and was obviously guided by the Climax breccia, a thrust zone.

The Flange dike so far as sampled from the Adit to the 6th level appears to be a phase of the diorite type in which andesine takes the place of the labradorite and quartz is sparingly present.

A specimen from the Climax dike gave similar results, as to certain of the larger sills. Camsell notes a similar andesine-quartz-diorite as occuring in the stocks or in the largest apopyses near the stocks.

Post-ore porphyries are of several types, two of which are important in the mine. The brown dikes were classed by Camsell as "keratophyre", with acid plagioclase and quartz phenocrysts in a groundmass of alkaline feldspars with some quartz and hornblende; Schmitt classified this rock as soda rhyolite porphyry. These brown dikes, seldom over 15 feet wide, run northwesterly through the high panel. They often follow axial fractures and are abundant in the Central fault zone which follows the steep limb between the Nickel Plate nose and trough. While post-ore, the brown dikes received some of the last products of the mineralization, especially pyrrhotite, blebs of which in the brown porphyry are surrounded by pale halos of alteration.

The black dikes cut everything else and are unmineralized and unaltered. They have phenocrysts of hornblende and bytownite in a groundmass of fine feldspars and glass, and are thus andesites. These black dikes, from an inch to ten feet wide, run north-south, and are nearly vertical. They interrupt the ore like a concrete wall but have no other relationship to it.

The manner of emplacement of all these porphyries is a matter of great interest, whether they moved in as melts and widened their channels by wedging apart the walls, or as fluids, more or less aqueous, that converted the walls by replacement into the crystalline aggregate now called porphyry. Nickel Plate Mountain offers a a magnificent field laboratory for the investigation of these matters, but the study is yet to be made. (Pl.3).

Some bits of evidence are, however, at hand.

1. The "chert breccia" sheet which lies at the base of the Upper Purple ore in the Nickel Plate Mine has been studied microscopically along its course through the ore zone and out into the fresh rock to the northward. In the southern part of the ore zone it is a porphyry; in the central part it is a fine grained breccia, with chert fragments in a groundmass of fine grained secondary quartz. Schmitt classed specimens of this phase variously as meta-andesite tuff and as recemented hornstone breccia. In the mine workings however, it is seen to be 'intrusive' in attitude, sending off numerous apophyses across and along the bedding. As mapped, it has the form typical of aplite replacements while its petrography resembles that of Tintic 'pebble dikes'. We regard it therefore as formed by progressive recrystallization of argillite brecciated along branching low angle shears. Out in the fresh region north of the ore zone it appears as "a shaly limestone or limestone which has been brecciated and recemented by calcite and quartz". (Schmitt)

2. Indicative again of the growth of porphyry in place by recrystallization is the coarse 'nigger head' type of breccia found in the Nickel Plate mine along the Flange-Midway junction from surface to lowest levels. where it occupies large portions of the ground. The same material also makes up much of the eastern part of the Climax gabbro lobe. In the mine this breccia displays at once rounded fragments of garnet, epidote and augite in matrix of "porphyry", i.e., hornblende, labradorite, augite, dipyrite and

epidote, and the direct reverse. It is impossible to state whether the fragments are predominately silicates or altered porphyry. From the surface, specimens of Climax rock were sent to Schmitt; from matrix, from porphyry fragments and from apparent intrusions. The petrographic reports are identical; meta-gabbro. Other specimens of the "sedimentary" portions of surface breccias were reported as calcareous sandstone (?) made up of hornstone, quartz, and calcite. meta-dacite (?) tuff (?), made up of hornstone, plagioclase and quartzite; meta-dacite (?) tuff (?) made up of quartz and plagioclase with much secondary dipyrite and leucaugite; and meta-dacite porphyry (or tuff) made up of plagioclase, quartz and actinolite or sericite. As Schmitt says, "This rock by further alteration might become like #43 (calcareous sandstone). Was it fragmental originally, or were both porphyries?

3. Along the easternmost branch of the Bradshaw fault is a porphyritic "dike" described in the field as follows:-

"Intrusive quartz porphyry or granite porphyry. Big feldspar phenocrysts, many quartz phenocrysts." Schmitt (1933) found this to be a "pegmatitic alteration of a shale (?) or tuff (?). The fine grained fabric of quartz represents the original rock."

4. Where details of contacts are available, as in the Nickel Plate stopes, they are found to be erratic; that is, the porphyry intermittently turns from following to crossing the bedding and at such places sends off irregular apophyses, much as does the aplite in Camsell's sketch of the south face of Nickel Plate Mountain. (Fig.9) The shapes are more easily explained by a process of recrystallization than by the movement of molten magma.

