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GEOLOGY OF THE SHEEP CREEK CAMP

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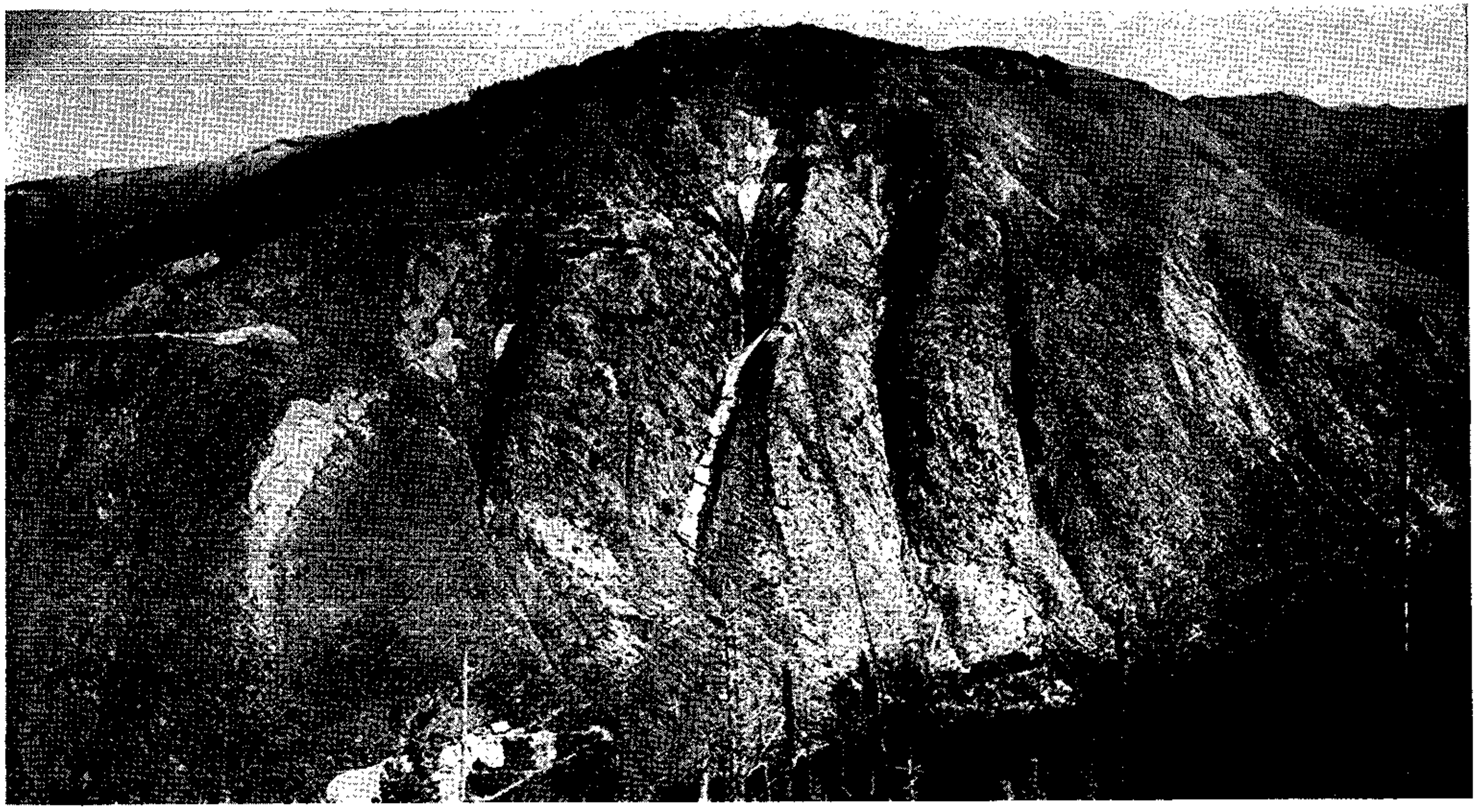

Looking north across valley of Sheep Creek.

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ERRATA

Page 7, Figure 8, and Figure 2 in pocket: For *Alexander* read *Alexandra.*

Page 13, line 9: For *Johnstone* read *Johnston.*

Page 32, line 23: For *Centigrate* read *Centigrade.*

Geology of the Sheep Creek Camp

CHAPTER I.—SUMMARY AND INTRODUCTION

GENERAL STATEMENT AND SUMMARY

The Sheep Creek camp has produced almost two-thirds of the lode gold credited to the Nelson Mining Division, and although the camp is currently non-productive, it ranks as the sixth camp in British Columbia in terms of total lode gold produced to the end of 1951.

The production of the camp has come from quartz veins that to the end of 1951 have yielded a total of 736,000 ounces of gold, 365,000 ounces of silver, 377,000 pounds of lead, and 312,000 pounds of zinc from 1,720,000 tons of ore. The production recorded year by year for the camp is set forth in Table VI on page 51. The accumulated gross value of the gold amounts to more than $24,000,000. Dividends paid from the profits of mines in the camp, mainly in the period 1935 to 1943, have amounted to $5,400,000.

Two main periods are recognizable in the productive history of the camp. The first began in 1899, reached its peak immediately before World War I, and ended in 1916. The second began in 1928 when a new vein on a new property, the Reno, was brought into production. In the next few years conditions became very favourable for mining gold, and the former producers, the Kootenay Belle and the Queen (Sheep Creek Gold Mines Limited), and a new producer, the Gold Belt, were equipped with modern mills. Production reached its peak in 1937 and was maintained at more than 135,000 tons a year until 1942. Thereafter production was mainly from the property of Sheep Creek Gold Mines Limited, which was shut down in 1951 after seventeen years of production. The camp is now inactive except for minor leasing-type operations. Both main periods ended in times that were unfavourable for gold-mining, the mines being closed after ore that had been developed under more favourable conditions had been entirely or almost entirely exhausted.

The output of the camp has come almost entirely* from oreshoots in quartz veins cutting folded quartzites that are part of a thick succession of Lower Cambrian and Precambrian(?) sedimentary rocks. The sediments are intruded by several stock-like granitic bodies, by an elongate swarm of quartz porphyry sills, and by numerous lamprophyre dykes. The granitic bodies are believed to be older than the ore and most of the lamprophyres to be younger. The quartz veins strike northeasterly across the axes of the folded sediments and generally dip steeply.

The Sheep Creek gold camp is within a district that contains numerous mining camps. Adjoining and near-by areas are important sources of tungsten and of silver, lead, and zinc. Several camps have contributed lode gold† in varying quantities. Interest in lead-zinc replacement deposits in areas adjoining the Sheep Creek camp has increased greatly since the field work for this bulletin was undertaken. Similar lead-zinc deposits have not been discovered within the boundaries of the area treated in the present report.

The sedimentary rocks in the Sheep Creek camp had been highly folded prior to the intrusion of the igneous rocks, and two tight northerly trending anticlines with an intervening syncline make up the major structures of the camp. Faults belonging to

* A very small part of the total gold production has been recovered from narrow high-grade veins in limestone.

† Properties in the several camps of the district have yielded up to 120,000 ounces of gold each. The occurrences of gold in the district are dealt with briefly in Bulletin 20, Part II, Lode Gold Deposits, Southeastern British Columbia, by W. H. Mathews, British Columbia Department of Mines, 1944.

four sets cut across the folded structures: (1) A group of northeasterly trending, southeasterly dipping, right-hand strike-slip faults with a small normal component of movement contain all the productive veins, (2) a very few northwesterly trending left-hand strike-slip faults, (3) several northerly trending normal faults, and (4) flat faults along which the hangingwalls have been thrust westward with respect to the footwalls.

The veins occupy the northeasterly trending faults and consist of quartz with minor amounts of pyrite and still smaller amounts of pyrrhotite, chalcopyrite, galena, sphalerite, and gold. The quartz in the veins is probably derived in large part by recrystallization of quartzite walls. Visible gold is rare. The ore is almost without exception confined to parts of the fault zones in which one or both walls are made up of quartzite, and the orebodies are, therefore, found where the veins intersect certain stratigraphic units, notably the quartzite units referred to as Upper Nugget and Upper Navada. The Motherlode member, also quartzitic, is for some unexplained reason almost completely lacking in orebodies. The Reno formation, predominantly argillaceous, is almost devoid of ore except in the Reno mine, where the rocks have been conspicuously metamorphosed. In the veins the ore occurs in shoots; the other parts of the veins are either too thin, or too low in grade, or both, to justify stoping. In any one vein the profitable oreshoots have been found within a vertical range of not more than 1,600 feet. This vertical range for successive veins lies within a depth zone that slopes regularly from the northern to the southern end of the camp. At the northern end it is 5,500 to 7,000 feet above sea-level, and at the southern end of the camp, 4 miles distant, it lies entirely below the 3,000-foot level. Above this zone the vein fracture may persist, but at least within the quartzites the veins are too narrow to contain orebodies. At the bottom of the zone the veins persist and may be even wider than within the zone. A few veins have been explored at depths of not more than 250 feet below the bottoms of the deepest stopes. Although these veins are of good width, the parts rich enough in gold to constitute oreshoots were too small and too widely scattered to encourage further exploration and development. Within the favourable wallrocks and within the favourable depth zone, those parts of the veins striking most nearly east are more likely to contain ore.

Displacement on vein fractures is variable, and in any one vein, other things being equal, the width increases with the amount of displacement. However, the vein filling is not necessarily wide in vein fractures on which displacement has been large, nor narrow in those on which displacement has been small.

The grade of vein matter is exceedingly variable, patches of high-grade ore being distributed apparently at random within a vein. The area of such a patch measured in the plane of the vein is rarely more than a few hundred square feet and commonly is much less. In general patches of ore of which the grade exceeds 5 ounces of gold per ton are larger and more common in the upper part of the productive zone than at greater depths.

LOCATION AND ACCESS

The Sheep Creek mining camp is situated in southeastern British Columbia, 24 air-line miles south of the city of Nelson, 28 miles east of the city of Trail, and 10 miles north of the International Boundary. The area is mountainous, and where Sheep Creek transects the mining camp, it occupies a narrow valley with sides that are steep or precipitous. Most of the mine buildings are on the lower slopes, but some are much higher, notably the Reno mine camp.

From a point near the mouth of Sheep Creek on the main paved highway 4 miles south of Salmo, a gravel highway extends up Sheep Creek. Salmo is a shipping point on a branch of the Great Northern Railway and is 25 miles by road from Nelson and 24 miles from the smelter at Trail.

The road up the valley of Sheep Creek extending to the Motherlode mill is 7 miles long. From the upper part, branches extend to the Gold Belt and Kootenay Belle main workings on the north side of the valley. From Sheep Creek Post Office a branch road leads to the Sheep Creek mine, and from that road a branch leads to the Ore Hill mine high on the south side of Sheep Creek valley. From the village of Sheep Creek a road extends northerly up Nugget Creek to the Reno mine. Branches from the Reno road give access to several properties. A former aerial tram-line linking the Motherlode mill to the Reno mine was no longer in operating condition in 1949, but a shorter tram-line leading from the mill to the Motherlode mine was still serviceable. Trails, most of which were badly overgrown, lead to the smaller properties in the area. In 1949 the roads to the Reno mine and many of the trails were in poor repair, and the road to the Ore Hill was impassable for vehicles.

FIELD WORK AND LABORATORY INVESTIGATIONS

The field work on which the present bulletin is based was undertaken in 1948 and 1949, when the Sheep Creek mine was still being operated and substantial parts of the underground workings on other properties were still accessible.

Geological investigations were carried out under the supervision of the writer in the summers of 1948 and 1949. M. C. Robinson served as senior assistant in 1948, having charge of the party from the middle of May to the end of June during the absence of the writer. D. Heddle and J. A. Gower also assisted with the field work in that year. In 1949 the writer was assisted by J. A. Gower and R. C. James. M. C. Robinson, in the winter of 1948–49, also undertook studies of the Sheep Creek ores as part of the requirements for an M.A. degree at Queen's University, and J. A. Gower, in the winter of 1949–50, made studies of distribution of values, vein widths, and mineralization in the Reno vein as part of the requirements for a B.A.Sc. degree at the University of British Columbia.

Plans of underground workings for use in plotting geological data were obtained from the mine-owners, and in the summer of 1948 F. W. Reger was employed to make a transit survey that determined the correct relative positions and orientations of the workings of each of the main properties.

The sources of production data are mainly the annual production returns made by the mine operators. These data are accumulated in and were obtained from the files of the Bureau of Economics and Statistics, Department of Trade and Industry. Data on production from individual veins were obtained from records in the mine offices. The principal production data are tabulated on pages 51 and 52.

METHOD OF STUDY

Surface mapping was carried on throughout the camp with the most intensive studies concentrated in areas of good exposures that gave promise of yielding data not available in underground workings. Plane-table surveys on a scale of 300 feet to 1 inch served for most of this work, although a cliff face 1,000 feet north of the Reno mine displaying particularly intricate structure was mapped on a scale of 100 feet to 1 inch. Some pace and compass surveys between points of known location were made in areas of heavy vegetation where plane-table surveying would be particularly difficult. Compass resections on near-by points were used wherever possible in these traverses to minimize errors in location.

The peripheral sections of the camp were examined by reconnaissance techniques, and the data thus accumulated were plotted directly on air photos. Points located by plane-table triangulation and intersection of creeks with surveyed claim lines were used as control in transferring geological data and contours from these photos to a corrected plan. A geological map with a scale of 1,500 feet to the inch has been prepared by means of a Kail radial planimetric plotter. Inasmuch as the scale of the photos varied from about 1,800 feet to 1 inch for the higher ground to 2,500 feet to 1 inch for the lowest parts of the area, errors of location are somewhat enlarged. The biggest handicap in the use of photos was a widespread cover of snow on the higher slopes at the time the pictures were taken; the snow cover effectively masked much detail. In spite of all precautions, therefore, the relative positions of two points on a single air photo may be in error as much as 100 to 200 feet on 1,500-feet-to-the-inch plan, and the error in absolute position may be still greater.

Most of the level workings in the mines of the camp were mapped in detail on a scale of 40 feet to 1 inch, and nearly all the other accessible level workings were examined and mapped on a smaller scale. All the workings below 6 level in the Kootenay Belle mine were flooded, but the existing geological map of the lower levels served well in permitting the extension of geological contacts into this inaccessible part of the mine. All workings in the Reno mine below 5 level were likewise flooded, but diamond-drill cores taken from the lower part of the mine made it possible to correlate the wallrocks of this vein with those of the mines farther south. Details of the structure as indicated in a geological section of the Reno mine, prepared by the Reno mine geologist, have been used to supplement data obtained from these drill cores, from personal studies in the higher levels of the mine, and from surface mapping on the hillside north of the mine. The two lowest levels on the Motherlode vein and the lowest level on the Queen vein were also flooded, and geological information on these workings remains incomplete.

Although substantial parts of the mine workings were accessible for examination, very little was left to indicate the character of mineralization except a few isolated pillars and the narrow or barren portions of the veins at and beyond the limits of stopes. Most of the work underground, therefore, was devoted to a study of wallrocks and wallrock structures.

In the course of the investigation vertical sections showing mine workings and structure of the folded beds were prepared for nearly all the productive veins of the camp (*see*, for example, Figs. 3 to 8). In these sections the boundaries between stratigraphic units and the outlines of workings on the veins have been projected along lines *parallel to the local trends of the major folds* onto vertical planes roughly paralleling the veins, though oblique to the bedrock structure. By means of this type of projection the configuration of the folds in the plane of the section are represented without distortion, and the outlines of stopes are shown in correct position relative to the contact of the bedded rocks with one wall of the vein. Where projection planes are parallel to one another, as is commonly the case, the comparison of wallrock structure and distribution of ore in near-by veins is facilitated. In this type of projection the outlines of workings are distorted. For example, the centre line of a raise may be depicted as an inclined or curving line where the vein departs from the vertical or is irregular in dip. However, this minor objection is greatly outweighed by the advantage of this method of projection in geological studies of the camp.

A composite plan has been prepared in which details are projected onto a limited number of horizontal planes corresponding approximately to the more important levels of the different mines (*see* Fig. 2). Such a plan avoids the distortion that is inevitable in a surface map because of the combined effects of irregular topography and inclined beds. In this plan where a working does not correspond exactly with the plane of projection, contacts have been projected *up or down dip* to the plane of projection so that the contacts appear throughout the different mine areas in correct relationship to one another. The level outlines have been projected *vertically* so that they, too, appear in correct position in plan relative to one another. In places on the composite plan, geological contacts may, therefore, be 20 to 30 feet removed from corresponding points on the walls of the workings.

SOURCES OF INFORMATION AND ACKNOWLEDGMENTS

Previous geological descriptions of the camp are to be found in Memoir 172 of the Geological Survey of Canada, " Geology and Mineral Deposits of Salmo Map-area, British Columbia," by J. F. Walker (1934), in a paper in the Canadian Institute of Mining and Metallurgy by R. A. McGuire (1942), and in several of the Annual Reports of the Minister of Mines of British Columbia. Descriptions of individual mines with accompanying geological notes have appeared periodically in the Western Miner, notably the

July, 1935, issue of this publication, and progress notes on mining developments have been published from time to time in the Annual Reports of the Minister of Mines and in the Western Miner.

Unpublished information on the geology and production of the individual mines has been made accessible by the present owners. Of particular assistance have been the geological maps of surface showings on the Golden Belle property prepared by J. R. Johnston, on the Reno property by E. N. Pennebaker, and on Gold Belt holdings by F. W. Reger, and the geological plans of level workings in the Kootenay Belle mine by J. R. Johnstone, in the Reno, Motherlode, and Nugget mines by C. C. Starr, in the Gold Belt mine by H. G. Lynch, and in the Sheep Creek mine by F. Buckle and others. Sampling records* of almost all the stopes of the Kootenay Belle mine have yielded a wealth of information on the distribution of values and vein widths in the three principal veins of this mine. Similar plans for the Reno vein have been prepared by J. A. Gower† from an assorted collection of more than 10,000 assay returns abandoned in the Reno mine office. The data from these two mines constitute the only detailed and comprehensive information on the grades of ore encountered in widely separated parts of a single vein. The records of grades and tonnages of ore drawn from various stopes in other mines together with some assay plans of some of the drifts confirm, but in general do not amplify, conclusions drawn from the data for the four veins mentioned above.