5. Invariably the porphyry sills and sheets show the bedding of the neighborhood. Also they contain very many septa of meta-argillite from a few inches to a few feet in thickness. In drill cores it is frequently necessary to log a dozen thin alternating layers of porphyry and argillite. These occurrences resemble coarsely layered injection gneisses. It is difficult to see how such thin septa could have been preserved had the porphyry layers come in as mobile melts.

With these five features in mind we are tempted to attribute the entire diorite-gabbro complex boxwork of sheets and dikes to an early stage of recrystallization by hot fluids (or gases) following shears and fractures, rather than by entry to the rock pile of true migratory melts. But final decision can well wait on the collection and analysis of the abundant available and yet untouched field material.

Alteration

Alteration has been found significant in recent years as a halo around orebodies and as the final stage of preparation for their introduction. In the belief that it might here also provide guides to the discovery and understanding of ore it has received close attention in the studies undertaken since 1932.

Camsell (1910) recognized that "the question of the metamorphism of the Nickel Plate formation is one which is intimately connected with a study of the orebodies-- It is certain that the impure limestones, and those interbanded with quartzites, have suffered more intense and widespread metamorphism than the purer massive limestone members of the top and bottom of the formation". This metamorphism, as he pointed out, consists in the development within the sedimentary beds of an intimate intergrowth of garnet, epidote, pyroxene (diopside), tremolite, axinite, and calcite. He regarded this as "contact metamorphism" produced directly by the intrusion of the diorite-gabbro complex, and included the sulphides arsenopyrite, pyrrhotitel chalcopyrite and sphalerite as contemporaneous components.

Bostock (1930) differed from Camsell as regards the relationships of the arsenopyrite with the gangue minerals. After presenting evidence fot the later age of the sulphides he says: "These relationships of the chief ore and gangue minerals are interpreted as showing that the formation of the gangue silicates took place before that of the sulphides."

The Kelowna studies (1932-40) have confirmed Bostock's interpretation. The sulphides were precipitated in channels which pervaded the strong but brittle garnet-epidote-diopside aggregate. But going beyond Bostock, the Kelowna geologists have concluded that these earlier silicates also developed from fluids moving on channels, and that these channels were determined by brecciation, low-angle thrusts, and bedding slips rather than by igneous contacts, except where these cross the beds and so make through-going breaks. The preference for argillareous and quartzitic strata as against pure limestone, as noted by Camsell, is attributed to the greater incidence of deformation and fracturing in varied formations, and to the ability of siliceous beds to maintain open channels. Fractures in limestone walls heal themselves;, those in quartzite walls do not.

The mass of silicate or skarn alteration is found, as we have seen, within the high panel between Bulldog and Nickel Plate crumples. It replaces the entire pile of Nickel Plate formation from the top of Sunnyside limestone through the Climax breccia and up to the lobe of Climax gabbro which caps the summit of the mountain. Keels of alteration hang down along the northwest dikes into and through the Sunnyside limestone itself. The core of this mass is principally garnet, with epidote and diopside; the upper crust is fine grained silica, while the margins, north, south and basal, are ragged and contain much calcite with residual ribs of white crystalline limestone. The floor of unaltered formation follows the top of the Sunnyside limestone, except for the keels above mentioned, across the central part of the high panel, but on both margins fresh material is found higher and higher in the Nickel Plate formation. Beds which are solid skarn silicates on the south flank of the Nickel Plate nose, for exa_mple, are mixtures of these silicates with calcite and marble in the adjoining trough to the northward and become fresh argillites a few hundred feet farther north. (Fig.11) The same condition in reverse is found as the south margin is crossed toward the south and southwest. As will be seen later, the orebodies are distributed within or closely along the inner side of these ragged margins, or in the floor close to the keels, which are similarly ragged and rich in calcite. This correlation between ore and marginal alteration is again attributed to the structural causes. The strong skarn, when close to and mixed with the more plastic marble and argillite, was more easily broken than when in large homogeneous masses. The mixture favored channels of alteration and recrystallization.

Within this great cup the porphyries are as much affected as the sediments. Here are found the pale augite-bearing phases which were indiscriminately classed as gabbros. Evidently the fluids of the alteration stage were not contemporaneous with the intrusions; they were for the most part subsequent, and altered porphyries and argillites alike.