Special acknowledgment must be made for the information, assistance, and courtesies given by H. E. Doelle, managing director of Sheep Creek Gold Mines Limited, and Dr. A. G. Pentland, geologist for this company; F. W. Reger, superintendent of the Gold Belt mine; A. Endersby, Jr., owner of the former Reno holdings; F. R. Thompson, O. Bellavance, and G. McIntyre, all of Sheep Creek; and H. C. Hughes, former Inspector of Mines for the Kootenay District.

* Sampling records include assays of samples, plotted on longitudinal sections of the vein, either in the plane of the vein or on a vertical plane.

† *See* p. 11.

CHAPTER II.—PHYSICAL FEATURES

GEOMORPHOLOGY

Surface Features

The Sheep Creek mining camp is in the southern part of the Selkirk Mountain system within a portion generally known as the Nelson or Quartzite Range. Drainage from the crest of this range is westward through the map-area along three major valleys, that of Hidden Creek on the north, Lost Creek on the south, and Sheep Creek near the centre. Mount Waldie and Reno Mountain exceed 7,200 feet, and the valley of Sheep Creek at the west edge of the map-area is at an altitude of 3,000 feet. The valleys of Hidden and Lost Creeks have not been cut so deeply; their floors near the western edge of the map-area are at altitudes of about 4,000 feet.

Relics of an old erosion surface of lower relief than is found in the present topography can be recognized in parts of the map-area. Relatively gently sloping surfaces, unrelated to bedrock structure, on the crests of the ridges on either side of Billings Creek are evidently the remains of this erosion surface. The broad valley of upper Fawn Creek, whose floor lies scarcely 2,000 feet below the adjoining summits, is thought to be another relic. The presence of relatively resistant granite at the mouth of this hanging valley has apparently retarded stream cutting in the present erosion cycle and has thus permitted the preservation of the mature surface. Whether or not the broadly flaring valley slopes of upper Sheep Creek can be attributed to this early surface is, however, problematical.

The present erosion cycle has led to the development of deep, steep-walled, V-shaped valleys; those of Sheep Creek and Waldie Creek on either side of Yellowstone Mountain are most notable. Here the valley walls extend upward at slopes of from 30 to 40 degrees to ridge crests as much as 3,000 feet above the streams. The valleys of both Sheep Creek and Waldie Creek have been cut to a considerably greater depth than those of their tributaries, which now cascade in their lower courses through vertical distances up to 1,200 feet. Although the valleys tributary to Sheep Creek and Waldie Creek are thus "hanging," it seems that differences in the rate of stream cutting, particularly where tributaries cross more resistant rocks than the main streams, rather than any glacial overdeepening, are responsible for the discordant relationships. The V-shaped form of Sheep Creek valley in the 2 miles above the mouth of Waldie Creek gives no suggestion of significant glacial scour.

Glacial activity may be partly responsible for the broad, steep-walled, U-shaped cross-sections of Hidden Creek and Lost Creek valleys. A fill of glacial and alluvial debris may exaggerate their U-shaped form, but Hidden Creek valley, at least, has bedrock exposed locally on its floor. Lost Creek valley has a straight course, which adds to the impression that glacial erosion has modified its form. Sheep Creek valley, also, in its uppermost 1 to 2 miles has a U-shaped form.

The work of alpine glaciers is apparent in the cirques and precipitous north-facing cliffs on ridges rising above the 6,000-foot level in the vicinity of Mount Waldie and Reno Mountain. None of the cirques is now occupied by permanent ice, although avalanche snow often lingers in sheltered localities within them well into August.

Evidence of the Cordilleran ice-sheet in the form of glacial striæ has been found as high as 6,500 feet in the Sheep Creek camp. The ice-sheet in this locality undoubtedly attained somewhat higher levels, although it is not known whether it ever buried the higher peaks such as Reno Mountain and Mount Waldie. The general direction of ice movement in this part of the Nelson Range appears to have been slightly east of south,* but wide departures from this trend are observed, notably half a mile north of Mount Waldie and half a mile northwest of Reno Mountain where striæ trend northeasterly,

* Daly, 1912; Little, 1949 and 1950.

almost at right angles to the prevailing direction. A few large ice-borne boulders are known, such as an enormous block of granite about 400 feet east of the Sheep Creek post office, but the sources of these and the direction of transport cannot be determined accurately. Glacial drift, which is thick on the valley floors but scanty at high levels, is predominantly of local origin.

Caves

Small cavities, apparently formed by solution, occur in massive quartzites at several places. Such cavities have been seen in quartzite (Upper Motherlode member) on the walls of 3E drift of the Kootenay Belle mine, where they occur about 1,000 feet below the present surface. They are only a few inches in diameter and a few feet long. The rocks forming the walls of these cavities are unaltered though coated with a sooty deposit, and the irregularities of their surfaces indicate a marked control of solution by the joint pattern of the quartzite. A similar though much larger cavity, 3 to 4 feet in diameter at its lower end and about 20 feet in height, occurs in quartzite (Upper Nugget member) in the lower level, north drift, of the Bonanza workings, approximately 600 feet below the present surface.

An opening in argillaceous quartzite (Reno formation), large enough to permit passage of boulders 1 foot in diameter, extends from surface to 6 level of the Ore Hill mine 60 feet below. Where intersected in the 6 level drift, the opening is now choked with boulders, some of which are quartz porphyry clearly derived from surface drift. A large flow of water enters the drift at this point. The opening is marked on surface by a pit, about 20 feet in diameter and 6 feet deep, in the bed of Billings Creek.

Cavernous limestone (lower part of the Laib group) occurs in both the Kootenay Belle 3 level crosscut and in the Gold Belt 1850 crosscut, 200 and 500 feet respectively below the surface. Ground-water can flow freely through both of these zones into the crosscuts.

What may have been a natural opening, developed by slumping over a zone of intense argillic alteration, occurs in the upper levels of the Kootenay Belle mine (*see* p. 48).

CLIMATE

The climate of the Sheep Creek camp is cool temperate, and the moderate precipitation is fairly well distributed through the year. Records made at Nelson, Trail, and other points in this part of the Province indicate that mean annual precipitation is between 25 and 30 inches in the main valleys and as much as 10 inches more in the adjoining mountains. The period of greatest precipitation is in midwinter, and the period of lowest precipitation in midsummer. Mean annual temperature at Rossland, a locality with almost the same altitude as that of the settlement of Sheep Creek, is 37 degrees Fahrenheit, the July mean is 64 degrees, and the January mean 22 degrees. Snow accumulates to a depth of several feet in Sheep Creek valley, and one-story buildings at high levels are almost completely buried at midwinter. Problems of snow removal along the road to the Reno mine proved so great that when the aerial tramway was built from Sheep Creek to the mine, no attempt was made to keep the road open throughout the winter. Snowslides are common in seasons of heavy snowfall, especially on over-steepened, north-facing rocky slopes and on hillsides which have been swept by forest fires. Several snowslides in the spring of 1949 demolished the office, part of the mill, part of the cook-house, and several smaller buildings in the holdings of the Gold Belt Mining Company Limited. Fortunately the mine was inactive at the time and no loss of life was sustained. One of the slides blocked the road to the mine until June, in spite of the fact that this obstruction was on a south-facing slope at an altitude of less than 3,400 feet. Avalanche snow lying that summer on the Kootenay Belle 6 level dump, altitude 3,320 feet, on the shady side of the valley, was expected to remain until the following winter.

Icing conditions around shafts and portals have added to the inconveniences of winter activities but do not interrupt underground mining. Icicles were seen around the mouths of chutes on 4 level of the Reno mine (altitude 6,400 feet) in late July, 1949.

VEGETATION

Vegetation includes dense Douglas fir and cedar-hemlock forests, notably on the north-facing slopes at lower levels where there is a deep cover of glacial drift. Similar forests grew on south-facing slopes at the turn of the century, but most of this timber has been destroyed by fire and replaced by a cover of perennial shrubs. Much of the land above the 6,000-foot level is open grassland, although here, too, there is evidence of earlier forest cover destroyed by fire. Trees are stunted and scattered above the 7,000-foot level, but some grow within a few feet of the highest summits. Some of the larger trees have been used for construction materials, mine timbers, and firewood, but large-scale logging activities other than those incidental to mining have not been conducted within the map-area.

WATER AND POWER

Water for mining, milling, and domestic purposes can be obtained in sufficient quantity at almost all seasons from Sheep and Waldie Creeks. Other supplies have been obtained from several small streams north of Sheep Creek, from Fawn Creek on the west to Clyde Creek on the east. At high altitudes water is in short supply except in the spring and early summer. Domestic water for the Reno mine had to be obtained largely from wells and small springs situated at points along the hillside as much as 3,000 feet south-east of the mine.

Water as a source of power has been obtained from both Sheep and Waldie Creeks, although the almost complete lack of storage facilities to compensate for reduced flow in winter months rendered the developments distinctly unsatisfactory. The Yellowstone mill, used between 1900 and 1916 for the treatment of ore from the Yellowstone and Queen veins, was operated by Pelton wheels with a generating capacity of 75 horsepower. A 6,000-foot flume from Sheep Creek and a 5,000-foot flume from Waldie Creek provided heads of 260 feet and 450 feet respectively. The old Kootenay Belle mill, operated from 1906 to 1909, was supplied with water from Sheep Creek under a 130-foot head. The power plant at the Mother Lode mill is supplied with water from Sheep Creek and its tributary, Curtis Creek, by 13,600 feet of pipe-line providing 5 cubic feet per second under a head of 660 feet. The plant is rated at 300 horsepower. A hydro-electric power plant was constructed in 1932 by Reno Gold Mines Limited on Sheep Creek 3 miles below the mouth of Waldie Creek. Authorized to use 18 cubic feet per second and provided with a head of 450 feet by 17,000 feet of flume and pipe-line, the plant was capable of generating 750 horsepower. Problems of maintenance of the flume and pipe-line, icing conditions in winter, and periodic low water made this plant an unsatisfactory source of power for the Reno mine and mill, and it was abandoned in 1937.

Electric power has been provided to the Sheep Creek camp by the West Kootenay Power Company since 1934. The transmission lines of this company extend to a sub-station on the north side of Sheep Creek 1,500 feet east of the mouth of Waldie Creek. From this point, power-lines extend to the various mines and mills.

CHAPTER III.—GEOLOGY

SEDIMENTARY ROCKS

Careful study of the stratigraphy of the sedimentary rocks of the camp is necessary to interpret the complex structures and to determine relationship between wallrocks and mineralization. For the purpose of detailed study, subdivision of some of the stratigraphic units established by Walker (1934) and a revision of smaller units described by McGuire (1942) have proven desirable and are incorporated in this report. Accordingly, Walker's Quartzite Range formation has been divided into three units, here referred to as the Motherlode, Nugget, and Navada members. The new term "Navada member" is being introduced for the rocks referred to by McGuire as " Reno quartzite " and " Reno argillaceous quartzite " but since found to be part of Walker's Quartzite Range formation and not within his type " Reno." The Reno formation itself is redefined to exclude calcareous and argillaceous beds now known to represent in the type section an infold of younger rocks. Work done in 1948 and 1949 by the Geological Survey of Canada has led* to a subdivision of the Pend d'Oreille series, and the term " Laib group " has been introduced for the lower argillaceous and calcareous beds of this series which extend into the Sheep Creek map-area.

The three subdivisions of the Quartzite Range formation, the Motherlode, Nugget, and Navada members, can be reasonably well recognized. Their limits can be ascertained throughout the camp with an error rarely more than 10 to 20 feet, and it seems probable that, within the 5 square miles mapped in detail, they represent four time boundaries.

Each of these members has been subdivided further. The Motherlode member can be divided into a lower and an upper quartzite zone separated by a readily recognizable argillaceous zone which may, however, be of relatively limited lateral extent. The Nugget member has also been subdivided into three units which can be distinguished from one another reasonably well. The lowest unit consists essentially of argillaceous rocks, the second is made up of mixed argillites and quartzites, and the upper is composed almost entirely of quartzite. The Navada member has been subdivided into an upper white quartzite separated by an ill-defined boundary from a lower part consisting of mixed white, grey, and argillaceous quartzite.

THREE SISTERS FORMATION

The Three Sisters formation, as exposed within the map-area in the core of the Eastern anticline, consists principally of grey grits but locally includes white quartzite and white grit. The formation has a maximum exposed thickness of about 500 feet at the crest of the Eastern anticline, and a much greater thickness may be concealed beneath the present erosion level. The grey grits are directly overlain by several feet of green schist commonly containing large dolomite rhombs and apparently representing a metamorphosed dolomitic tuff. This member, though thin, is distinctive and serves as an effective marker for the top of the Three Sisters formation in this locality. The base of the formation is not exposed within the area.

The formation is exposed in a single belt along the axial plane of the Eastern anticline. North of Waldie Creek this belt varies in width from 600 to 1,100 feet; to the south it narrows rapidly and terminates at the 6,400-foot level at the tightly folded crest of the anticline. The same rocks may perhaps be exposed in the valley east of Mount Waldie, but on the southeast ridge of Mount Waldie they are buried beneath the overlying Motherlode quartzite at the crest of the Eastern anticline.

The correlation of the rocks of this belt with the Three Sisters formation of the type locality, 3 miles to the east, seems justified by the fact that grits and other coarse clastic

* Little, H. W., 1950, pp. 15–21.

Table I.—Correlation of Sedimentary Rocks

Walker (1934)	McGuire (1942)	Mathews (1950)	Park and Cannon (1943)
Pend d'Oreille series: Lower part.	Pend d'Oreille series:	Laib Group (1,000 ft.+).[2]	
Reno formation.	Reno series: Reno argillite.	Reno formation (50 to 900 ft.).[2] Upper Reno. Lower Reno.	Maitlen phyllite.
Quartzite Range formation.[1] (Quartzite 2,600 ft.)	Reno quartzite. Reno argillaceous quartzite.	Quartzite Range formation (2,000 ft.±).[2] Navada member: Upper Navada. Lower Navada.	
	Nugget series: Nugget quartzite.	Nugget member (540 to 900 ft.): Upper Nugget. Middle Nugget.	Gypsy quartzite.
(Argillaceous member 200 ft.)[1]	Nugget argillite.	Lower Nugget.	
(Massive white quartzite 1,600 ft.)[1]	Motherlode series: Motherlode quartzite. "Basal" argillites.	Motherlode member (1,000 to 1,100 ft.): Upper Motherlode. Middle Motherlode. Lower Motherlode.	
Three Sisters formation.		Three Sisters formation (500 ft.+).[2]	

[1] Thickness in the type locality, 3 miles east of the Sheep Creek camp.
[2] Thickness or range of thickness in or adjacent to the Sheep Creek mines.

Table II.—Table of Formations

Age	Formation	Member	Unit	Lithology	Thickness in Feet	
Lower Cambrian	Laib Group			Argillite.	200[1]	1,000+[1]
				Grey limestone.	150[1]	
				Argillaceous in some localities, elsewhere dominantly calcareous.	300–500[1]	
				Limestone and argillite.	150–300[1]	
				Argillaceous beds, biotitic and amphibolitic schists.	100–300[1]	
				Limestone.	0–60[1]	
Precambrian (?)	Reno Formation	Upper Reno		Impure dark bluish or greenish quartzite with some grit beds.	125[2]	50–900[1]
		Lower Reno		Argillite, argillaceous quartzite.	450±[2]	
	Quartzite Range Formation	Navada Member	Upper Navada	Massive white quartzite.	20–160	120–300
			Lower Navada	Dark, thin-bedded quartzites and argillaceous quartzites.	100–140	
		Nugget Member	Upper Nugget	Massive white quartzite.	135–375	540–900
			Middle Nugget	White, grey and dark quartzites, dark *argillaceous quartzites, and argillite.*	175–300	
			Lower Nugget	Argillite and dark argillaceous quartzite.	150–225	
		Motherlode Member	Upper Motherlode	Massive white quartzite.	370–450	1,000–1,100
			Middle Motherlode	Argillite, grey grit and green schist.	50	
			Lower Motherlode	Massive white quartzite.	500–700	
	Three Sisters Formation			Grey grit, white quartzite and grit and green schists.		500+[1]

[1] Thickness or range in thickness for the northwestern part of the camp, near the Reno mine.
[2] Average thickness from measurements near Reno mine.

rocks are common in this unit and almost completely absent in the overlying Quartzite Range formation. The lithology is by no means identical at the two localities, and no beds that correspond to the green schist exposed within the Sheep Creek camp have been recognized at the type locality. The stratigraphic interval between the top of the gritty beds in the Sheep Creek camp and the base of the Reno formation is approximately 2,000 feet, which is considerably less than the corresponding interval, 4,400 feet, in the exposures to the east. Lateral gradation of the beds, a feature readily apparent in higher members, together with thinning and thickening of the less competent strata as a result of folding, may easily account for the differences noted.

The competency or incompetency of the strata of the Three Sisters formation under the folding and faulting that have affected the Sheep Creek camp is not clearly apparent. The presence of the grits along the axial plane of the Eastern anticline, in a structural position corresponding to the beds of the Middle and Lower Nugget members of the Western anticline, together with the marked shearing between grit fragments shown in thin section, suggests, however, that the Three Sisters formation forms a relatively incompetent structural unit. None of the faults that cut the competent quartzite members of the overlying Quartzite Range formation is known to extend into the Three Sisters formation, and this rather negative evidence also suggests that the gritty beds are relatively incompetent. Within the limits of the camp no gold-bearing veins are known in this formation, and no underground work has been done in the formation.

Quartzite Range Formation

Motherlode Member.—The Motherlode member consists predominantly of massive white quartzite, much of which is so homogeneous that stratification can scarcely be discerned. A zone up to 50 feet thick of argillite, grey grit, and green schist occurs in the middle of the member, and the upper and lower limits of this zone provide two useful boundaries for subdivision of the Motherlode member into three parts. Thinner zones of argillaceous rocks, of grit, and of green schist or amphibolite occur in other parts of the member, but these are apparently of limited lateral extent.