Microscopic studies made by Harrison Schmitt for the Kelowna investigation show two or three stages of progressive replacement in the porphyries. In stage 1, leucaugite grows at the expense of original hornblende and augite, if any. In stage

2, the secondary leucaugite is replaced by epidote, dipyrite, pargasite and sulphides; while original labradorite or other plagioclase goes to sericite, dipyrite, and carbonates. In stage 3, cracks are filled with leucaugite, dipyrite, carbonates, chlorite, quartz (very little) and arsenopyrite. Still later comes the pyrrhotite. Schmitt said, (March, 1933):

"Augite appears to have formed continuously from an early magmatic stage to almost the (latest) hydrothermal stage-- It is surely interesting to see primary hornblende altering to augite, a reversal of the normal order. In some cases common hornblende altered to pargasite, then to augite, then the augite back to pargasite! The tendency of the alteration in general seems to have been to decrease the iron. Scapolite (especially dipyrite), next to leucaugite, is the most characteristic and abundant alteration product, representing of course the introduction of much chlorine".

A tabulation of Schmitt's results showed that the dipyrite correlates closely with proximity to orebodies. Normally less than 5 per cent. of the altered porphyry, near stopes it ranges from 25 to 70 per cent.

One general aspect of the alteration deserves consideration. Here, as so often elsewhere, the pervasive recrystallization decreases the iron content, which is thus made available for reprecipitation in marginal halos and in specialized channels. This sifting process may provide the source of the widespread pyrrhotite found on Nickel Plate Mountain, particularly in the fresh dark diorites just outside the productive area. May it not also provide a source for both the iron and the other metals which, precipitated in late specialized channels, make up the orebodies?

VI. Orebodies of Nickel Plate Mountain.

Paragenesis

The orebodies consist of certain sulphides disseminated in the necessary amounts in special portions of the skarn and marble alteration complex. Commercial values are in gold, with minor silver and copper. Other metals may, under favorable market conditions, add to the value of the ore; notably arsenic and cobalt. But throughout the long history of Nickel Plate Mountain gold has been the essential valuable product.

As has been stated above, it is now known that the sulphides were precipitated later than the skarn, and that they were introduced along cracks, often of microscopic size. Studies by Bostock (1930) established an order of precipitation as between the various sulphides. His sequence is:

"Arsenopyrite first; then chalcopyrite; and finally pyrrhotite. Chalcopyrite has replaced arsenopyrite to some extent, but has preferred the gangue minerals with the exception of garnet. Pyrrhotite in turn has replaced chalcopyrite and the gangue minerals with the exception of garnet. -- After the fracturing of the garnet and arsenopyrite crystals---the deposition of the main quantity of chalcopyrite and then pyrrhotite took place. The arsenopyrite that, associated with calcite, occurs in veins, is thought to be of slightly later deposition and to correspond with the later arsenopyrite mentioned by Camsell".

Bostock did not determine the relationship of the rather sparse sphalerite.

Harrison Schmitt (1933) confirmed and sharpened Bostock's sequence. Working with scores of type specimens from various orebodies, he found sequences such as these:

In Sediments	In Porphyry
garnet	hornblende
calcite	plagioclase
leucaugite	leucaugite
dipyrite	dipyrite
arsenopyrite	arsenopyrite
chlorite	calcite
quartz	lawsonite (?)
clinozoisite	clinozoisite

(a) The arsenopyrite is intimately associated with the dipyrite.

(b) Dipyrite, chalcopyrite, pyrite, clinozoisite, clacite and chlorite are closely associated.

(c) Pyrite, sphalerite and "unknown" are the latest minerals.

Still more refined studies of the sulphides themselves have been carried on in recent years in the University of British Columbia by H. V. Warren, J. M. Cummings and others for the Kelowna Company. Some of their earlier conclusions, which were published in 1936, are given below:

"The following paragenesis is suggested.

(1) Formation of silicates.

(2) Introduction of arsenopyrite. (NOTE. Cobaltite occurs as tiny inclusions in and completely surrounded by arsenopyrite.)

(3) Introduction of pyrrhotite, chalcopyrite and sphalerite.

(4) Fracturing and veining of ore by calcite stringers.

The gold appears to have been deposited in and contemporaneously with arsenopyrite--- Numerous tiny inclusions of gold-- from 7 microns down to the limit of microscopic resolution--are distributed erratically throughout the arsenopyrite, without any apparent tendency to be controlled as to size or location by the enclosing sulphide. Although gold occurs directly in pyrrhotite in a few places, it is commonly in or surrounded by arsenopyrite even though pyrrhotite is the dominant mineral in the section".

Considering all these petrographic data together, it would appear that the gold was brought into the orebodies at a stage closely following the development of secondary leucaugite, by fluids from which dipyrite and arsenopyrite were also precipitated in close association. In later stages fluids of different composition brought in sphalerite, chalcopyrite, clinozoisite, etc., but little or no gold. Here on Nickel Plate Mountain, therefore, the gold is not, as is so frequently the case, brought in by the latest fluids and precipitated in a quartz gangue. If Warren's diagnosis of contemporaneity with arsenopyrite is correct, it was brought in with the earliest sulphides and was precipitated in a gangue chiefly of the scapolite, mineral, dipyrite.