The thickness of the Motherlode member on the western limb of the Eastern anticline ranges from 1,000 to 1,100 feet; on the eastern limb of this same fold the thickness is but 400 to 600 feet. The thickness of the Lower Motherlode beds on the western limb of the fold varies from about 500 to 700 feet; the argillaceous Middle Motherlode beds are as much as 50 feet thick, and the Upper Motherlode strata have a thickness of from 370 to 450 feet. This subdivision of the Motherlode member has not been extended to the eastern limb of the Eastern anticline, and the thicknesses of the corresponding beds there are not known.

The Motherlode member is exposed only in the axial region of the Eastern anticline. It extends southward in two subparallel belts on either side of a central core of Three Sisters formation. In the area southeast of Mount Waldie they merge into a single broad zone astride the axis of the anticline.

The competency of the Motherlode quartzites under conditions of folding is distinctly greater than that of the argillaceous rocks of the overlying beds. Relatively small dragfolds, a few tens of feet across, are to be seen on the southeast ridge of Mount Waldie, but none are as tight and complex, nor is the variation in thickness of beds between crest and limb of the fold by any means as great as can be found in the argillaceous rocks. Refraction of vein faults toward the presumed direction of maximum compression, together with a diminution in amount of drag in the beds on either side of a fault surface, as the fault passes from argillaceous rocks to Motherlode quartzite, also indicates greater competency of the quartzite. Notwithstanding the relatively high competency and the composition of this member, only in the Motherlode mine is a vein known to contain an orebody in the Motherlode member.

Nugget Member.—The Nugget member has been subdivided into three units. The lowest unit consists essentially of argillaceous rocks, the second of mixed argillite and quartzites, and the upper almost entirely of quartzite. The base of the lowest " important " quartzite bed is regarded as the top of the Lower Nugget, and the top of the highest " important " argillaceous zone is regarded as the base of the Upper Nugget. The recognition of the critical quartzite bed and argillaceous zone, particularly in different limbs of the folds, is at places uncertain, and there is considerable doubt whether the same two stratigraphic horizons have been correctly identified at all points in the camp. The argillaceous horizon marking the top of the Middle Nugget cannot be traced continuously across the faulted crest of the Western anticline, and it is a matter of hope rather than certainty that the same argillaceous beds have been identified on opposite limbs (*see* Figs. 7 and 8). There is some reason to suspect, too, that this argillaceous zone within the Sheep Creek mine in the Western anticline corresponds to a zone of dark quartzite 125 feet stratigraphically above (west of) the top of the Middle Nugget as mapped in the Kootenay Belle mine and other workings of the Eastern anticline (*see* Fig. 7). Each of the three units of the Nugget member as they have been mapped may not, therefore, be entirely contemporaneous in all parts of the camp. Nevertheless, each unit maintains the same general lithological characteristics throughout.

The Lower Nugget beds comprise argillites interbedded with dark argillaceous quartzites but are devoid of any zones of light-coloured quartzite more than a few feet thick. The total thickness of beds as mapped varies from 150 to 225 feet. The succession is notably incompetent but, sandwiched as it is between the much more competent rocks of the Motherlode member on one side and the Middle and Upper Nugget beds on the other, it does not display the complex dragfolds and great variations in thickness that are so characteristic of the similarly incompetent Reno formation.

Structural sections of the tightly compressed Western anticline in the Sheep Creek mine suggest that only the beds above the Motherlode and Lower Nugget are involved in the fold, and that the Lower Nugget argillites may have provided a zone of shearing between closely folded beds above and relatively unfolded rocks beneath. No vein is known to contain oreshoots in the Lower Nugget beds.

The Middle Nugget beds, 175 to 300 feet thick, comprise a succession of beds of white, grey, and dark quartzites, dark argillaceous quartzites, and minor amounts of argillite, with readily apparent stratification. These form a distinctly less competent assemblage of rocks than the massive quartzites of the Upper Nugget but, on the other hand, they make up a much more competent unit than the beds immediately beneath them. Large variations in thickness of some of the more argillaceous rocks of the Middle Nugget member are inferred particularly near the axial plane of the Western anticline, but the total thickness of beds on the limb of a fold seems to be fairly constant. Northeasterly trending faults extend through this unit with almost the same strike and displacement as in the adjoining Upper Nugget beds. Under more than usually favourable conditions the veins may contain oreshoots where they intersect the Middle Nugget beds and, indeed, a conspicuous quartzite bed at the base of the Middle Nugget is host for an important oreshoot in the Motherlode vein. More commonly, however, vein fractures cutting the Middle Nugget beds contain either no quartz or quartz with subcommercial gold values.

The Upper Nugget beds ranging in thickness from 135 to 375 feet and averaging 250 feet are made up predominantly of massive white quartzite, much of which is so homogeneous that bedding can be recognized only by careful study. The lower part of the succession in the Kootenay Belle mine contains a zone of dark, well-bedded quartzite which, as mentioned above, may correspond to a zone of argillaceous quartzite assumed to mark the top of the Middle Nugget in the Sheep Creek mine to the west. In general, however, dark quartzites are absent and beds of argillite are scarcely more than films along widely spaced bedding planes. Examination of thin sections shows, however, that even the white quartzite contains impurities in the form of scattered but oriented flakes of muscovite.

The Upper Nugget beds make up the most competent structural unit of the camp. Folds developed within these beds are, in general, more open than those of any other part of the succession. Faults crossing the Upper Nugget quartzites are commonly clean cut and display a minimum of drag. Nearly all the productive veins in the camp, with the exception of the Reno and Bluestone veins, have yielded ore from the Upper Nugget beds, and it is estimated that fully half the production of the camp has been from those parts of the veins which cut this 250-foot succession of strata.

Ranges in thickness of the subdivisions of the Nugget member are noted above. The total thickness of the member ranges from 540 feet to about 900 feet in the western limb of the Eastern anticline, and over the greater part of its length it has a thickness of about 750 feet. On the eastern limb of this same fold the thickness ranges from 800 to 1,200 feet. The three subdivisions have not been mapped separately on the eastern limb, and consequently their thicknesses are not known. In the Western anticline the base of the member is not exposed even in the deepest mine workings and the top of the Lower Nugget beds has not been recognized. The Upper Nugget has a thickness on the eastern limb of the fold of about 250 feet, and the Middle Nugget is represented by as much as 300 feet of mixed argillaceous and arenaceous beds.

Navada Member.—The Navada member, so named from its exposure in and near the Navada adit, comprises the beds hitherto referred to as Reno quartzite or "upper white quartzite" and the underlying Reno argillaceous quartzite or "thin beds." It represents the top 200 feet of the Quartzite Range formation, extending from the top of the Nugget member to the top of the highest of the thick and massive white quartzite zones in the succession.

The lower half to two-thirds of the Navada member is made up of dark thin-bedded quartzites and argillaceous quartzites, becoming more quartzitic toward the northeast part of the camp and more argillaceous toward the southwest. The boundary between the Lower and Upper Navada is rather ill-defined. The upper part of the member is composed throughout of white quartzite that is massive except where markedly squeezed during folding as on the western limb of the Western anticline.

Though the quartzite of the Upper Navada tends to be a relatively competent structural unit, its relative thinness and its isolation from the Upper Nugget quartzite by the relatively incompetent Lower Navada beds have rendered it susceptible to rather close folding and to notable thickening and thinning. The observed range in thickness of the Upper Navada is from a maximum of about 160 feet near the crest of the Western anticline to scarcely more than 20 feet on the western limb of the Western anticline. The greatest thickness was measured on the 3500 vein, between the 600 and 1100 levels of the Gold Belt mine, and the least, near the inner end of the 1850 crosscut of the same mine. Wherever the Upper Navada quartzite is abnormally thin as on the lower levels of the Gold Belt mine, it is also cut by closely spaced joints paralleling the bedding.

Oreshoots have been found in Navada quartzite in several of the veins of the Gold Belt mine, in the Kootenay Belle A vein in its lower levels, in the Bluestone vein, in the Reno vein, and apparently also in the Queen vein. The lower Navada beds have been distinctly less favourable for localization of ore, but a considerable tonnage has been recovered in this part of the succession from the 8000 and 8200 veins of the Gold Belt mine and from the Queen vein.

Reno Formation

The Reno formation, first described by Walker (1934, pp. 3, 8), was defined by a measured section extending from the top of the Quartzite Range formation on the ridge of Reno Mountain (*see* Fig. 3) about 1,000 feet northeast of the summit to the base of the Pend d'Oreille series about a quarter of a mile north of the Reno mine. The beds in this section were thought to be part of a homoclinal succession on the western limb of the Eastern anticline. Later and more detailed studies by mine geologists indicated that the structure is by no means as simple as had been thought and that in the type section some of the beds have been repeated by folding at least three times. Moreover, in one place, along the axis of the Central syncline, an infold of the younger calcareous and argillaceous sediments of the Laib group (Lower Pend d'Oreille) is present. These conclusions have been confirmed by the writer. Accordingly, the Reno formation is redefined, following Walker's original intent, as those beds lying between the top of the Quartzite Range formation, east of the summit of Reno Mountain, and the base of the infolded Laib (Pend d'Oreille) beds, now known to be less than 50 feet west of this summit. The formation in the sense followed here includes only the lowest 662 feet of the former type section and excludes all the calcareous beds. Even the eastern end of the original measured section is involved in several minor folds, and it is apparent that the Reno formation as revised has a stratigraphic thickness of considerably less than 662 feet at this locality.

At its base the Reno formation is predominantly argillaceous. Its contact with the underlying Navada quartzite is sharply marked, and there is little evidence of interfingering of quartzite and argillite. Higher in the Reno formation argillaceous quartzite becomes common, and the uppermost part of the formation includes beds of impure dark bluish or greenish quartzite. Some of these quartzitic beds contain scattered gritty fragments, generally of opalescent quartz; and lenses composed entirely of grit* or more rarely of fine conglomerate are present. Some of the impure quartzite in the upper part of the formation is abundantly charged with magnetite; in other places it may be distinctly ferruginous but devoid of magnetite. No attempt has been made to map two subdivisions of this formation, a quartzitic member above and an argillaceous below, except in and to the north of the Reno mine, where excellent exposures and economic interest justify the careful study necessary. Here the upper member has an average thickness of about 125 feet, and the lower member a thickness of about 400 to 500 feet.

Variation in thickness of the Reno formation as a whole is extreme. In the western limb of the Western anticline, in the lower levels of the Gold Belt mine, the formation has a thickness of as little as 50 feet. Northeast of the Reno mine, on the eastern limb of the Western anticline, it has a thickness of about 900 feet. On the western limb of the Eastern anticline its thickness ranges between 300 and 500 feet, and on the eastern limb of this fold it ranges from about 300 feet to possibly 1,000 feet. These variations can be attributed almost entirely to thickening and thinning resulting from folding. Abnormally great thicknesses are probably in every case brought about by duplication of the incompetent beds by tight and small-scale folding.

The Reno formation has been notably incompetent during folding throughout the extent of the camp. Dragfolds are numerous and complex. Detailed study of the smaller dragfolds, a few inches in amplitude, indicates that they have been formed on the flanks of somewhat larger folds, a few tens of feet in amplitude and bear no direct relationship to the dominant flexures of the camp, namely, the Eastern and Western anticlines and the Central syncline. Variation in thickness of single argillaceous beds is extreme. Beds of quartzite a few inches thick can, however, be traced without interruption through a myriad of minor tight folds.

Under conditions of fracturing, the Reno formation is also distinctly incompetent, except in the vicinity of the Reno mine, where it has been subjected to contact metamorphism and where former argillites have been converted to spotted schists and biotite-rich hornfelses. Most faults either die out or diminish in displacement, and their attitude changes markedly where they pass from the Navada quartzite into the Reno beds. The fact that these features are not displayed to the same degree in the Reno mine suggests that metamorphism took place prior to faulting. On the other hand, the lack of any notable change in the character of folds in this formation between the Reno mine and localities farther south, together with the fabric of the altered rocks (*see* p. 36), suggests that metamorphism took place after folding.

* Grits are known only in the Three Sisters formation, in the Motherlode member, and in the uppermost part of the Reno formation, and serve as valuable key horizons.

The Reno vein contains extensive orebodies in the Reno formation where argillaceous rocks of the formation have been strongly metamorphosed to relatively competent spotted schist. Two of the veins in the upper part of the Gold Belt mine* have yielded a minor quantity of ore in the Reno formation, but none of the other veins of the camp has been productive in the Reno formation.

Laib Group

The term "Laib group," as applied by Little (1950, pp. 15–18) to the lower part of the succession hitherto referred to as the Pend d'Oreille series, includes in the Sheep Creek area a succession of argillaceous and calcareous sediments directly overlying non-calcareous rocks of the Reno formation.

The most complete sections of the Laib group within the camp are on the upper slopes of Reno Mountain and on the ridge extending west from the Donnybrook adit. In the latter section six distinct members can be recognized, of which the first, third, and fifth from the bottom are distinctly calcareous. The other three members are almost exclusively argillaceous. The lowest member, better exposed on Reno Mountain than it is north of the Donnybrook adit, consists of a limestone bed up to 60 feet thick but generally much less, and locally missing. Numerous dull-red ferruginous patches, a few inches to a few feet across, are present in this limestone on the north slope of Reno Mountain. The second member, exposed north of the Donnybrook adit and in both limbs of the syncline on Reno Mountain, comprises argillaceous beds, metamorphosed to biotitic and amphibolitic schists, with an aggregate thickness varying from 100 to 300 feet. This is overlain in the core of the Central syncline and on the slopes southwest, west, and northwest of the Donnybrook adit by a third member, 150 to 300 feet thick, composed principally of limestone but locally including an argillaceous zone that in its central part is as much as 100 feet thick. A fourth member, west of the third in the Donnybrook area, is argillaceous and from 300 to 500 feet thick. A fifth member, as much as 150 feet thick, composed of grey limestone is conspicuous northwest of the Reno mine where some rock was quarried for the production of lime. Stratigraphically above and to the west of this limestone is a broad belt of tightly folded homogeneous argillites. No estimate can be made of the thickness of this sixth member, except that it is probably many hundreds of feet.

Elsewhere in the camp some, but not all, of the six members described above can be recognized. Variations in thickness and lithology may account for the difficulties in correlation in some places, inadequate exposures in others, and structural complications in still others. Throughout most of the camp the basal limestone can be identified, although in places it presents characteristics not apparent in the type locality on Reno Mountain. In the Central syncline near Sheep Creek, for example, argillaceous and chloritic lenses are common; near the Ore Hill mine irregular patches or bands of buff dolomite are common within the limestone. The colour of the limestone itself, though commonly grey, is in places white, cream, or blue. The second member can be recognized west of the Gold Belt mine, southwest of the Ore Hill mine, and at surface and underground exposures on both sides of Sheep Creek. The third member is well defined southwest of the Ore Hill mine, but west of the Gold Belt mine it grades upward into a thick succession of calcareous rocks of varying degrees of purity in which no clearly defined boundaries can be recognized until the base of the sixth member is reached.

Age and Correlations

A Lower Cambrian age is now well established for the upper part of the succession exposed in the Sheep Creek camp in spite of the fact that no fossils have been found within the camp itself. Park and Cannon (1943, p. 15) report the discovery of the impression of a Cambrian trilobite in quartzites of the Gypsy formation, 15 miles south

* *Minister of Mines, B.C.,* Ann. Rept., 1934, E 16. The veins are the C vein, known in the lower workings as the 3050 vein, and D vein, which has no equivalent in the lower workings of the Gold Belt mine.

of Sheep Creek, more precisely from the upper part of this unit in rocks probably equivalent to the Navada or Upper Nugget. Okulitch (1951, p. 405) reports the discovery of the olenellid trilobite *Nevadia* at Addy, Washington, 60 miles southwest of Sheep Creek in the Addy quartzite, believed to be correlative with the Gypsy quartzite. Little (1949, 1950, pp. 17–18) finds in beds of the lower part of the Laib group 7 to 10 miles south of Sheep Creek Lower Cambrian pleosponges similar to the *Olenellus* fauna of the Donald formation in the Purcell Range.

The age of the rocks in the lower part of the succession in the Sheep Creek camp remains in doubt. They lie conformably below the Lower Cambrian beds but contain no known fossils.

The correlation of the rocks of the Sheep Creek camp with those of near-by areas is indicated in Table I, Correlation of Sedimentary Rocks.

Sediments of Hidden Creek Valley

Sediments of unknown age, referred by Little (1950, pp. 23–24) to the Seeman group, are exposed within the map-area on the lower slopes and floor of Hidden Creek valley. These comprise limestone, argillite, and quartzite, or their metamorphic equivalents. Although many of the individual rock types in this group of sediments can be duplicated in the Sheep Creek camp, the sequence in the two localities is markedly different. In field mapping the two groups of rocks can be readily separated on a structural basis as well, for the beds of Hidden Creek have been warped into easterly trending structures truncating the northerly trending folds of the Sheep Creek camp. The contact between the sediments of Hidden Creek valley and those of the Sheep Creek camp has not been observed, but the abruptness of the change in structure suggests that they are separated by a major fault.* No gold-quartz mineralization, such as is characteristic of the Sheep Creek camp, is known to occur in the sediments of Hidden Creek valley.

IGNEOUS ROCKS

Granitic Intrusives

Several granitic masses occur in or close to the Sheep Creek mining camp—one in Sheep Creek valley west of Fawn Creek, another in Lost Creek valley, a third exposed only in the bottom of the Queen shaft, Sheep Creek mine, and a fourth on Hidden Creek northwest of the map-area.