Structural Controls

The orebodies are contained in the beds of the Nickel Plate formation, from Sunnyside limestone almost to the Climax breccia. Originally weak, plastic lime argillites, these beds show in detail many crumples and slicing through these many small shears approximating the bedding planes. But from the earliest stages of deformation factors appeared which tended to reduce the plasticity, increase the strength of the pile and prepare it for the ore channels.

First was the introduction of the sill-like sheets of hornblende-diorite-porphyry, coupled closely in time with the dikes of hornblende-andesine-porphyry. Essentially contemporaneous with the crystallization of the primary porphyry minerals was the development of calcite in the adjacent argillites, converting them in part to marble. With this coarsening of grain throughout the rock pile came increased perviousness, permitting the hot fluids to reach and recrystallize entire masses of the formation, making the widespread garnet-leucaugite alteration and further coarsening and stiffening the rocks.

The Nickel Plate formation, when this stage was reached, was no longer plastic. Deformation took place mainly on thrusts and fractures instead of by crumpling. True, the crumples continued to grow and the porphyry sheets are bent on them, but these bends are far less acute than those in the argillites, and they are accompanied by flattish shearing between beds and porphyry, by axial faulting, and by crackling and brecciation on the axes. These grosser breaks provided the channels for the next stage of recrystallization, in which arsenopyrite and gold came in with dipyrite, calcite and clinozoisite. Continued deformation cracked the arsenopyrite, etc., and the later sulphides, chalcopyrite, sphalerite, pyrrhotite and pyrite followed, and with gangue minerals occupied the cracks and completed the mixture now mined as ore. The structural control of the ore-bodies, the reason "why gold is where it is", is therefore a resultant of the combined processes of persistent deformation, intrusion, recrystallization and precipitation in progressively limited channels.

The orebodies are found grouped along the folds, where they are controlled in closer detail by sharp crumples and by flattish shears; and especially by shearing cracks along low-angling sheets of the "Midway" type and transverse "Flange" dikes. Such cracks, mineralized with thin seams of dipyrite-arsenopyrite rich in gold, appear to provide the major channels through which the ore-bearing fluids rose from the depths and spread out into the thick tabular "mantos" of which the orebody systems are composed.

There are three general systems, each system coincident with a certain portion of the alteration cup.

<u>Nickel Plate System</u> lies along the northern margin, with orebodies principally in the central horizons of the Nickel Plate

formation. The marble line marking the outer limit of skarn is found on the northern edges of these orbodies, (Fig.11).

Sunnyside System lies along the floor, with orebodies in the lower horizons of the Nickel Plate formation. The marble line is found beneath these orebodies. (Fig.12).

Bulldog System lies along the southern margin, with orebodies in the lower horizons of the Nickel Plate formation. (Bulldog orebeds are approximately the same as Kingston, for the westward slope of the mountain between these prospects is, if anything, a little steeper than the dip of the beds.) The marble line is found on the southern edges of these orebodies. (Fig.10).

Nickel Plate System

The Nickel Plate System (Pl.4 and 5) is by far the most thoroughly explored and developed. Its cluster of orebodies is known now to have a length, down the dominant axis, of at least 3000 feet, and to range from an elevation of 5900 feet at the Nickel Plate Glory Hole to 4300 feet on the west side of the Mascot Fraction. The breadth of the cluster, along the strike of the individual ore beds, is 500 feet on Adit 4 (5600 feet elev.) and somewhat more on the 12th level, (5000 feet elev.) at the eastern side of the Mascot, which is the lowest level with a wide spread of development. At 4500 feet, on the western side of the Mascot, the developed breadth is about 250 feet. The stopes of the Hedley Gold Mining Company period lie in a strip about 200 feet in breadth which angles down across the cluster, as now enlarged, from the southern edge on the upper levels to the northern edge on the lower levels. (Fig. 13).

The enlarged cluster coincides, primarily, with the Nickel Plate crumples, which comprise the following elements: (Fig.14)

		Folds	Associated Dikes (a)
1.	Minor	North Nose	North Flange
2.	Major	Trough	
3.	...	...	Central Dike
4.	Major	Main Nose	
5.	...	...	Flange
6.	Minor	South Trough	
7.	Minor	South Nose	

(a) ... Of hornblende-andesine-porphyry. Brown and Black dikes are not considered significant.

The fault and dike patterns are largely coincident. They make a braided shear system with dominant west-northwest members and subordinate northwest members. The indicated motion is westerly on the north side, and in the system shortening of the ground has taken place from the northeast to southwest, producing the crumples which strike northwesterly; and lengthening has taken place from northwest to southeast, producing steep normal tension faults which strike north by east. In addition to the andesine porphyry dikes which are shown on Fig. 14, the system carries brown dikes along the dominant and subordinate shear planes, and black dikes along many of the tension faults. Such is the general structure in plan.

In axial, or northwest section, the structures involve the intercalated porphyry spreads, the angling Midway dike with its mineralized slear cracks, the "shingles" of ore along the back and bottom of the Midway, steep cross-faults and the upper and lower limits made by silica cap and limestone floor respectively. These are shown on Plate 5. On this it should be noted that the majority of spreads are composed of normal hornblende-labradorite porphyry; that at least two, No. 1 sill above Sunnyside ore, and Big Sill beneath Yellow ore, are quartz-andesine hornblende porphyry; and that the Midway usually shows some primary augite, making it a gabbro. Note also that the alteration in both porphyry and argillite is most intense and gold values highest close to the Midway, and that neither floor nor top of alteration conform precisely to bedding. The orebodies <u>above</u> the Midway grade out to assay limits toward the <u>northwest</u>, while those <u>beneath</u> that dike grade out toward the <u>southeast</u>. Where the Midway is of gentle dip the orebodies on its back may maintain their commercial gold content for as much as 3000 feet (Purple ore from Glory Hole to 15th level), but where, as below the 12th level, the Midway steepens and enters the beds below the Yellow, the individual layers of ore appear to fade out within a few hundred feet. Here, however, the Midway or Hot Sill itself may be so heavily mineralized as to become ore. The cross faults (and associated black dikes), with displacements of 20 or 30 feet, have in general no correlation with primary gold values; but in upper levels partial oxidation may have resulted in enrichment along them. The Rodgers fault at the Glory Hole is the classic example of this. These faults, however, by bringing footwall or hanging wall porphyry across the end of a stope, complicate mining and in old days frequently led to the premature abandonment of an orebody.

In cross, or northeast section, (Fig.15), the Nickel Plate system presents a complex pattern of folds, bent porphyry sheets, axial dikes and faults, with alteration progressing out northward in the higher beds and with ordbodies fitted into the folded beds between the porphyries, and particularly into the corners between Midway sheet and Flange dike, and Chert-Breccia sheet and North Flange dike. Conforming to the alteration edge, the higher orebodies are staggered to the northward with respect to the lower ones. Basically this stagger of alteration and ore may be due to the fact that the Nickel Plate Nose is steeper on the north limb, so that its axis is farther north in the higher horizons. It is exaggerated by the fact that later, post-porphyry deformation tended to slice the structure along flat shears, with a northward movement of the upper slices, and mineralization worked out on these shears.

The position of the chloritized porphyry-argillite breccia on the steep limb between Nose and Trough, at the crossing of Central Fault and Midway dike, is also well shown on this cross section. This breccia is a loose rubbly crackled complex of highly altered fragments coated with such late-stage minerals as tremolite, chlorite, pyrite and lawsonite. Apparently a conduit of such rubble canalized the final fluids along this trace. On the lower levels (Fig. 16) of the Nickel Plate Mine this breccia expands into the beds between Central fault and Flange dike and takes the place of ore, seriously complicating exploration.

Sunnyside System

The Sunnyside orebodies lie about 500 feet stratigraphically below the Nickel Plate Yellow ore bed, between No. 1 sill and the top of the compact dark blue Sunnyside limestone. (Pl.5). But they are less dependent upon bedding control than has been supposed. As has been stated above, the floor of the skarn alteration does not conform in detail to the top of the limestone, but works up and down through the beds below No. 1 sill and drops into keels along transverse dikes. The orebodies hug the lower margin of alteration rather than any specific horizon. They also synchronize with crumpled zones and with dikes which traverse these in westerly and northwesterly directions. Sunnyside ore is typically richer in calcite than that of the Nickel Plate orebodies, and it may be very poor in arsenopyrite and other sulphides.