The first-mentioned body is exposed in a roughly elliptical area 1¾ miles from north to south and three-quarters of a mile from east to west. It consists for the most part of biotite granite. A specimen from the vicinity of Fawn Creek at the 3,700-foot level, near the eastern edge of this stock, consists of microcline-microperthite, unstrained quartz, and minor oligoclase, locally zoned, together with small flakes of biotite, muscovite, chlorite after biotite, and garnet. Walker (1934, p. 14) reports that on the northwest side of this stock fine-grained granite intrudes porphyritic granite, and this in turn intrudes hornblende granodiorite. On the east side, however, granite extends to the walls of the stock. Along its eastern margin the granite is in direct contact with limestone of the lower part of the Laib group, and on its northern edge it intrudes argillaceous rocks higher in this succession. The walls of the stock, where seen by the writer, are nearly vertical, and its contacts extend directly down the steep north slope of Sheep Creek valley with no sign of divergence to suggest notable widening of the stock with depth. Walker suggests that the roof of the granodiorite mass at the northwestern part of this stock was not far above the present erosion level. The roof of the granite body lay no lower than the 5,700-foot level in its northern part, and its walls extend downward to the 3,000-foot level in Sheep Creek within a horizontal distance of 1 mile. Clearly the upper surface of this intrusion was one of great irregularity. Judging from the bowing of the folded beds around the stock, particularly on its western side, room was made for the granite by the thrusting aside of pre-existing rocks.

* Little, 1950, p. 31.

The intrusive mass of Lost Creek valley is exposed over an irregular area about 4 miles by 4 miles* and through a vertical range of almost 4,000 feet. One specimen from the northern margin of the stock, 1¼ miles south 30 degrees west of the summit of Mount Waldie, consists of microcline-microperthite, abundant albite, and strained quartz, together with strained muscovite, and a minor amount of garnet. There is sufficient plagioclase to justify the term " quartz monzonite " for this particular rock. The stock transgresses folded beds which extend south from the Sheep Creek camp, but, unlike the Sheep Creek stock, this one has not disrupted the pre-existing structures.

The granitic intrusive of the Sheep Creek mine (*see* Fig. 7) has been intersected only in the bottom of the Queen shaft and in a diamond-drill hole drilled from the west end of 12 level on the Queen vein. One granite fragment from the Queen dump consists of microcline-microperthite, strained quartz, minor oligoclase, together with muscovite and garnet. Marked metamorphism in the impure quartzites of the west end of 8 level on the Queen vein may be attributed to this intrusive mass, and a similar degree of metamorphism in the wallrocks of the lower level at the west end of the 81 and 85 veins suggests that the granite may extend at least 2,000 feet to the south. The intrusive has not, as far as can be determined, disturbed the folded beds of the Western anticline in its vicinity, and in this respect, as well as in its lack of biotite, it more closely resembles the Lost Creek stock, 3 miles to the south, than the granitic mass exposed only half a mile to the west in Sheep Creek valley.

A small part of a fourth granite intrusive extends into the northwestern corner of the map-area but has not been investigated in detail by the writer. Numerous granitic dykes, possibly apophyses of this stock, intrude the rocks on the south slope of Hidden Creek valley as far east as the crest of the Western anticline, but none is known to be present in the immediate vicinity of any of the mines.

The age relationships of the four granite intrusives to one another and to the faults and veins of the Sheep Creek camp are not known with certainty. Presumably all were intruded after the major folding of the area. Granites in the Ymir area, several miles northwest of the Sheep Creek camp, are cut by vein fractures having the same general strike and right-hand offsets as the northeasterly trending vein faults of the Sheep Creek area.

One other granite intrusive (*see* Little, 1949 and 1950; and McAllister, 1951) may be of considerable structural significance. This stock, 4 to 7 miles north of the Reno mine beyond the area mapped, is elliptical in plan and is from 2 to 3½ miles across. It is surrounded by a belt of Ordovician sediments warped into parallelism with the walls of the intrusive on all sides as if by forcible injection of the granite. The Ordovician sediments are surrounded, in turn, by sediments of unknown age (*see* p. 24), which are likewise bowed around the intrusive. The persistent easterly strike of these beds on the floor of Hidden Creek valley north of the Reno mine can be attributed to the very marked disturbances accompanying the intrusion of this stock. The inferred fault at the northern termination of the Sheep Creek structure (*see* p. 24, and Little, 1950, p. 31) may also be attributed to the same disturbance. The position of this intrusion and the accompanying tectonic movements in the structural history of the region and its relationship to the northeasterly trending faults and mineralization are worthy of further investigation.

To account for the bottoming of ore in the various veins, McGuire (1942, pp. 169–190) postulated a granite mass underlying the entire Sheep Creek camp at shallow depth. The granite found in the bottom of the Queen shaft, 250 feet below the lowest stopes, has been considered a part of this mass, which was supposed to approach to within a similar distance of known orebodies in other parts of the camp. The postulated upper surface of the intrusive would be remarkably regular, sloping continuously from the 5,000-foot level near the Reno and Bluestone mines to the 2,200-foot level at the Queen shaft, 2½ miles away. Such a regular surface would be unlike the highly irregular

* Walker, 1934, map.

roofs of any of the stocks exposed in this area. The concept, moreover, fails to account for the lack of metamorphism comparable to that in the lower workings of the Queen vein in the lower levels of such mines as the Gold Belt and Nugget. A granite mass extending up to the levels postulated in widely separated parts of the camp is, thus, wholly unsubstantiated.

A concealed body of granite may, however, underlie parts of the camp at variable and generally greater depths than McGuire has suggested. In several places, for example, inclusions of granite are found in lamprophyre dykes, apparently carried upward in the lamprophyre magma from some underlying source. One such inclusion in the Sumit workings, altitude 5,560 feet, was probably transported thousands of feet from its source, for no granite is known to be exposed on surface within a mile of this point, and granite is absent in underground workings of the Sheep Creek mine 2,350 feet below and 2,100 feet to the northeast of the occurrence. One inclusion in a lamprophyre dyke on 781w drift of the Sheep Creek mine consists of a very coarse porphyritic granite, unlike any rock known to occur on surface in the near-by stocks.

Quartz-porphyry Sills and Dykes

Quartz porphyry, or aplite, as it has commonly been called in the camp, occurs as a major sill swarm and as isolated sills and dykes. The rock is light grey, greenish grey, or less commonly brownish grey on fresh surfaces and nearly white where weathered. On small exposures it may have a distinct superficial resemblance to the purer quartzites, from which, however, it can be distinguished by the presence of widely scattered phenocrysts of quartz and feldspar. In a few instances the groundmass of the quartz porphyry is extremely fine grained and has a cherty appearance not seen in any of the quartzites. Pegmatitic lenses have been found in the quartz porphyry only at one locality—the Fawn crosscut. Joints in the porphyry are generally confined to three sets, oriented nearly at right angles to one another and commonly spaced at intervals of a few feet. The quartz porphyry tends to be fully as resistant to erosion as the quartzites, and is commonly well exposed except in areas of deep overburden.

Under the microscope the rock is seen to be made up of scattered phenocrysts of quartz, microcline-microperthite, and rare andesine and biotite in a dense groundmass of feldspar, quartz, and muscovite. Aggregates of phenocrysts are present locally. The quartz phenocrysts may be either euhedral or embayed. The groundmass texture in one specimen is micrographic; in a second it is microspherulitic. Another specimen has a dense groundmass consisting of irregular masses of quartz and untwinned feldspar intermingled with shreds of muscovite. In still another specimen, from the Fawn crosscut, segregation of these minerals has taken place, and relatively clear clusters of minute grains of quartz and feldspar are surrounded by a network of muscovite-rich bands. The muscovite flakes show a strong preferred orientation along two directions that are inclined to one another at an angle of about 30 degrees. The other minerals of the groundmass, although occurring as more or less equidimensional grains, also show a distinct preferred optic orientation. The groundmass texture of this specimen is thus metamorphic rather than igneous. Though an incipient schistose texture is indicated in thin section, the schistosity is not sufficiently pronounced to be obvious in hand specimen. The metamorphism, moreover, appears to be local, for it is not apparent in other specimens of the quartz porphyry from the same belt of sills.

Two chemical analyses of unaltered quartz porphyry are tabulated in Table III, together with an analysis of a greatly altered quartz porphyry from the vicinity of the Kootenay Belle cave zone (*see* p. 27).

The main quartz-porphyry sill swarm extends along the east limb of the Central syncline for the length of the camp. In many places it is represented by two or three parallel or *en échelon* sills separated by narrow bands of sediments. In a few places these bands of sediments are absent and the quartz porphyry may then be considered a multiple sill consisting of one or more younger masses, displaying chilled margins, injected into or

Table III.—Chemical Analyses of Unaltered and Altered Quartz Porphyry*

	1	2	3
SiO_2	74.60	74.66	72.72
TiO_2	0.09	0.06	0.06
Al_2O_3	14.47	13.32	15.22
Fe_2O_3	0.65	0.55	0.78
FeO	0.43	0.85	0.22
MnO	0.07	0.13	0.08
MgO	0.17	0.45	0.45
CaO	0.72	0.31	0.32
BaO	n.d.	0.16	0.18
Na_2O	2.48	3.00	0.46
K_2O	5.79	4.69	5.51
P_2O_5	0.05	0.04	0.04
CO_2	0.03	0.80	*Nil*
H_2O+	0.38	0.98	2.86
H_2O-	0.05	0.22	1.30
ZrO_2	n.d.	*Nil*	*Nil*
S	n.d.	0.10	*Nil*
Total	99.98	100.32	100.20
Less oxygen equivalent of S	--------	—0.05	*Nil*
True total	99.98	100.27	100.20
NORMS			
Quartz	36.4	37.4	47.6
Orthoclase	34.2	27.7	32.6
Albite	21.0	25.4	3.9
Anorthite	2.9	1.7	1.7
Corundum	3.0	2.7	7.9
Hypersthene	0.66	2.2	1.1
Magnetite	0.94	0.80	0.80
Ilmenite	0.17	0.11	0.12
Apatite	0.18	0.09	0.09
Pyrite	--------	0.16	--------
Carbon dioxide	0.03	0.80	n.d.
Water	0.43	1.2	4.2
Hematite	--------	--------	0.23

* Analyses made in laboratory of British Columbia Department of Mines, G. C. B. Cave, Chief Analyst.
1. East side of sill swarm in Fawn crosscut.
2. Kootenay Belle mine from wall of crosscut leading to 6w drift, unaltered part of sill, 70 feet from main crosscut.
3. Kootenay Belle mine, from wall of crosscut leading to 6w drift, altered part of sill, 40 feet from main crosscut.

alongside earlier quartz porphyry. In still other places only a single intrusion of quartz porphyry has been recognized. A few hundred feet south of the summit of Reno Mountain, quartz porphyry is absent along the line of the sill swarm. Between the 5,400- and 5,750-foot contours west of the Motherlode mine, even where overburden is thin and composed of local detritus, no quartz porphyry is evident, and it is probable that the igneous rock is absent at the bedrock surface in this area. Heavy overburden on the south slope of Waldie Creek valley makes it impossible to trace the quartz-porphyry sills continuously, but exposures at intervals indicate that the swarm extends (with but few interruptions) for a total distance of 5½ miles from the north slope of Reno Mountain to the west ridge of Mount Waldie.

The width of the swarm reaches a maximum of 150 feet, in the 1850 Gold Belt crosscut, where it is made up of three sills, 75, 6, and 9 feet wide, separated by two bands of sediments 15 and 45 feet wide. In the Fawn crosscut the swarm has a width of 90 feet, made up of a 60-foot sill and a 25-foot sill separated by a few feet of sediments. In the No. 3 level of the Clyde workings the quartz-porphyry zone is 95 feet wide, represented by two sills 45 and 20 feet wide separated by a belt of sediments about 30 feet wide through which cuts a quartz-porphyry dyke of unknown thickness. On the south bank of Sheep Creek the swarm is represented by only two sills, 30 and 6 feet wide, separated by 15 feet of sediments, and in a few localities along the line of the swarm, as indicated above, the quartz porphyry may be absent.

The main sill swarm throughout its known length and depth is at or close to the Reno-Laib contact on the eastern limb of the Central syncline. The maximum known departure from this stratigraphic horizon occurs on the north slope of Reno Mountain where the sill swarm crosses a major dragfold and in one place lies 60 feet east of, and in another place 220 feet west of, the Reno-Laib contact. Elsewhere the quartz porphyry lies within a few tens of feet of the contact. In nearly every place where the walls of the quartz-porphyry sheets are exposed they either parallel the stratification of the adjoining sediments or cut across it at a very small angle. The bedded rocks of the camp as followed northerly are repeatedly offset to the east along the northeasterly trending vein fractures (*see* Fig. 2), but the sill swarm is not similarly displaced. The local strike of the quartz-porphyry belt is, as a rule, somewhat farther to the east of north than that of the bedding within individual fault blocks. In some, and probably most, instances individual quartz-porphyry sheets trend slightly more toward the east than the beds, but a few of the sills may be strictly parallel to the beds and *en échelon* to one another. Major dragfolding of the Reno-Laib contact has been observed in the sediments of the north slope of Reno Mountain, but the quartz-porphyry belt is not similarly folded. Instead, in this locality the easterly dip of the belt (*see* Fig. 3) is somewhat greater than that of the bedding, and individual sheets of quartz porphyry either cut at a low angle across the stratification or occur as a series of lenses paralleling the beds and lying *en échelon* within the belt (*see* Fig. 2).

A few quartz-porphyry sills occur beyond the limits of the main sill swarm. One of these is exposed in several workings between the 6 level crosscut of the Kootenay Belle mine and the 7E crosscut of the Sheep Creek mine (sill shown as a line of dashes in Fig. 2 and in pattern in Fig. 8) where it lies near the base of the Upper Navada beds. This sill, which has a thickness of 15 feet on 10 level of the Kootenay Belle mine, pinches upward and dies out a few feet below 5 level. This sill is 15 to 20 feet wide in the 7E crosscut and in the Midnight adit, but in the lowest Alexandra adit it is represented by two sills with an aggregate thickness of about 15 feet at approximately the same stratigraphic position. Another quartz-porphyry sill occurs at the top of the Navada member in the 6 level crosscut of the Kootenay Belle mine. Still another exists within the Upper Nugget beds near the summit and along the north ridge of Mount Waldie. The only other quartz-porphyry body known in the camp is a northerly trending dyke cutting Laib argillites on the ridge crest half a mile northwest of the Reno mine.

The relationship of the quartz porphyry to the granitic stocks in the vicinity of the camp is not known as they have not been seen in contact with one another.

The approximate time of intrusion of the quartz porphyry relative to the structural history of the camp can be established, even though not all the quartz-porphyry sills are of precisely the same age. The sill swarm and, presumably, the outlying quartz-porphyry sheets post-date the major folding of the camp. At least some of the sills, and probably all, post-date the major right-hand fault movement on the northeasterly trending vein fractures. In the Kootenay Belle 6W drift a quartz-porphyry sill clearly cuts across the vein fracture, offsetting by dilation (*see* Goodspeed, 1940) both the fracture and the vein quartz that occupies it. Banding in the quartz is truncated by the sill. Although very clearly later than the vein quartz, it is doubtful that the quartz porphyry here is also later than the sulphide mineralization. Rare pyrite veinlets cut through the quartz porphyry in the vicinity of the vein and a few grains of sphalerite lie along the vein-porphyry contact. Very low gold values, amounting to 0.00055 ounce per ton of rock, accompany the sulphides cutting the quartz porphyry.* McGuire (1942, p. 181) also reports that low gold values have been found at depth in the porphyry, but particulars are not given. A composite sample of the quartz porphyry from the Clyde workings did not contain detectable amounts of gold. In exposures in the Clyde adits a fracture continuous with the vein fracture extends from the sediments into the quartz porphyry with some deflection in trend. On the east side of the sill swarm in both the Clyde No. 2 and Clyde No. 3 adits no measurable offset of the quartz porphyry-sediment contact could be detected, and it is certainly less than 2 inches, notwithstanding the fact that a right-hand offset in the adjoining sediments is at least 3 feet and elsewhere on the same vein fractures attains 31 feet. On the west side of the sill swarm in the Clyde No. 3 adit, quartz porphyry terminates against the vein fracture. At one place a projection of quartz porphyry extends across the fault and has been faulted *to the left* about 10 inches. It is apparent that this sill has been affected only by very late movement along the Clyde vein fracture which was in the opposite direction and of much smaller magnitude than that of the main period of faulting. The quartz porphyry has not been seen in contact with any of the other vein fractures in the camp, but the relationship is presumed to be the same as in the localities where direct observation is possible.

The quartz porphyry was clearly intruded as a melt along pre-existing planes of weakness having a northerly strike and a steep dip. Dilation offsets have been observed not only in the Kootenay Belle mine (*see* p. 28), but also on surface where the Reno-Laib contact is intersected by the sill swarm. A dilation offset of the Clyde vein fracture is also indicated in the No. 3 adit.

Pre-vein Basic Dykes

Basic dykes of pre-vein age are known in a few localities, notably in the lower levels of the Gold Belt mine and in two or three places in the Sheep Creek mine. These dykes occupy fractures that strike northerly, approximately parallel with the axes of the major folds, and dip nearly vertically. The dykes are clearly offset by the right-hand strike-slip movement of the northeasterly trending vein fractures and are truncated by any vein quartz that may be present. The most striking dykes are dark, banded rocks, with metamorphic texture, rich in biotite, epidote or clinozoisite, quartz, and commonly a pale-green amphibole. Pyrite is conspicuous in these dykes and at least locally is accompanied by gold. The banding and metamorphic texture may be attributed to recrystallization during minor shearing movements along the dykes. Whether the dykes were introduced as a magma or formed by metasomatism of the pre-existing quartzite is problematical. No metasomatism even remotely similar to this has, however, been detected in the quartzites away from the dykes.

One dark greenish-grey pyrite-bearing dyke of pre-vein age occurs in the Gold Belt mine. It has been observed in the 2180E drift (4750E and 4775E, Gold Belt co-ordinates) and in the 2182E drift (4920E and 4950E) on both walls, at the eastern end of the 1982E drift (4895E) on the south wall only, in the 1850 crosscut (2,260 to 2,275 feet from the portal) on both walls, and in the 1823E drift. It has not been observed in spite of careful search at its projected position in the 1980E drift, the 1882E drift, or in the 1623E drift, and it must be concluded that the dyke terminates upward between the 2100 and 1975 levels at the 8000 vein and at somewhat higher levels farther north. A pre-vein pyrite-bearing dyke has, however, been reported in the 1635E drift (6090E on the south wall, 6150E on the north wall) along its extension. Where the dyke has been examined in detail it attains a maximum width of about a foot.