The aspect of the Sunnyside orebodies in plan is given in Plate 4. The controlling features may be summarized as follows:

Sunnyside 4½ (Fig.12), consists of major high grade orebodies, the richest yet found on Nickel Plate Mountain, located in the corner where the skarn alteration flattens out southward from its northern margin. They lie along a zone of northwest crumples, identical with the southern part of the Nickel Plate zone. In this zone are two transverse dikes which diverge in a westerly direction. The more northerly dike follows an anticlinal nose and along it is a deep skarn keel which cuts down through the Sunnyside limestone into underlying thin banded cherty beds. Across the top of this keel is a spread of porphyry, the Flipper Sill, which makes with the two dikes, intersections like those of the Flange with the Midway. (Fig.6). The orebodies are nested into the crotches made by these intersections, principally into the ones above the Flipper. While the ore shows bedding replacement it seldom goes out on the beds as far as 50 feet from the dikes. In contrast, it follows up along the dike for 100 feet or more.

The contacts are strongly sheared and mineralized and porphyry itself may become rich ore, particularly in the eastern end of the orebodies where the two dikes meet. The upper part of the ore on the north side of the north dike is made up of skarn-porphyry breccia identical with that already described in the Nickel Plate orebody system. Toward the west the alteration floor drops down across the beds more sharply than the Flipper Sill (Fig.12), and the ore diminishes westerly in size and value as it gets farther from the underlying marble line, much as does Nickel Plate ore as it is followed southerly from the northern marble line.

One hundred feet above the Flipper sill is No. 1 sill, composed like the Flange and other transverse dikes of andesine-quartz-diorite. As Fig. 6 shows, orebodies are being developed above this also in the crotches made by the north dike. These orebodies in turn lead upward and eastward toward the old Silver Plate tunnel, in which in early days spots of ore were discovered but were not aggressively developed.

Sunnyside 4 is a minor low grade orebody, found only near the surface at the collar of No. 4 incline. It lies along the top of the marble, following gently west-dipping beds which almost immediately as traced westward, turn up on a strongly brecciated axis into a belt of steep easterly dips. The ore was lost at the breccia which however shows low gold values in drill holes between Sunnyside 4 and the Silver Plate. This breccia, with the accompanying belt of steep east dips, seems to be continuous on the surface in a north-south direction from Silver Plate and the end of Sunnyside 4½ to Sunnyside 3 where the steep dips mark the east edge of the orebody. The inlets of ore in all three instances seem to rise along this belt of sharply reversed structures.

Sunnyside 3 has moderately large and rich orebodies which like those of Sunnyside 4½ hug the sides of a dike which is axial to an anticlinal crumple (Fig.17). Here the crumple is very sharp, for the east limb is vertical; and is assymmetrical, the axis (and the dike) dipping 60 degrees southwesterly. A keel of alteration along the dike cuts down into the bedded cherts below the Sunnyside limestone. The orebodies lie largely within this keel, and are nearly 150 feet beneath No. 1 Sill. Down dip to the northwest they are cut off by a steep northeast fault.

<u>Sunnyside 2</u> although the largest orebody of the Sunnyside System, with a production of 100,000 tons of ore of good grade (1 oz. gold per ton), occurs in a structure of moderate intensity, a northwest plunging syncline. The rich core of the orebody coincided with the axis of the syncline, from which ore spread out on the beds just below No. 1 Sill for 200 feet on the west limb and for 100 feet on the east limb, which at that point turned down on a mild anticlinal axis. Whether this reversal is preliminary to a plunge down into steep east dips, as at Sunnyside 3, cannot be ascertained for lack of croppings.

The orebody extends down for 200 feet westward from the outcrop on a floor of marbleized argillite, diminishing somewhat in size and in gold value. There it is cut off by a large northeast fault of steep southward dips, a fault which cuts across also the south end of the Sunnyside 3 outcrop. Apparently the northwest side has been displaced toward the southwest by motion with a large horizontal compenant. Despite the drag along this fault the Sunnyside 2 structure remains mild at the west end, and the strong crumples with axial dike (?), within which its inlet would be expected to lie, have not been found in that direction.

<u>Sunnyside 1</u> is insignificant. It occurs on a very mild anticline which is traversed by a small dike. Like Sunnyside 2 this ore is along bedding close below No. 1 Sill and rests on marble.

In general, the Sunnyside orebodies which are highest stratigraphically, like Nos. 1 and 2, show the widest spread on bedding, while those deepest in the formation cling most closely to the dikes. In this category are Nos. 3 and 4½. This relationship accords with that found, as already stated, in the Nickel Plate system of orebodies. It also accords with the pattern of the porphyries themselves, which rise from the base of Nickel Plate Mountain as stocks and dikes, to spread into the maze of sills and angling sheets after they enter the Nickel Plate formation. From porphyry to ore the fluids have found mostly steep fracture channels in and below the Sunnyside limestone, and mostly flattish shear channels in the overlying highly altered argillites.

Bulldog System

The south limit of the alteration floor on which lie the five Sunnyside orebodies is reached on the Bulldog claim, 1000 feet to the south of Sunnyside 2. Here the alteration margin turns upward and successive beds of skarn above the Sunnyside limestone run out southward into fresh blue argillites. South of the Bulldog workings even the beds above No. 1 Sill are unaltered.

In the workings themselves, however, the floor of alteration is still almost 100 feet below No. 1 Sill, and in this interval lies the Bulldog orebody. It coincides in position with the common limb between an anticline on the southwest and a syncline on the northeast, the complete fold plunging north by west, much like that of Sunnyside 3. Like that also, this Bulldog fold contains an axial dike, and carrying the resemblance to a further degree, the Bulldog orebodies are cut off below by a steep northeast fault.

On the surface the Bulldog mineralization is chiefly pyrrhotite, with some chalcopyrite and sphalerite and little arsenopyrite or gold. In this it resembles marginal portions of many Nickel Plate stopes. On the lower tunnel level, however, arsenopyrite and gold in commercial amounts are present and an orebody has been developed, promising well for further exploration down this Bulldog crumpled zone toward the northwest.

As the southern margin of the alteration is followed beyond the Bulldog, it crosses the Horsefly, Rollo and Warhorse claims to the Kingston. In this course it is intercepted by sundry complexities of structure, of which the most notable are steep east-west fractures in the Horsefly and a flat west-dipping thrust (?) plane traceable from the Rollo to the Kingston. All of these carry intermittent spots of mineralization associated with a weak marginal type of alteration. The Kingston has the most substantial showing (Fig. 10) and the strongest alteration, but its ore is high in chalcopyrite and pyrrhotite with low arsenopyrite, resembling the Bulldog ore at the surface. Still other occurrences of mineralization are found well within the skarn to the northward of this alteration margin, high up in the Nickel Plate beds and close under the silica cap. The best are on the I. X. L., Exchange Fraction, Climax, and Copper Cleft claims (Pl. 4). The first two of these seem to be spreads along bedding close to low-angle dikes of the Midway type; while the two latter are fissure fillings along the edge of transverse dikes of Flange type.

The precise form and importance of all remain to be determined. But they show that some at least of the ore mineralization went for great distances into and up through the heart of the skarn in the alteration cup. The concept that these are upward leaks from important orebodies down near the floor of the alteration must be considered, and if possible tested.

VII. Technique of Ore Hunting

Choice of Places

It will be clear from these brief descriptions of the developed orebodies of Nickel Plate Mountain that no routine method will automatically discover and develop new ore. Neither can any simple geometrical method thoroughly test so large a three-dimensional mass as Nickel Plate Mountain. There must be a selection of preferred targets of practical size, which can be successively tested to a conclusive result.

Such preferred targets will be the places where there is a concentration of the features already found in the stoped areas; such as---

(a) Strong alteration, preferably skarn mixed with calcite and close to the marble line.

(b) Strong structure, anticline-syncline with some steep bedding.

(c) High proportion of porphyry spreads with intense bleaching by leucaugite and with a high content of dipyrite.

(d) Low-angling porphyry sheets of Midway-Hot Sill type.

(e) Transverse dikes of andesine-quartz-diorite.

(f) Strong shearing and fissuring.

(g) Mineralization of the gold bearing stage, that is, arsenopyrite-dipyrite, calcite, clinozoisite. Chalcopyrite is indicative of marginal ore. Pyrrhotite by itself is not a good criterion, being far more generally distributed than the ore.

These features are discovered by careful surface mapping, supplemented by drill-hole records where such are available. Some new drilling from the surface may be justified to determine the attitude of (d) (e) and (f) and the depth of the marble line; but until detail of structure is worked out in underground openings such drilling cannot be expected to hit the rich core of an orebody except by good luck.

Plate 6 presents the preliminary study of Prospecting Area A, one of the preferred targets recommended by Billingsley in 1927. This study was followed by the drilling of two holes from the surface which supplied additional data on the position of the white marble floor but which found no ore, although one core showed according to G. P. Jones, an interesting association of arsenopyrite and gabbro. The closing of the mine in the same year stopped further investigation until the Kelowna Campaign of 1933-34, the results of which are shown in Figure 12. The orebodies as now known have also been added to Plate 6.

The point we wish to make inthus setting up the "before and after" comparison is that precise and costly underground exploration is essential to the thorough testing of even such a comparatively well known target as Area A of 1927. This fact was not fully recognized at that time. The Kelowna campaign involved a long crosscut from the Nickel Plate workings, aimed for the heart of Area A. When this crosscut neared No. 1 Sill, which was known to make the roof of the "orebeds", it was swung toward the north in order to hit the marble floor near the northern edge of the crumpled belt. Before reaching the marble, the crosscut encountered such strong mineralization in the form of calcite, quartz and pyrrhotite, with some arsenopyrite and gold, that the campaign proper was delayed while this was explored. It is now known to be a "halo" above the orebodies.