* Assays were made of pan concentrates of heavy minerals from large samples of the rocks. By this means gold beads large enough to be weighed could be recovered. That not all such heavy concentrates contain detectable amounts of gold has, however, been shown by assaying a pyrite-bearing lamprophyre dyke, and it is considered that the quantities reported here, though small, are significant.

The offset measured along the 2180E drift between the two segments of the dyke is 23 feet, but the beds in this vicinity have been offset 73 feet. Computed net slip (*see* pp. 40–41, and Appendix) along the vein fracture totals 56 feet in this locality, but net slip after intrusion of the dyke has been only 24 feet. Fully half the fault movement had, it seems, taken place before intrusion of the dyke. On the next vein to the north, the 8200, the net slip between segments of the dyke is computed to be about 36 feet, but beds measured approximately 100 feet to the east of it have been moved only 28 feet. The net slip in this part of the vein fault is known to diminish rapidly eastward, and it is probable that the total net slip near the dyke is appreciably more than 28 feet. It seems, however, that little, if any, movement had taken place along this fault prior to the intrusion of the dyke.

The rock composing the dyke is highly variable along its length. In its exposure in the 2180E drift it consists of bands alternately rich in a pale greenish-brown biotite, epidote, and quartz, together with minor pale-green amphibole, and abundant pyrite occurring as cubic crystals disseminated throughout the rock. On the west side of the 1850 crosscut the rock is very similar but lacks the amphibole. On the opposite side of the 1850 crosscut the rock along the extension of the dyke consists essentially of quartz and pale-brown biotite with minor chlorite and carbonate. At this point the pyrite occurs either as irregular grains disseminated sparsely through the rock or concentrated in quartz-carbonate veinlets. Dark-green dyke rock adjoining the biotite-rich material at this locality bears a startling resemblance to the post-vein lamprophyres rather than to the pyrite-rich pre-vein dyke, and there is a possibility that a later magma was injected along the side of the earlier pyrite-bearing dyke. This lamprophyre dyke rock consists essentially of olivine (composition 90 per cent forsterite) partly altered to talc, and of augite in a biotite-rich groundmass. Widely scattered, small round masses of feldspathoid occur in the rock. The principal mineral of these masses is analcite or a member of the sodalite group, but it is accompanied by minor amounts of nephelite.

Traces of gold accompany the pyrite at no less than two localities in the pre-vein dyke.* On the walls of the 2180E drift the pyrite, which makes up almost 5 per cent of the rock, was found to contain 0.01 ounce of gold per ton. The dyke rock itself thus contains about 0.0005 ounce of gold per ton. Since this locality is immediately adjacent to a gold-bearing vein and hence susceptible to later mineralization, a second sample was taken from the extension of this dyke on the east wall of the 1850 crosscut. Using the procedure followed previously, the rock was found to contain 0.0006 ounce of gold per ton.

A chemical analysis of the dyke in the 2180 drift (4775E, north wall) is listed in Table V, analysis 4 (*see* p. 34). The rock proves to be appreciably richer in silica and poorer in soda than the later lamprophyres as shown in Table V, analyses 5, 6, and 7.

A dyke in the 468 drift, Sheep Creek mine (9390E, Sheep Creek co-ordinates), consists of alternating bands of pale-blue amphibole, greenish-brown biotite, clinozoisite, and quartz, and minor amounts of carbonate and pyrite. Its general appearance is that of the Gold Belt dyke. Calculated net slip between the two segments of the dyke on either side of the 68 vein fracture is very nearly the maximum for the displacement of beds along this fracture. It seems, therefore, that little, if any, faulting had taken place in this vein zone before intrusion of the dyke.

A hornblende diorite dyke, observed only on the south wall of the Queen vein, 270 feet east of the Queen shaft, is truncated by the vein. It is fine grained, non-porphyritic, has a trachytic texture, and consists principally of calcic andesine, brown hornblende, and green biotite.

An olivine lamprophyre dyke, 2 inches wide, possibly of pre-vein age, occurs in the 585 drift of the Sheep Creek mine (8910E Sheep Creek co-ordinates). It consists of olivine altered to antigorite and carbonate in a dense carbonate-rich groundmass. Two segments of the dyke on opposite sides of the vein fracture are separated by about 4 feet.

* *See* footnote on p. 29.

The horizontal separation of beds along the vein fracture in this locality is about 20 feet. If of pre-vein age, this dyke was injected after much of the vein faulting was completed.

Post-vein Basic Dykes

Basic lamprophyre dykes of post-vein age, from a few inches to a few feet thick and characterized by visible crystals of biotite or altered olivine or both, occur locally in the Sheep Creek camp. In hand specimen these basic dykes appear dark green or grey green and commonly contain either glistening black flakes of biotite or pale-greenish granules of olivine, or both. An alteration of the dark biotite to a pale-green variety is observed in the bleached margins of a few dykes. The altered olivine in a few places is either dark green or, where abundantly charged with iron oxides, dark red. Some dykes are characterized by abundant biotite and no olivine. In others, rich in olivine, biotite may be inconspicuous, although it is rarely, if ever, absent from the groundmass. One dyke, a few feet wide, on 8 level of the Sheep Creek mine, 75 feet south of the Queen shaft, was found to have an olivine-rich phase at its south side grading within 6 inches into a biotite-rich phase, relatively poor in olivine, making up the rest of the dyke. In this vicinity a single olivine-rich dyke branches eastward into two biotite-rich dykes and one olivine-rich dyke. One specimen of lamprophyre, from the Reno mine, contains miarolitic cavities.

The strike of the dykes is nearly parallel to that of the adjacent sediments, except locally where they follow vein fractures, and their dip is predominantly steep and to the east or southeast. Where they are enclosed by sediments that dip steeply eastward, they commonly conform to the bedding, and locally in westerly dipping beds concordant sheets of the basic rock can be found. In most instances, however, the dykes show no close relationship to the bedding for any large part of their extent, but many show a closer relationship to pre-existing faults. The Queen, Thompson, and Hangingwall faults (*see* pp. 44–46) are, for example, occupied by the basic dykes for a considerable proportion of their extent, and many of the vein fractures are locally occupied by these dykes. Wherever the dyke follows a vein fracture, it passes off into the south wall from a few feet to a few scores of feet southwest of the point where it passes off into the north wall. In other words, the deflection of the dyke path on entering the vein fracture has been consistently to the right. In some such instances the dyke may occupy approximately the same stratigraphic horizon on the opposite sides of the vein fault.

The dykes post-date most or all of the vein faulting, and the few that are broken by later movement along the vein are commonly offset to the left. Thus, as in the case in the Clyde No. 3 working (*see* p. 29), the final movement along the vein has been the reverse of the prevailing direction prior to the injection of the dykes. Late movements along the Queen, Thompson, and Hangingwall faults have sheared the basic dykes occupying these zones.

The greatest concentration of basic dykes has been found in the Sheep Creek mines where as many as eight cross a single vein along 1,000 feet of drift on one level. In most parts of the mine from its southern to its northern end, at least four subparallel dykes are present. In the Gold Belt mine, the dykes are less abundant, only two, or locally three, being present in the lower levels and only one on most of the drifts of 1400 and 1100 levels. In the Reno mine, at least three subparallel dykes cross the vein on any one level. In the mines of the Eastern anticline, dykes are scarce, only one being present in most of the levels of the Motherlode mine and only two on most of the levels of the Nugget mine. No basic dyke has been mapped in the Kootenay Belle mine, but the 6 level dump contains a small amount of dyke rock.

Inclusions are common in many of the dykes. The most common inclusions are angular fragments of quartzite such as could have been torn from the adjoining dyke walls. Some of the inclusions, however, consist of granitic rocks which must have originated hundreds or perhaps thousands of feet away and been carried in the lamprophyre magma to their present positions. These far-travelled inclusions tend to have somewhat rounded outlines. One such inclusion, in an olivine lamprophyre from the Sumit workings, shows incipient vitrification. Biotite in this rock has been almost completely converted to patches of magnetite granules in a feldspathic matrix. Narrow reaction zones occur along the boundaries between quartz and feldspar. Whatever glass may have been formed as a result of heating has, however, become completely devitrified.

Under the microscope the basic dykes themselves are seen to be made up of large and more or less euhedral crystals of altered olivine or biotite, or both, in a felted groundmass containing biotite, chlorite, carbonate, and in most examples minor amounts of feldspar. Augite is locally present. Analcite or a member of the sodalite group has been observed in one of the dykes. Quartz, closely associated with carbonate, occurs in a few of the dykes.

The olivine grains, commonly 1 to 5 millimetres across, are in almost every example completely altered, but one specimen contained a few relics of the original mineral of which microscopic characteristics (2V,90 degrees $\pm$ 5 degrees) indicate that the composition is close to that of forsterite. The alteration products may be either talc, antigorite, carbonate and antigorite, or pale bowlingite. No systematic distribution of the four different types of alteration has been detected. Talc, for example, has been found through a vertical range of 2,300 feet in the southern part of the camp and at altitudes both above and below the antigorite. Pressure at the time of alteration cannot, at least by itself, account for the differences in the alteration products. The work of Bowen and Tuttle (1949) indicates that temperature and composition are much more important than pressure in determining what stable minerals may occur in the system $MgO—SiO_2—H_2O$. They found that pure forsterite is unstable in the presence of water vapour at temperatures below about 400 degrees Centigrate and tends to decompose into serpentine and minor amounts of brucite. They found, too, that in this system serpentine does not develop above a temperature of about 500 degrees Centigrade, nor talc above a temperature of about 800 degrees Centigrade. These data do not indicate the temperature at which the lamprophyric magma was intruded, but merely that alteration to talc and serpentine took place below the temperatures mentioned. The change presumably took place during the cooling of the magma shortly after its intrusion.

Biotite occurs both as phenocrysts and in the groundmass. The crystals are generally euhedral, varying in thickness from less than 0.01 millimetre to more than 0.5 millimetre, and in diameter from less than 0.05 millimetre to as much as 5 millimetres. In some instances the biotite may be fine grained near the margins of a dyke and coarse grained at its core.

Augite is present in a few of the specimens as euhedral crystals which show no trace of alteration even where the adjoining olivine has been completely converted to talc or serpentine.

Sodic feldspar is seen in a few dykes as very small, more or less euhedral crystals widely scattered through the groundmass. In most of these dykes it is present in amounts of less than 15 per cent. In many of the dykes no feldspar of any type has been seen, but it is probable that they contain a small amount of feldspar that has been completely obscured by the widely distributed carbonate and chlorite flakes. Potash feldspar, like sodic feldspar, occurs generally in minor amounts in the groundmass and in some instances, like the plagioclase, may be completely obscured by the other minerals. In one of the specimens in which it has been observed it forms plume-like aggregates. In another specimen, plume-like aggregates of feldspars, together with minor amounts of quartz and carbonate, form ellipsoidal masses as much as 2 millimetres in diameter that are wrapped about by flakes of biotite, as in the variolitic kersantite from the Pend d'Oreille limestone described by Daly (1912, pp. 312–313).

Carbonate and chlorite make up a major part of the groundmass in many of the dykes.

Rosiwal analyses of four of the specimens are listed in Table IV.

Table IV.—Rosiwal Analyses of Post-vein Basic Dykes

	A	B	C	D
	Per Cent	Per Cent	Per Cent	Per Cent
Altered olivine	33	45	45	----
Chlorite	35	30	30	4
Carbonate	15	15	5	41
Biotite	12	10	12	7
Feldspar	4	----	----	44
Black opaques, etc.	1	----	----	4
Augite	----	----	8	----

A—568W drift, Sheep Creek mine.
B—481W drift, Sheep Creek mine, west of Queen fault.
C—568E drift, Sheep Creek mine.
D—283W drift, Sheep Creek mine.

The abundance of olivine and biotite, the apparent scarcity of feldspar, and the common alteration with the development of antigorite, serpentine, carbonate, and talc suggests the affinity of these lamprophyres to such ultrabasic rocks as mica olivinite and kimberlite. Chemical analyses (*see* Table V) do not, however, confirm this affinity. Use of the terms "minette," "kersantite," and "absarokite" for these rocks is more justified, but in view of the gradation and close relationship between biotite-rich and olivine-rich forms the use of distinct names seems unwarranted. Simple terms such as "biotite-lamprophyre" and "biotite-olivine lamprophyre" are appropriate for these rocks. The term "lamprophyre" is here used, as recommended by Knopf (1936, pp. 1745–1749), simply for a dark porphyritic rock with mafic phenocrysts and with idioblastic mafic minerals in the groundmass.

Chemical analyses of the biotite-olivine lamprophyres (*see* Table V) indicate that they are more siliceous than is suggested by microscopic examination. Normative composition bears relatively little similarity to the modal composition of the rock, although the common presence of olivine and the less common presence of nephelite in the norm do conform with the common presence of olivine and the rarer occurrence of a feldspathoid in the mode. Close correspondence between norm and mode are not, of course, necessary. Much of the potash and alumina that appear in the norm as orthoclase actually occur in the rock in the biotite. It is of interest that were calcite considered a primary mineral in the calculation of the norm, the presence of neither olivine nor nephelite would be suggested by the analysis. The universal occurrence of modal carbonate in the olivine-bearing rocks indicates, however, that carbon dioxide actually accompanies the magma. The carbonate, it seems, must be regarded as a product of the deuteric alteration of pre-existing minerals, and the quartz which is so closely associated with this carbonate is presumably released at the same time. Chlorite probably also falls in the category of a deuteric mineral.

Relationship of some of the biotite-olivine lamprophyres to other rocks are indicated by the chemical analyses, relationships that would be overlooked on the bases of mineralogical examination alone. The chemical similarity of the olivine-biotite lamprophyre of the Gold Belt mine (analysis 7) to the biotite-plagioclase kersantite from a dyke 3 miles west of Mount Waldie* is particularly striking, and there can be little doubt that the two rocks are heteromorphic forms developed from a single magma. The chemical similarity between these two dykes and the Salmon River monzonite stock,† 5 miles west of Mount Waldie, is also striking, notwithstanding the fact that the monzonite consists predominantly of orthoclase, labradorite, augite, and biotite. These rocks have been derived from magmas of similar chemical composition, but presumably differences in the physical conditions under which they crystallized, notably in confining pressure and rate of cooling,

* Daly, 1912, pp. 312–314.
† Daly, 1912, pp. 304–306.

Table V.—Chemical Analyses of Basic Dykes

	4* Per Cent	5* Per Cent	6* Per Cent	7* Per Cent	8 Per Cent	9 Per Cent
SiO_2	52.34	41.82	44.44	48.84	47.42	50.66
TiO_2	0.94	0.28	0.68	0.80	0.70	1.32
Al_2O_3	11.04	8.34	10.37	14.41	15.65	16.91
Fe_2O_3	3.39	2.30	2.60	3.04	2.66	1.71
FeO	4.38	6.70	5.89	4.81	4.05	6.17
MnO	0.40	0.14	0.12	0.14	0.10	0.16
MgO	7.48	17.20	14.30	5.87	4.90	5.50
CaO	6.90	4.56	6.16	6.96	8.56	8.26
Na_2O	0.66	1.37	1.33	3.10	2.60	2.89
K_2O	4.43	3.03	3.77	4.09	4.10	4.45
P_2O_5	0.45	0.42	0.53	0.64	0.54	0.91
H_2O+	2.06	3.00	3.04	1.58	2.60	1.06
H_2O-	0.12	0.90	1.10	0.23	0.30	0.14
CO_2	0.94	9.62	5.62	5.56	6.24	----------
FeS_2	4.59	----------	----------	----------	----------	----------
SrO	----------	----------	----------	----------	----------	0.08
BaO	----------	0.15	0.18	----------	----------	0.23
ZrO_2	----------	*Nil*	*Nil*	----------	----------	----------
S	----------	0.52	0.16	----------	----------	----------
Totals	100.12	100.35	100.29	100.07	100.66	100.45
Less oxygen equivalent of S	----------	0.26	0.08			
True totals	----------	100.09	100.21			
NORMS						
Quartz	9.88	----------	----------	----------	----------	----------
Orthoclase	26.17	17.90	22.28	24.16	24.46	26.13
Albite	5.58	11.29	10.92	22.58	15.20	16.77
Nephelite	----------	----------	0.18	1.97	3.69	4.26
Anorthite	14.08	8.01	11.24	13.33	18.90	20.02
Diopside	8.97	9.97	12.93	13.67	16.68	13.32
Hypersthene	18.79	0.07	----------	----------	----------	----------
Olivine	----------	33.64	26.34	9.58	5.97	11.19
Magnetite	4.92	3.33	3.77	4.41	3.94	2.55
Ilmenite	1.78	0.53	1.29	1.52	1.36	2.43
Apatite	1.04	0.99	1.24	1.48	1.24	1.86
Water	2.18	3.90	4.14	1.81	2.90	1.20
Carbon dioxide	----------	9.62	5.62	5.56	6.24	----------
Calcite	2.14	----------	----------	----------	----------	----------
Pyrite	4.59	0.84	0.26	----------	----------	----------

4. Pre-vein basic dyke, 2180E drift, Gold Belt mine.
5. Olivine-rich phase, lamprophyre dyke, 8 level, Queen vein, near Queen shaft.
6. Biotite-rich phase, same locality as (5).
7. Olivine-biotite lamprophyre, 1882W drift, Gold Belt mine.
8. "Kersantite" (biotite-plagioclase lamprophyre), 3 miles west of Mount Waldie (Daly, 1912, pp. 312–314).
9. Monzonite, Salmon River stock, 5 miles west of Mount Waldie (Daly, 1912, pp. 304–306).

* Analysed in laboratory of British Columbia Department of Mines, G. C. B. Cave, Chief Analyst.

have led to marked differences in the ultimate mineral content. The two specimens from the 8 level of the Queen vein (analyses 5 and 6) differ notably from the others in having a much lower silica content. It can be shown, however, that if the abnormally high content of olivine were eliminated, these rocks would, like the Gold Belt dyke (analysis 7), closely resemble Daly's kersantite and Salmon River monzonite. Accumulation of olivine in a monzonitic magma may, therefore, account for the unusual composition. These rocks, with their high content of olivine, are unlike any of the analysed rocks listed by Washington (1917, p. 597), except leucite absarokite from the Yellowstone area.

A better understanding of the physical conditions under which these lamprophyres crystallized and which were responsible for their present mineral content could lead to a better understanding of the conditions under which the Sheep Creek ores, which seem to be nearly contemporaneous with these intrusive rocks, were deposited. Such an understanding could lead in turn to a better explanation of the distribution of the ores with depth and could possibly indicate other localities in the Salmo area where conditions of the Sheep Creek mineralization were repeated. Further investigation of the chemical and mineralogical compositions of the lamprophyres of the area is clearly warranted.

Miscellaneous Dykes

A few dykes observed in the camp do not fall clearly into the three categories outlined above. Most of them are of local occurrence, and their relationships to one another and to the structural history of the camp are unknown. A few of them are pegmatite dykes, rarely more than 2 inches across, found locally on 5 level west near the Queen vein, and in the 781w drift of the Sheep Creek mine. Several sills and dykes of grey fine-grained felspar porphyry and hornblende porphyry occur in and to the north of the Reno mine. Diorite porphyry occurs in talus in considerable abundance along the Waldie Creek trail three-quarters of a mile east of the Bonanza mine buildings but has not been traced to its source. A similar diorite porphyry occurs as a dyke in the Eureka adit on the north side of Yellowstone Mountain. This dyke, about 20 feet thick, cuts the Eureka vein fracture and offsets it by dilation. The rock consists of widely scattered phenocrysts of andesine in a matrix of strongly zoned andesine, brown biotite, and minor muscovite, quartz, epidote, and chlorite.

METAMORPHISM

Throughout the greater part of the Sheep Creek camp the grade of metamorphism of the sedimentary rocks is low. Sandstone, for the most part, has been recrystallized to quartzite, and shale to argillite, but no characteristically metamorphic minerals have been formed. A poorly developed schistosity roughly parallel to bedding occurs in some of the argillaceous rocks where movement during folding has been fairly intense, and a closely spaced, sheeted jointing occurs in the quartzite where attenuation of the beds is great (*see* p. 21).

Locally metamorphic effects have been important, notably in the northern part of the camp and in the vicinity of the granitic intrusives. The outermost manifestation of this metamorphism is the development in argillaceous sediments of a spotted appearance such as might be produced by scattered raindrops on the surface of the rock. Microscopic examination shows that these dark-grey spots consist essentially of lens-shaped segregations of quartz and micas. The spotted rocks occur near the Gold Belt mill, fully 3,500 feet from the nearest exposure of the granite stock in Sheep Creek valley, and again about 3,300 feet southeast of the portal of No. 5 level, Reno mine, much farther from any known major intrusive mass. With a higher grade of metamorphism the argillaceous rocks become converted to lustrous white and grey mica schists such as are developed near the Columbia adit and 2,100 feet southeast of the Reno mine. Andalusite is present at these same localities, occurring as elongated prisms oriented at random within the plane of bedding and schistosity. Tremolite occurs about as far from the Sheep Creek valley stock in the calcareous sediments as does andalusite in the argillaceous rocks. The development of abundant biotite characterizes a still more intense stage of metamorphism. Glistening biotite schist and biotite-rich hornfels occur both in the lower western workings of the Sheep Creek mine and in the vicinity of the Reno mine. Garnet occurs in a few places in the sediments of the north slope of Reno Mountain, and amphibolite has been developed from the green schists of the Three Sisters and Motherlode beds on the east ridge of Reno Mountain.

Some of the metamorphism described above can clearly be attributed to the granite intrusives. The stock exposed in Sheep Creek valley has, for example, an aureole extending for 3,300 feet at least to the east and a comparable distance to the north. The intrusive at the bottom of the Queen shaft has a smaller aureole.

The stock northwest of the Reno mine is not surrounded by a wide aureole. The metamorphism of the rocks of Reno Mountain seems to increase toward the north, not the northwest, and cannot be attributed to the stock. The nearest intrusive body known in this direction lies almost 4 miles away (*see* p. 25). Another smaller granite mass lies 2 to 3 miles northeast of Reno Mountain.* It is not known whether either of these intrusive bodies is the source of the metamorphism.

The time of metamorphism at least in part post-dates the period of major folding. The biotite developed by this metamorphism in the Reno Mountain area, for example, is unstrained and lacks the preferred orientation that would be expected had it developed while shearing movements were going on. Andalusite developed both here and in the vicinity of the Sheep Creek valley stock is regarded as probably an anti-stress mineral† and, like the biotite, it lacks preferred orientation. Finally, as noted previously (*see* p. 22), the nature of the folds in the metamorphosed areas differs little, if any, from those in the equivalent rocks beyond the limits of metamorphism.

STRUCTURE

Folds

The dominant structure of the Sheep Creek camp is a major northerly trending anticline paralleled on its west by a smaller anticline, and an intervening tight syncline.

The larger Eastern anticline can be traced northward from Mount Waldie through the camp as far as Hidden Creek valley where it terminates abruptly against a belt of easterly trending rocks from which it is separated in all probability by a major fault. The Eastern anticline can also be traced southerly and southwesterly from Mount Waldie as far as the South Fork of Salmo River, 5 miles beyond the boundary of the Sheep Creek camp. In this distance it plunges southward and becomes less tightly folded.

The axial plane of the eastern fold strikes about north 15 degrees east in the southern part of the map-area, about north 20 degrees east in the central part, and about north 10 degrees east in the northern part. The dip of the axial plane, judging from the attitude of the bedding on the limbs, is about 75 degrees east on the Lost Creek-Waldie Creek divide, and a mile to the north the dip is about 65 degrees east. In the Kootenay Belle mine the beds of the overturned western limb dip easterly at angles ranging from 75 degrees in the upper levels to 55 degrees in the lower levels, and the axial plane, near by, almost certainly dips somewhat less steeply. Farther north again, the axial plane becomes more erect and on the east ridge of Reno Mountain it is within 10 degrees of vertical.

The plunge of the Eastern anticline within the camp is difficult to determine, but the disappearance southward of the Three Sisters beds indicates a southerly plunge at an undetermined angle. On the southeast ridge of Mount Waldie, dragfolds in the Motherlode beds have a plunge ranging from zero to a maximum 8 degrees north, suggesting that the direction of plunge of the major fold may locally be reversed. In the area 5 to 6 miles south of Mount Waldie a southerly plunge is again apparent, and in this vicinity‡ attains an angle of as much as 30 degrees.

The Western anticline is much more completely explored by underground workings than the Eastern, and its complexities are much better known at least within the confines of the Upper Nugget and Navada members. Throughout its length this fold is overturned

* Little, 1949, map.
† Turner, 1948, p. 30.
‡ Little, 1949, map; 1950, map; Walker, 1934, map.

to the west. The limbs tend to maintain fairly regular dips, and the warping in the quartzite to be concentrated in relatively narrow belts close to axial planes. For much of its length the western limb dips steeply eastward, and the eastern limb dips from 25 to 60 degrees eastward. However, between the Queen and 81 veins in the Sheep Creek mine the fold is known to be complex, and the structure is further complicated by faulting (*see* Figs. 7 and 8). In this part the Navada and Upper Nugget beds are folded tightly at the crest of the main anticline, and on the western limb are bent in a subsidiary fold, concave eastward, whose axial plane dips at a low angle to the east. In the subsidiary fold the bending of the Navada and Upper Nugget beds is moderate, but the relatively incompetent Middle Nugget member is folded more tightly.

The plunge of the anticlinal axes at the crest of the Upper Navada and Upper Nugget beds is to the south at angles up to 10 degrees from the Reno mine to the 8000 vein of the Gold Belt mine (*see* Fig. 9). In the Sheep Creek mine, on the other hand, the plunge of the axis at the crest of the Middle Nugget beds is about 5 degrees to the north. It is probably significant that Sheep Creek valley crosses the Western anticline at a structural low. The tendency for the limbs of the fold to maintain fairly regular dips and for warping in the quartzite to be concentrated in relatively narrow belts close to axial planes is noted throughout the Western anticline.

In working out the detailed structure, difficulties arise because of the scarcity of clearly defined stratigraphic horizons and of exposures in which it is possible to trace a single bed continuously through any extended vertical range. A few key horizons, such as the tops of the Three Sisters formation of the Nugget and Navada beds, and of the Reno formation, can be recognized with assurance, but clearly defined horizons within the various members are rare and of very limited extent. In a few cliff faces a single bed can be traced for part or all of the height of the cliff, but underground it is possible only to observe the intersection of particular horizons with the level workings or in a few instances with raises. Attitude of bedding can be recognized nearly everywhere underground, but the presence of minor folds of uncertain shape makes it difficult to project stratigraphic horizons for any great distance from the points of observation.

Dragfolds on a small scale are generally unimportant in the mines of the western limb of the Eastern anticline, and no major flexure is known to have been crossed in the underground workings. A major complex dragfold is exposed in this limb on the slopes of Reno Mountain at the Reno-Laib contact. Here, as many as five minor folds, a few tens of feet across but as much as 200 feet in amplitude, extend from the major dragfold (*see* Fig. 3). The same major dragfold is exposed in the Upper Nugget and Navada beds on the north face of the peak half a mile south of Reno Mountain. Another dragfold occurs in the Upper Nugget beds on the lower slopes of Sheep Creek valley south of the Clyde workings. The attenuation of the Upper Nugget beds in the lower workings of the Motherlode mine suggests that the latter dragfold may extend to a point not far below and to the west of the lowest level.

Dragfolds are numerous in the Western anticline, particularly in less competent members and near the crest of the structure. The cliff face north of the Reno mine provides an excellent exposure of some of the extremely complex folds within the incompetent Reno formation. Folding in the thick-bedded quartzites is by no means as complex. Several tight folds with amplitudes of a few tens of feet exist in the quartzite in most places near the crest of the Western anticline (*see* Figs. 3 and 6) but are generally absent on its limbs. It is not always possible to determine which of the dragfolds near its crest mark the highest part of the structure, and it seems possible, indeed, that the highest part of the structure may lie in a particular dragfold at one level, and in another dragfold at a different level.

Very small dragfolds have been developed on the flanks of larger dragfolds and these in turn on the flanks of the Eastern and Western anticlines. The smallest folds, therefore, bear no direct relationship to the two main folds and cannot be used indiscriminately in interpreting the gross structure. The small folds indicate the relative direction of interbed movement and by so doing indicate where the axial plane of the next larger fold lies. The plunge of the dragfolds, however, appears to correspond rather closely to the plunge of the main structures, and lineation in the bedding planes on the limbs of the dragfold parallels the axes of the dragfolds.

Several minor flexures, not more than a few feet across, have been noted in the quartzites on 6 level of the Kootenay Belle mine on the walls of both the A and Black veins. If they were interpreted as dragfolds on the flanks of a major anticline, these flexures would indicate that its axis lies to the west of this locality, not to the east as determined by detailed mapping. They cannot, therefore, be attributed to stresses set up during the period of folding. It would appear instead that these flexures have developed along restricted zones of movement on which the west side has dropped several inches to a few feet with respect to the east side, and that had conditions been different steeply dipping faults might have developed in their place. The time of this movement with respect to vein faulting is not known.

Joints

Joint systems are well developed in much of the quartzite of the camp. Three sets of joints, spaced at intervals of a few inches to a foot or two, and dividing the quartzite into rectangular or rhombohedral blocks or slabs are most common. The best developed of the joint sets is almost invariably the one paralleling the bedding. A second set, generally somewhat less well developed, is approximately perpendicular to the bedding, being nearly vertical and striking at right angles to the stratification. A third set, still less well developed, has approximately the same strike as the bedding but dips in the opposite direction. This third set also intersects the bedding at very nearly 90 degrees, and as the bedding is commonly steep, this set of joints has generally a rather low dip. Four sets of joints are also common—one set paralleling the bedding, a second paralleling the strike of the bedding but dipping in the opposite direction, and two steeply dipping sets cutting obliquely across the bedding. In some instances these two latter sets have almost the same strike but dip steeply in opposite directions; in other examples they have slightly diverging strikes but nearly the same dip. Joint sets in directions other than those listed above are not common, and very few, indeed, cross the bedding at an angle of 45 degrees or less. In the massive quartzites of the Upper Nugget and Upper Motherlode members, where stratification is inconspicuous, no clearly defined joint pattern may be evident, and instead only a series of short irregular cracks traverse the rock in all directions.

Joints are not as a rule well developed in the argillaceous rocks, but a crude schistosity parallel to stratification and, less commonly, a fracture cleavage roughly parallel to the axial planes of adjoining folds can be observed in a few places.

Faults

General.—Four well-defined sets of faults can be recognized in the Sheep Creek camp:—

(1) A group of northeasterly trending faults with a right-hand strike-slip movement predominant; this is the most important group as all the known productive veins are found along faults of this group.

(2) A few northwesterly trending faults, at least some of which appear to be the same age as the first-mentioned group, having a left-hand strike-slip movement.

(3) A few northerly trending normal faults which clearly post-date the first group.

(4) Nearly horizonal faults in which the hangingwall has been displaced westward with respect to the footwall and which also post-date the first group.

Northeasterly Trending Faults (Vein Fractures).—The northeasterly trending faults are of great importance as it is in these breaks that all the commercial vein mineralization has been found. For that reason they can be referred to as vein fractures. The faults of this set, particularly those from which ore has been mined, are the best known and, because of their economic importance, merit the most detailed discussion. It will be understood that conclusions relative to displacement and other features apply to faults of this group whether they contain vein matter or not.

From Reno Mountain on the north, at least to the upper slopes of Mount Waldie on the south, these faults or vein fractures occur at intervals of generally not more than 500 feet. The strike of the fractures is, almost without exception, between 50 and 90 degrees east of north, although these extremes are exceeded in a few of the fractures for short distances. The north wall of each vein fracture has been displaced eastward with respect to the south wall for distances of from a few feet to more than 200 feet. Also on some and perhaps all of them the north wall has moved up with respect to the south wall a distance which appears to be only about half the strike-slip movement. Many vein fractures consist of single fractures or a group of closely spaced fractures within a zone a few feet wide; some, however, consist of branching, subparallel or *en échelon* fractures distributed across a zone as much as 200 feet wide, and these might better be described as fracture systems.

The northeasterly trending fractures cut obliquely across folded beds, transgressing various members of the Quartzite Range and Reno formations and locally cutting strata of the Laib group. The character and attitude of the fractures in the competent quartzites differ markedly from their character and attitude in the less competent argillaceous and calcareous rocks. However, within the camp, the attitudes show from place to place systematic variations that cannot be attributed to the nature of the wallrock alone.

Variations in the strike of these fractures can in large part be correlated with changes in the competency of the wallrocks; thus the Queen vein fracture cutting through quartzites in the Western anticline has an average strike of north 60 to 65 degrees east, but in the argillaceous and calcareous schists of the Central syncline it has an average strike of north 50 degrees east. It is a rather general rule that as any one of these fractures extends from quartzite into argillaceous members it swings to the left by as much as 15 degrees. One exception to this general rule occurs where the displacement on the fracture is small within the quartzitic member and diminishes to zero within the argillaceous member. Under such circumstances the fracture surface may swing either to the left or to the right as it enters the argillaceous rocks, or it may give rise to two or more branches which bend in opposite directions. A second exception to this rule is found immediately above or below a relatively flat-lying contact between argillaceous and quartzitic rocks. Here it is geometrically impossible for a single continuous fracture to develop with the appropriate attitudes for each of the two rock types. Under these circumstances a series of *en échelon* fractures tends to be developed, principally in the argillaceous rocks but extending into the adjoining quartzites. Each of these *en échelon* fractures tends to strike nearly east within a zone that strikes north of east parallel to the fractures in the adjoining quartzite. Examples of these *en échelon* zones of fracturing are to be found in argillaceous rocks overlying a gently dipping quartzitic member near the crest of the Western anticline on 5 level of the Reno mine, as well as in the Bluestone mine, and in the 1782 level of the Gold Belt mine. An example of an *en échelon* zone in argillaceous rocks underlying a quartzite member which dips at a moderate angle is to be found on the 9 level of the Sheep Creek mine along the 92 vein zone.

Where the displacement is great, two different rocks, quartzite and argillite for example, may constitute the opposite walls for many feet along the length of the fracture. Under this circumstance the strike of the fracture seems to have been determined almost entirely by the more competent of the two rocks—the quartzite in the example cited.

The general trend of the vein fractures is not uniform in all parts of the camp. In the northern part the average strike within the quartzite is north 75 to 80 degrees east; in the southern part of the camp, notably in the Sheep Creek mine, their average strike is north 60 degrees east; and between the two areas intermediate trends prevail.

A change with depth, in strike of a single vein fracture, even within one stratigraphic unit, is common. In one of the most extreme examples, the Kootenay Belle A vein, the strike of the vein across Upper Nugget beds is about north 67½ degrees east on 1 level, and in the same beds on 10 level, 1,370 feet below, it is about north 80 degrees east. In several of the vein fractures of the Sheep Creek mine a similar tendency is apparent, the fracture trending more nearly east at depth than it does at higher levels. In the Motherlode mine, however, where the vein fracture crosses the Nugget member, no significant change of the average strike with depth is observed.