Subsequently the marble line was reached and the crosscut turned to meander southward on this. Within 100 feet it encountered a sharp anticline with a transverse dike and strong ore mineralization, which developed into the first of the Sunnyside 4½ orebodies. To so develop it has required, however, hundreds of feet of drifts, crosscuts and raises, and thousands of feet of short carefully pointed diamond drill holes. Truly there is no broad and easy way to find an orebody on Nickel Plate Mountain.

Drifting and Drilling

The nature of the underground exploration in the vicinity of an orebody is best illustrated in the Nickel Plate mine. We take as an example the development of Lower Purple ore north of the Central Fault, between the 1½ and 5 levels. (Pl.7)

The workings north of the fault from which this program was conducted were, as shown, confined to a long crosscut on the 4th level close along the Central Fault, with no ore; and a short drift on the 1½ level, with a small stope. The stages of work were as follows:--

(a) Drift on footwall of ore bed to determine its structure. This led to delimination of Trough and North Nose, of Chert Breccia sheet, and of North Flange dike.

(b) Drill fans of short diamond-drill holes to search for ore on folds and in corners between North Flange and Chert Breccia.

(c) When ore shoots have been found trace them upwards and downwards by fans of holes aimed at the controlling structures from suitable places on upper and lower levels.

(d) In general, any discovery of ore, however small, should be vigorously followed up; and any unexpected blank or "no good" holes should be checked, for such blanks may be due to fault gaps or to interruption by steep or transverse dikes. Our experience has been that every shoot of ore, no matter how small, has a long dimension. It is a manto, not a kidney, and is persistent along its channel. The problem is to find and define the channel and to project it correctly up and down.

Stoping

Geological control of stoping is merely a further refinement of the control of drifting. Mapping must be carried on along all the faces of the advancing stope because of the ever-present danger of interruption by dikes or by cross faults. (Fig.18). Frequently the dike will follow a fault, and the ore beyond will be offset up or down from a few feet to as much as twenty. In old and familiar regions the faults and dikes are known and their effects can be foretold, but in new ground offsets must be estimated. Short diamond drill holes can be very helpful under these conditions.

The greatest care, however, is exercised in keeping track of porphyry contacts and of bedding attitudes. Both are obscure and erratic, yet supremely important. Porphyry, which has been quietly following bedding planes for hundreds of feet, will abruptly turn up or down steeply and crosscut the ore beds, obliterating the orebody. Or the beds themselves, which have maintained a consistent west dip of 25 degrees throughout an entire stope, will without warning swing back and dip 60 degrees north. It is not always easy to detect these bends, for shearing following the old dominant dip may continue out across the new limb, giving the illusion of persistent uniformity. In one classic instance an old stope had been stopped along its north edge from Adit 4 down to the 4th level, a slope distance of 400 feet, supposedly at the limit of pay ore. Yet the orebody had merely turned sharply downward on the steep limb of the Main Nose.

It was subsequently developed for an additional 200 feet around the Trough. (Fig. 19).

The trick, in making geology serviceable in the stoping of ore, is to maintain at all times a consciousness of the three dimensional nature of these orebodies. The ore can go anywhere in three dimensions. The way it actually has gone is inferred through familiarity with its environment. If it is Upper Purple ore, for example, the footwall is chert breccia, and if this can be found again, as by the help of short drill holes, the trail can be picked up. (Fig. 20). If it is Orange ore, lying above the angling Midway, due allowance must be made for the vagaries of that porphyry sheet. And so forth.

Constant attention to these details has been proved to make the difference between stopes advancing steadily from level to level along the course of their ore shoots, and stopes abandoned here, there and everywhere as hopelessly squeezed out between porphyry walls.

It is just as important to recognize a true end of ore and to know when to cease further efforts. The distinction is structure. Along the controlling structure, we must be persistent; but going away from it we must expect to reach natural limits. Examples have been mentioned already of ore spreading away from a marble line and playing out, and of ore shingles along the Midway which go only so far out into the hanging wall or foot wall beds. The geologist in the stope must constantly keep in mind all of these relationships. And for his reward the resident geologist visiting daily and mapping each new face in crosscut, drift and stope, learns the geology as can no one else. Inevitably he gains new concepts from the wealth of new observations, and in due time he advances the geological theory of the mine and the district into a new stage of its evolution.