The dip of the vein fractures is steep and generally to the south, the known extremes being 45 degrees south (Kootenay Belle A vein between 5 and 6 levels east) and 80 degrees north (parts of Reno vein). An average dip of about 85 degrees to the south prevails within quartzites throughout most of the camp, except in the southeastern part (Kootenay Belle mine and south) where distinctly lower dips, also to the south, are common. Commonly vein fractures that are nearly vertical in their upper parts dip toward the south at a lower angle at depth. However, the Nugget vein fracture, which dips 75 degrees south in its upper part and is nearly vertical at depth, is an exception to this general rule. Sudden changes in the dip of a vein can in most instances be related to a change in the character of the wallrocks. The attitude of bedding is important in determining the dip of the vein fracture as it passes from quartzite into argillite. If the dip of the quartzite-argillite contact is vertical, the dip of the fracture in argillite tends to be very nearly the same as in the adjoining quartzite. Where, however, the fracture transgresses beds that dip at a steep to moderate angle to the east, the southerly dip of the fracture tends to be distinctly lower in the argillaceous beds than it is in the quartzites; this condition is well displayed in the eastern workings of the Queen vein. Where a southerly dipping fracture crosses beds that dip at a moderate angle to the west, the dip of the vein fracture in argillite should, ideally, be steeper than in the quartzite, and perhaps even be vertical or dip toward the north; this condition has been exposed in the upper workings on the Queen vein.

The displacement along each of the northeasterly fractures has been such that the north wall has been moved to the east with respect to the south wall. In two veins, the 92 and the 8200 (Columbia), the north wall moved up and to the east with respect to the south wall. In the 8200 vein the vertical component of displacement is about half the horizontal, and the direction of movement is, thus, about 30 degrees from the horizontal. In at least a dozen other veins distributed throughout the camp, mullion structure on the vein walls plunges at angles of from 15 to 33 degrees westward, corresponding with the direction of movement observed in the 92 and 8200 veins. Since the vein fractures throughout the camp are similar in attitude, in angle of refraction at argillite-quartzite contacts, and in right-hand offset of beds, it is probable that all had similar directions of displacement.

The net slip on any fracture, on which the movement has both a horizontal and a vertical component, is not the same as the offset measured along a level line on the fracture between two parts of a formerly continuous horizon (the " horizontal separation " in fault terminology). However, the net slip can be computed* from the horizontal separation, the apparent dip of the bedding measured in the fracture plane, and the angle between bedding and direction of movement also measured in the fracture plane.

The horizontal separation along the vein fractures ranges up to at least 212 feet (*see* Appendix, pp. 79–83); the computed slip on these vein fractures, assuming the slip has been in a direction plunging 25 degrees southwest, ranges from zero to more than 200 feet. Only two vein fractures are known to have displacements of more than 100 feet—the Yellowstone vein with a computed net slip of 120 feet and the Queen vein with a computed net slip of as much as 230 feet. Maximum slip on nearly all the other ore-bearing vein fractures varies from 10 to about 80 feet.

* The method of computing the net slip is outlined in the Appendix, pp. 79–83. The Appendix includes a tabulation of observed data and calculated net slips.

Variations in net slip, as computed from observations on horizontal separation, may be both large and abrupt along many of the vein fractures (*see* Figs. 5–8). Along the Queen vein, for example, the computed net slip ranges from 230 feet at 5 level near the Queen shaft to 160 feet on 3 level about 600 feet west of the Queen shaft, at the top of the Navada member, and to 65 feet on 3 level 200 feet farther west again, at the top of the Reno formation. Computed net slip near the eastern end of the Motherlode vein on 3 level changes from 45 feet to 11 feet within a horizontal distance of only 140 feet. Variations in displacement with depth are also striking. The computed net slip along the Kootenay Belle A vein at the top of the Navada member changes from 1.7 feet at 6 level to 10 feet at 8 level, 31 feet at 9 level, and 40 feet at 10 level.

Most variations in displacement on a vein fracture are related to changes in wallrock. In thick quartzite beds, drag is of minor importance, nearly all the movement along the fracture zone is concentrated in a single fracture, and displacement is, in general, the greatest. In argillaceous and calcareous beds, in which a considerable part of the movement along the zone is distributed across a zone of dragged beds, the movement along the central fracture is correspondingly smaller. Many vein fractures have small displacements in quartzite and die out in adjoining argillaceous rocks where they may perhaps be represented only by inconspicuous flexures. The failure to locate the 57 vein fracture of the Sheep Creek mine in the argillaceous rocks immediately west of the Thompson fault may be explained by just such a dying-out of a minor northeasterly trending fracture.

Some of the variations in movement may be governed not by local changes in competency of the wallrocks, but by changes in the over-all competency of large units. In the higher levels of the Western anticline the width of quartzite is small, and the behaviour of rocks under stress may be different from their behaviour at lower levels where a much greater amount of resistant quartzite is present. Downward increases in the amount of displacement along the Queen and 3500 veins can conceivably be explained in this way. Vertical changes in displacement along the vein fractures of the Eastern anticline cannot, however, be accounted for in such a manner, for the proportions of quartzitic and argillaceous rocks at widely different levels in the fold are very nearly constant. This explanation, moreover, fails to account for the fact that the displacement along the 81 vein of the Sheep Creek mine increases downward, and that of the adjoining 83 vein decreases downward.

Variations in the distribution of movement between adjoining fractures may offer a satisfactory explanation for many of the changes in amount of displacement along any one fracture. Thus much of the deformation in the zone adjoining the 81 and 83 veins may have been concentrated along the latter vein fracture at high levels and along the former at lower levels. A similar relationship holds for the Kootenay Belle A and B veins. The displacement along the A vein at the base of the Upper Nugget quartzite tends to increase downward between 1 and 3 levels, but that along B vein tends to decrease downward between these same two levels. The changes in displacement on this pair of veins as well as on the 81 and 83 thus appear to compensate one another. It should be noted, too, that east of the junction of A and B veins the amount of displacement is approximately the sum of the displacements of the two individual vein fractures to the west. Movement along the 8000 and 8200 vein fractures of the Gold Belt mine may also be compensating, with nearly all the displacement concentrated in the latter vein in the western limb of the Western anticline, but the displacement more uniformly distributed in the eastern limb, particularly at lower levels. Whether the variation in displacement of many of the other vein fractures can be explained in this way is not known, for the presence, and the amount of displacement, of parallel fractures within the same vein system may be undetected. However, any abnormally great decrease in displacement along any one vein fracture, if it cannot be attributed to changes in wallrock, should raise a suspicion that there may be in the vicinity branching or parallel fractures along which part of the movement of the zone has been concentrated.

The movement along adjoining vein fractures was not necessarily simultaneous. The pre-vein basic dyke of the Gold Belt mine, as noted on page 29, was intruded after half the movement of the 8000 vein fracture was complete but before any appreciable part of the movement along the 8200 vein fracture had taken place.

Not all the movement along the vein fractures has been right hand. A left-hand movement along the Clyde vein fracture that took place after the intrusion of the quartz-porphyry sills has already been noted (*see* p. 29). Lamprophyre dykes crossing the Queen, 75, and 2590 vein fractures have also in places been displaced to the left from a few inches to 2 feet. A broad zone of drag in the Kootenay Belle A vein on 5 level west indicates a right-hand movement along the fault (fracture) zone as does the observations on offset beds. A narrow zone of drag within this broad zone indicates, however, that a left-hand movement has been superimposed on the earlier right-hand movement. In only one place in the camp, on 5 level west of the Reno vein, is there evidence that the late left-hand movement may anywhere have attained or exceeded the magnitude of the earlier right-hand movement. Here a left-hand offset amounting to about 1 foot has been observed across the vein. However, it must be admitted that this offset may have been caused by dilation accompanying vein formation in a fracture along which there has been negligible displacement.

Some left-hand movements may be of recent origin. H. E. Doelle informed the writer that movements along the Queen vein fracture were observed during the course of mining. A chalk mark drawn across the back of the 7 level drift (10410E, Sheep Creek co-ordinates) showed a left-hand offset of about 3 inches after a period of a year. Movement began at the time stoping was commenced and stopped with the cessation of mining operations in this vicinity. Strains relieved during mining in this part of the vein were presumably responsible for the rock bursts in near-by stopes. Rock bursts have also been reported from the 75 vein where left-hand movements on the vein fracture have also been noted, but whether the latter movements are of recent origin is unknown. No mining has taken place in the Clyde vein, and, therefore, the left-hand movement noted can hardly be attributed to man's activity in its vicinity.

The lateral extent of most of the vein fractures exceeds 1,000 feet, and a few are known to extend for more than 3,000 feet, crossing both the Western anticline and the western limb of the Eastern anticline. The Queen vein, for example, has been traced almost continuously on 3 level of the Queen mine about 2,400 feet, and its extension easterly across the McCune adit and the Kootenay Belle workings adds at least 1,430 feet and possibly 1,900 feet to its known length. The Yellowstone fracture has been traced on surface or underground for 3,750 feet. The Motherlode and 3500 veins are almost in line with one another and are separated by only 1,200 feet of unexplored ground. These may be part of a single fissure 4,000 feet long. The Reno vein system has been traced for a horizontal distance of more than 2,000 feet, the 8200 (Columbia) for 1,600 feet, and the A vein (Kootenay Belle mine) for more than 1,500 feet. It is a general rule in the camp that the vein fractures with the largest displacement tend to be the most continuous. Some with relatively small displacement, like the 57 vein fracture, along which movement may not have exceeded 10 feet, are continuous only across the Upper Nuggest quartzite and die out in the argillaceous rocks on either side. Their length may be only a few hundred feet.

The vertical range through which vein fractures are known to occur exceeds 4,750 feet, between the lowest level of the Queen vein in the central part of the camp and the highest exposures of the Reno vein on the north and of an unnamed vein fracture 750 feet south of Mount Waldie on the south. No individual fracture has been traced through such a great range, but several extend to depths of more than 1,600 feet. The Reno vein system, for example, has been followed continuously to a point 1,900 feet lower than its highest outcrop, and the Kootenay Belle A vein has similarly been followed virtually without interruption to a point 1,680 feet lower than its highest outcrop. The Nugget, 3040, 3500, and 81 vein fractures have been opened at intervals to depths of 1,650, 1,840, 1,900, and 2,000 feet respectively below what are apparently their surface exposures. The upper part of each of these vein fractures has been removed by erosion, and the lower limit has not been attained in underground workings. The 57 and 44 vein fractures are known only at depth, having been opened at points 2,700 and 2,600 feet respectively below the surface.

Branching of vein fractures is common. The Kootenay Belle A and B vein fractures and the Nugget and Calhoun vein fractures are pairs that converge and join along strike. The general line of junction in each example plunges to the east at a steep angle. The 75 and 76 vein fractures of the lower levels of the Sheep Creek mine, on the other hand, are nearly parallel in strike but apparently converge upward to a single fracture on 2 level. The plunge of the junction of these two fractures is undetermined. Other examples of branching fractures are found in the vicinity of flat-lying argillite-quartzite contacts (*see* p. 39) where *en échelon* fractures tend to be developed. The Reno vein system has a particularly complex pattern of branching fractures which are, however, restricted to a zone less than 100 feet wide, except in the lower and eastern part of the Reno mine.

The interval between successive northeasterly trending faults (vein fractures) is rarely more than 500 feet in the more fully explored parts of the camp. At least twelve of these faults, of which ten are known to have contained ore, occur in a length of 4,500 feet along the Western anticline in the Sheep Creek mine. No less than ten such fractures, of which five have so far yielded ore, occur along a 3,000-foot length of the western anticline in the northern part of the Gold Belt mine. The spacing of the fractures tends to be irregular, with the intervals between them ranging from 200 to about 500 feet in the northern part of the Gold Belt mine and from less than 50 feet to more than 700 feet in the Sheep Creek mine. Inasmuch as some of the vein fractures may not be developed in argillaceous rocks and may not be exposed in more heavily drift-covered areas, fractures present in quartzite may have remained undetected in parts of the camp which have not been fully explored underground. Large gaps between known northeasterly trending fractures can most probably be attributed to incomplete information on structure within the quartzites.

Movement along the northeasterly trending faults (vein fractures) is not uniformly distributed throughout the camp. Much of it seems to be concentrated in the region immediately south of Sheep Creek where the two fractures with the largest displacement, the Queen and Yellowstone vein fractures, occur. As a result of repeated displacements in a section of the Western anticline slightly more than 3,000 feet long from the 81 vein to the Yellowstone vein, the ground farther to the north has been shifted fully 440 feet northeast with respect to the ground to the south. The average ratio of fault movement to distance along the fold axis is here almost 15 per cent. The total movement recorded along northeasterly trending faults (vein fractures) within a block of ground slightly more than 3,000 feet long from the 76 to the 44 veins is, on the other hand, little more than 100 feet, or less than 4 per cent of the length of the block. The known displacement per unit length of the fold is here about one-quarter of that in the block of similar size adjoining it to the north. In a 2,800-foot length of the Western anticline from the 2360 to the 4600 veins of the Gold Belt mine aggregate movement along the vein fractures is about 225 feet, or about 8 per cent of the length. Along a 2,200-foot section of the western limb of the Eastern anticline from the Alexandra vein to the unnamed fracture at the portal of Kootenay Belle 2 level, the sum of the net slip on vein fractures is somewhat more than 200 feet, or about 9 per cent of the length of the section. Along a 2,600-foot section of the same limb of this fold from the 1500 vein zone to the unnamed fracture 100 feet north of the Motherlode vein, the aggregate movement along northeasterly trending fractures is between 150 and 200 feet, or about 7 per cent of the length. Detailed information on the aggregate slip along the vein fractures is not available for any other large block of ground. The ratio is highest in the section between the 81 and Yellowstone veins and in the adjoining section of the Eastern anticline. It is concluded, therefore, that this part was subjected to the greatest stress during the development of vein fractures.

Northwesterly Trending Faults.—Four northwesterly trending faults are known. Two of these are in the Sheep Creek 5 level crosscut south of the 57 vein, another is in a branch of the 1880 drift of the Gold Belt mine, and the fourth, referred to as the Blacksmith fault, is in the eastern workings of the Motherlode mine. The average strike of these four faults is north 45 degrees west, and the dip is nearly vertical. Beds intersected by the faults have been offset to the left through distances as great as 26 feet. The fault in the 1880 drift intersects a dragfold and has displaced it horizontally. The direction of movement along the other faults is not known. The northwesterly trending fault of the 1880 drift contains mineralized quartz, but an assay plan made by the Gold Belt mine does not indicate any place where the gold content exceeds 0.10 ounce per ton across the width of the vein. It is evident, however, that this fault existed prior to mineralization. The Blacksmith fault, on the other hand, offsets the Motherlode vein fracture and is unmineralized.

Northerly Trending Normal Faults.—Five northerly trending normal faults are known to occur in the camp. Three of these, referred to as the Queen, the Thompson, and the Hangingwall faults, are exposed only in the underground workings of the Sheep Creek mine. A fourth is exposed in the Cayote adit. The fifth, which may be referred to as the Weasel Creek fault, occurs in the eastern part of the map-area. Probably dip-slip movement predominated in all these faults, but some strike-slip movement occurred in both the Queen and Thompson faults. The total displacement along these faults ranges from a few tens of feet to more than 1,000 feet. The first three of these faults are of post-vein age. The Weasel Creek fault and the fault in the Cayote adit have not been observed in contact with any vein or vein fracture and their age relationships are unknown.

The Queen fault, so named after its discovery in the workings on the Queen vein, is the largest of the known post-vein faults in the western part of the Sheep Creek camp. It can be traced underground in the Sheep Creek mine from the Yellowstone vein on the north to the 57 vein on the south, a total distance of a mile, and it has been recognized on all levels of this mine from 2 to 9. Along the Queen vein this fault has not been identified with assurance below 7 level, although at lower levels on this vein several faults are known, any one of which might be the principal extension of the Queen fault. Possibly in this part of the mine the Queen fault splits into several minor faults. A shallow gully on the hillside west of the Queen shaft, directly up dip from the known position of the fault underground, may well mark the trace of the zone of crushing. The fault has not been recognized north of Sheep Creek where its continuation above the creek level presumably lies entirely within Laib beds and beyond the limits of underground workings.

Within its known limits the Queen fault varies in strike between north 5 degrees west and north 10 degrees east. Its dip varies between 40 and 48 degrees to the east. It consists generally of a single zone of gouge up to several feet in width within a much broader zone of dragging and subsidiary faulting. However, at the 81 vein it is known to be represented by two fault zones up to 90 feet apart (*see* Fig. 8) and, as previously stated, at the Queen vein may branch downward in places into two or more smaller faults.

The total displacement along the fault in the vicinity of the Queen vein as indicated by the offset of the west orebody and of stratigraphic horizons is slightly more than 350 feet. The east (hangingwall) side of the fault has been shifted 55 feet northward and about 350 feet down dip with respect to the west side. Since in this vicinity the dip of the fault approximates 45 degrees, the heave* and throw* are both about 250 feet. At the 92 vein the strike-slip, heave, and throw are very nearly the same as at the Queen vein. At the 81 vein the strike-slip is about 50 feet, and the dip-slip about 375, slightly more than farther north.

A vein cut by a fault is offset by an amount and in a direction that depend not only on the amount and direction of displacement on the fault, but also on the attitudes of the

* Heave is the horizontal component of fault movement, and throw the vertical component, both measured in a vertical plane at right angles to the strike of the fault.

vein and the fault. The offset is measured horizontally at right angles to the strike of the vein, and can be determined graphically or mathematically for any level.*

The offset in an upper level (3 level) of the Queen vein is 85 feet to the right, corresponding to an average vein dip of 85½ degrees to the north. At successively lower levels the observed dip of the vein adjacent to the fault passes through the vertical, to 80 degrees and less to the south. The calculations† show that this change in dip should lead to a reduction in offset with depth, as is observed to be the case, and that between 10 and 12 levels where the dip to the south is about 70 degrees the offset should be small and to the left. The failure to identify the Queen fault on 10 level, near its projected position close to the Queen shaft, may be explained in part by the smallness of the offset at that elevation.

The Thompson fault, like the Queen fault, is exposed only in the workings of the Sheep Creek mine. This fault, too, has been traced from the Yellowstone vein on the north to the 57 vein on the south, in which distance its strike is nearly the same as that of the Queen fault. Its dip is to the east at angles varying from 50 degrees to almost 90 degrees. The highest dips are found in the upper workings from the 81 to 92 veins, and the lowest dips in the southern part of the mine. From the 81 vein south at and below 5 level the fault tends to follow the contact of the Middle and Upper Nugget beds. At higher levels from the 92 vein south it tends to follow the upper axial plane of the Western anticline. On the Queen vein, however, what is apparently the Thompson fault *occurs well to the west of this axial plane. Drag, absence of any repetition of beds* where the fault intersects strata dipping more gently to the east, and the apparent displacement of the crest of the Western anticline in the 583E and 585E workings of the Sheep Creek mine, all indicate normal faulting. Estimates of the amount of displacement in the vicinity of the 583E and 585E drifts vary somewhat, depending on the form assumed for the crest of the Western anticline, but the dip-slip, it seems, can be no more than 50 feet nor no less than 30 feet. There is no reliable information on the dip-slip displacement along this fault at any other place. The strike-slip movement cannot be measured accurately. Observed offsets of veins cut by this fault are commonly left hand, and range from a few feet to as much as 50 feet. Examples of right-hand offsets of a few feet are also known.

A third post-ore fault within the Sheep Creek mine, the so-called "Hangingwall fault," is exposed in the upper workings of the 81, 83, and 85 veins above (east of) the Thompson fault. Here the Hangingwall fault has a strike of north 30 degrees west and a dip of about 80 degrees to the west. Apparent offset of the top of the Nugget member in the eastern end of the upper workings on 81 vein suggests a normal movement (*see* Fig. 8) of a few tens of feet. Strike-slip movement is probably negligible.

A normal fault exposed in the Cayote adit at two places strikes from north 15 degrees west to north 10 degrees east and dips 45 to 70 degrees east. A dip-slip component of movement of about 50 feet is indicated, but a strike-slip component, if any, cannot be measured.

The largest normal fault known in the Sheep Creek camp lies in the eastern part of the area beyond the limits of all the important mines. This fault has been traced from the Sheep Creek-Lost Creek divide on the south to the east ridge of Reno Mountain on the north, a distance of 6 miles. It follows the strike of the beds north 0 to 15 degrees east throughout this extent. Along part of its course it is closely followed by Weasel Creek, but elsewhere it is marked on the surface only by small ravines and by a repetition of the same stratigraphic units on opposite sides. The deflections in the trace of this fault

* In the graphical solution, differences in the dip of the vein in the two segments can be considered. In the mathematical solution the following formula is used: $F = H \cos b - S \sin b - T \cot d$ where F is the *offset* measured to the right; H and T are the *heave* and *throw* of an easterly dipping fault; S is the left-hand *strike-slip* on the fault; *b* is the *angle* in the horizontal plane, *between the fault* and the vein, measured clockwise from the fault to the vein; and *d* is the average *dip* of the vein to the south.

† The values for several of the terms in the equation applied to the Queen fault and the Queen vein may be taken as H, 250 feet; T, 250 feet; S, 55 feet; and *b*, 60 degrees. Values of *d* of 100 degrees (i.e., dip 80 degrees north), 80 degrees, and 70 degrees give offsets of +121 feet, +33 feet, and −14 feet, the minus sign indicates offset to the left.

caused by topography indicate a moderate to steep westerly dip. At the one place where the fault zone is exposed, on the south slope of a ravine 2,000 feet northwest of the mouth of Curtis Creek, it consists of a belt of shattered rocks so ill defined that its dip cannot be determined. Judging from the distribution of the sedimentary units on either side of the fault, the dip-slip movement is not less than 1,000 feet.

Flat-lying Faults.—Many flat-lying faults, with displacements measurable in feet or tens of feet, occur throughout the camp. Their dip is low, generally less than 15 degrees, to either the east or west. One such fault on the cliff face north of the Reno mine passes eastward into a steep easterly dipping fault that follows the bedding. In every exposure where the relationships can be determined, the hangingwall block has moved westward with respect to the footwall block. Striations on the surface of one of these faults indicate a movement in a direction north 85 degrees west. Displacement of the line of intersection of the 3500 vein and the top of the Navada member on 1400 level of the Gold Belt mine indicates a movement of north 70 degrees west. The amount of movement on the latter fault was 45 feet. Displacement along the fault on the cliff face north of the Reno mine has been 36 feet. As a rule the displacement along the flat faults is only a few feet; however, a displacement of about 200 feet along a flat fault seems to offer the best explanation for a discrepancy between the geology of 6 and 8 levels of the Ore Hill mine. Most, if not all, of the flat-lying faults are post-vein in age. One flat-lying fault in the 1830 drift of the Gold Belt mine offsets a lamprophyre dyke, but the fault north of the Reno mine is cut by a lamprophyre dyke.

Structural History

Of the events that have been deduced in the structural history, the earliest was folding that developed the major structure of the Sheep Creek camp. This folding affected the Lower Cambrian sediments within the camp and Middle Cambrian and Ordovician sediments in near-by areas.* It is not known whether Jurassic beds exposed west of Salmo were involved in this same folding. It is also uncertain whether the Lower Cambrian sediments were converted to quartzites and argillites before or after folding.

The major structure consists of two northerly trending anticlines with an intervening syncline (*see* p. 36). In the course of major folding, primary dragfolds developed on the flanks of the major anticlines and syncline, and secondary dragfolds appeared in turn on the limbs of these smaller flexures. Even within the limited area of the camp it appears that the amplitude of the Eastern anticline decreases from north to south.

Intrusion of granite followed folding. Some, but not all, of the intrusion was accompanied by local disturbance of adjoining sediments. Metamorphism of the sediments took place in the vicinity of the intrusives.

Northeasterly trending faults (vein fractures) and northwesterly trending faults appear to be, at least in part, conjugate shears. Both could be produced by an east-west compressional component of forces, and combined they result in a slight crustal shortening in an east-west direction and an extension in a north-south direction. These faults could be a late expression of the same forces that brought about folding. However, inasmuch as they cut the major flexures and dragfolds, it is clear that these faults were developed after folding was essentially complete. The northeasterly trending vein fractures in the Reno mine appear to post-date the pronounced metamorphism of that locality (*see* pp. 22, 36), which in turn post-dates folding.

Development of the pre-vein basic dykes along northerly trending fractures took place before movement on the northeasterly trending faults was complete and, indeed, before movement on some of these faults had commenced. Whether these dykes were formed by injection of magma or by replacement along fractures, they indicate a period of extension or at least of low compressional stress in an east-west direction across the dyke fractures.

* Park and Cannon, 1943, Plate I and pp. 28–34; Little, 1950, p. 34.

Renewed movement along the northeasterly trending faults (vein fractures) led to right-hand displacement of the pre-vein dykes. This movement may have been accompanied by displacement on the northwesterly trending faults, and, if so, a slight crustal shortening in the east-west direction and extension in the north-south direction resulted. Quartz was introduced into the vein fractures that were developed as actual or potential openings. This quartz was fractured by additional movements along the same fault zones, but it is not known whether the ore minerals were deposited during this period of faulting.

Intrusion of northerly trending quartz-porphyry sills and of post-vein lamprophyre dykes followed completion of the right-hand fault movements on the northeasterly trending faults. These instrusions involve a slight but significant east-west crustal extension, indicating that the former east-west compressional forces had relaxed.

Flat-lying faults along which the hangingwall blocks have been displaced westward are post-vein in age and developed during the period in which the post-vein lamprophyre dykes were introduced. The flat-lying faults do not represent either simple shortening or extension in an east-west direction but must have developed in response to forces that acted at an angle to the horizontal plane.

Normal faulting followed the intrusion of many, if not all, of the lamprophyre dykes, and indicates a further period of crustal extension in an east-west direction.

The structural history of the camp also includes intermittent uplift recorded in erosion surfaces. The marked difference in the vertical range over which ore has been found (*see* p. 61) may perhaps reflect non-uniform uplift since the time of vein formation.

ARGILLIC ALTERATION, KOOTENAY BELLE MINE

A large zone of altered and brecciated rock and of clay-like detritus has been encountered in underground workings of the Kootenay Belle mine (*see* Fig. 7). The zone has a known vertical range of at least 800 feet, extending from 7 level to a point above 2 level. Its length from north to south exceeds 440 feet on 6 level, but it is not more than 360 feet nor less than 220 feet on 2 level. Its maximum known thickness, on 6 level, approaches 100 feet. The strike of this zone is north 5 to 10 degrees west, whereas the bedding here strikes about north 5 degrees east. The dip of the zone is more than 80 degrees to the east, except above 3 level where somewhat flatter dips prevail, and away from this highest part the dip of the altered zone is steeper than that of the overturned bedding. In the upper part of the mine the zone is entirely within the Upper Nugget quartzites, but at 6 level the alteration extends into argillaceous quartzite of the Lower Navada beds.

Two smaller bodies of similarly altered rock occur in the Kootenay Belle mine, one at the junction of 2 level crosscut with B vein, the other 100 to 140 feet to the west of this junction. Both are within the Upper Nugget quartzite. The former body may conceivably be a part of the main zone, although it is off the line of its average strike; the latter body is clearly separate.

The reason for localization of the alteration is obscure. If the argillic alteration is concentrated along a belt of shattering and faulting, this belt terminates abruptly to the north, south, and above with no signs of movement extending into unaltered quartzites.

The alteration where relatively weak, as along the margins of the zone, has rendered the quartzite somewhat friable and locally has produced sooty deposits of iron oxide along joint planes. Closer to the centre of the zone the rocks are intensely altered, and in one place quartz porphyry has been rendered so soft that a pick can be driven an inch into it with a single blow. In many places the altered rocks are clearly undisturbed, but elsewhere they consist of a coarse breccia of jostled quartzite blocks whose bedding planes lie at random attitudes. The centre of the zone on 6 level is marked by a breccia composed of assorted friable rock fragments, a few inches to a few feet in diameter, embedded in a clay-like matrix, the whole so soft that it can be readily cut with a knife. Most of the fragments appear to represent original quartzite blocks, but some, marked by brown to black parallel bands, have probably been derived from the distinctly bedded argillaceous rocks of the Navada member. The matrix of the breccia is locally banded, and dark fine-grained banded layers may be interstratified with masses of lighter-coloured breccia. The dip of this banding is highly variable, but moderate to high dips are most common. There is a tendency for the bands to dip away from the walls of the zone.

Changes brought about as a result of incomplete argillic alteration are shown by chemical analyses of samples (*see* Table III, analyses 2 and 3, p. 27) from a single quartz porphyry sill occurring in 6 level west. Sample 2 is of fresh quartz porphyry 70 feet west of the main crosscut, and sample 3 is of partly altered quartz porphyry 40 feet west of the crosscut. The initial composition of the quartz porphyry at both points must have been nearly identical. As a result of the incomplete argillic alteration, significant amounts of water have been added to the rock, the greater part of the original soda has been removed, and much of the iron has been converted to the ferric state. Assuming negligible change in mass as a result of alteration, small amounts of potash and alumina have been added to the rock and a small amount of silica has been removed. Microscopic examination of the partly altered quartz porphyry indicates the presence of some quartz and a great deal of a clay-like mineral of uncertain identity.

Completely argillized sediments from the centre of the zone on 6 level consist almost entirely of minute flakes of a micaceous mineral, probably muscovite, together with smaller amounts of iron oxides. Quartz is notably absent in this material, notwithstanding its abundance in the unaltered rock. No trace of this mineral was found by careful microscopic examination, and no gritty particles exist in the argillized material to suggest its presence.

A small volume change as a result of the alteration is indicated. Had appreciable expansion taken place, the Navada-Nugget contact, which is crossed obliquely by the zone of alteration, would have been noticeably offset. The apparent absence of such an offset (*see* Fig. 8) testifies against any great increase in volume. A small decrease in volume would not necessarily lead to movement in the walls of the zone and hence to an offset in the Navada-Nugget contact. Instead the material making up the zone might contract and slump downward during the course of alteration, leaving an open space above. That this may have taken place is suggested by the brecciation and jostling within the zone and by the tendency for banding in the breccia to dip toward the centre of the zone where the alteration and volume decrease would be greatest. Open space now exists at the upper end of the altered zone at and above 2 level near B vein. About 20 feet above the 2 level crosscut the dip of the zone becomes less than 35 degrees, so low in fact that loose blocks now lying within it do not slide down into the crosscut. Although some material was almost certainly removed from the altered zone during the early mining activities, it is questionable whether the entire opening, and particularly the upper part with its gently dipping floor, was created at that time. However, the amount of open space that may have existed here prior to mining would be a very minor fraction of the volume of the argillized zone, and any volume decrease would necessarily have been small.

The major changes in the zone of argillic alteration, as indicated by mineralogical studies and chemical analyses, have been the development of micaceous or clay minerals at the expense of quartz and feldspar. Removal of silica alone would not account for the observed relationships as the change from quartzite to a residual clay would involve a very large volume decrease. Introduction of alumina and potash, sufficient for the conversion of all the quartz to mica or clay minerals, would lead to a volume increase of about 2:1, and it is almost certain that such an increase would have been detected. Only a combination of the two processes, it seems, can account for the small volume changes indicated. The changes are similar to those adjoining the tungsten-bearing veins of Boulder County, Colorado, described by Lovering (1941, pp. 229–279), but are more complete and affect a much greater volume of rock. Lovering attributes removal of silica to early acid solutions, and sericitization to later alkaline solutions. Similar solutions may have been active within the argillized zone of the Kootenay Belle mine.

The relationship between the veins and the zone of alteration is generally concealed. In a few places, however, the relationships can be observed, and in each instance the vein fracture on approaching the zone swings sharply to the left into the bedding planes of the altered quartzites. On the opposite side of the zone a second fracture, *en échelon* with the first, swings out of the bedding plane and bends sharply to the right into the unaltered rocks. The two fractures on opposite sides of the altered zone are almost in line with one another. This consistent relationship of vein fracture to zone of alteration indicates that a belt of incompetent rocks existed prior to vein faulting, although whether such incompetency in quartzites was caused by brecciation or by alteration is uncertain. The argillic alteration in the post-vein quartz porphyry of 6 level west shows, however, that at least part of the alteration took place after movement along the northeasterly trending vein fractures was complete.

A small zone of alteration, like that in the Kootenay Belle mine, occurs in the Fawn 5 level crosscut in argillaceous beds of the Laib group, but no breccia is exposed at the latter locality. No similar alteration has been observed elsewhere in the camp.

CHAPTER IV.—VEINS AND MINERALIZATION

SOURCES OF INFORMATION

When the study of the ore deposits of the camp was undertaken, nearly all the ore had been extracted from the parts of the veins so far developed. Isolated pillars and low-grade or narrow parts of the veins remained, but they scarcely provide adequate and representative samples of the material that has constituted ore. Mine records of vein widths and grades have, however, yielded valuable data on the characteristics of the ore-bodies and to their changes with depth. A general relationship between productivity of different parts of the veins and the adjoining wallrocks is, moreover, readily apparent from a study of the mine workings. A study by M. C. Robinson (unpublished M.Sc. thesis, Queen's University) of fifty-four polished sections constitutes the principal source of information on the relationships of the vein minerals. Further information has been sought in special studies of ore specimens by the writer, by Dr. F. G. Smith and A. D. Mutch of the University of Toronto, and by M. C. Robinson and J. A. Gower.

GENERAL DESCRIPTION

The gold deposits of the Sheep Creek camp consist essentially of quartz veins containing as a rule minor amounts of sulphides. Pyrite is the most abundant sulphide; galena and sphalerite are present, but as a rule it is only where the veins cut limestone that these two minerals occur in commercial quantities. Nearly all the production of gold has been from those parts of the veins where one or both walls consist of quartzite of either the Nugget or the Navada members of the Quartzite Range formation. Vein fractures cutting argillite are generally devoid of quartz* or are occupied by only a thin band of barren vein matter. The extent of the productive part of any vein along the vein is, therefore, limited by the distribution of the favourable quartzite in its walls. Within the favourable quartzites, oreshoots make up varying proportions of the veins. The upper limit of orebodies is most commonly the ground surface, or in the Western anticline the crest of the quartzite beds, but in places in the southern part of the camp, even within a single type of rock, veins become narrower upward to the point that they cannot be mined economically. In general, vein widths do not diminish downward; on the contrary, vein widths are average or greater than average on the lowest levels of most mines. However, high-grade ore occurs less abundantly in the lower levels, and the proportion of the vein that could be mined profitably diminishes. On the lowest levels on which several veins have been explored no ore was found, or the proportion of ore to submarginal parts of the vein was such that no net profit resulted from exploring and mining the veins on those levels. In the veins that have been explored, oreshoots have been found within a vertical range that is not more than 1,600 feet for any vein. This productive range is found at elevations that from north to south are progressively lower.

PRODUCTION

The year by year production of the Sheep Creek camp and the production attributed to individual veins are set forth in Tables VI and VII, pages 51 and 52.

The total recorded production from 1899 to 1951, inclusive, amounts to 736,015 ounces of gold and 364,793 ounces of silver, from 1,721,580 tons of ore. Lead amounting to 377,568 pounds and zinc amounting to 312,633 pounds were contained in crude ore, gravity concentrates, and flotation concentrates shipped to the smelter. Recovery of lead and zinc was recorded from 188,000 tons of ore, and lead alone from a further 18,000 tons. These figures indicate an average of approximately 2 pounds of lead, and

* Lenses of quartz paralleling the bedding in the wallrocks are relatively common in the more argillaceous strata but not in the quartzites. For completeness it may be noted that these lenses have not been productive and their presence has been revealed only by occasional intersections in the mine workings.

slightly less zinc per ton of ore. In the 1,500,000 tons of ore for which the returns do not indicate any lead or zinc content, it is unlikely that the content of either averaged as much as 2 pounds per ton.

The production of each of thirty-two individual veins is set out in Table VII. Company estimates of tonnages and average grades of ore extracted from various stopes and veins are the sources of information on the production for the veins of the Sheep Creek, Reno, and Gold Belt mines. McGuire (1942) quotes production figures for the individual Kootenay Belle veins for the period March 31st, 1934, to September 1st, 1941, but records are not available prior to or since that time other than for the total production of the mine.

Table VI—Recorded Production, Sheep Creek Camp

Year	Motherlode, Nugget, Reno		Queen and Sheep Creek		Kootenay Belle		Gold Belt		Total Production of Camp	
	Ore Milled or Shipped	Gold	Ore Milled or Shipped	Gold	Ore Milled or Shipped	Gold	Ore Milled or Shipped	Gold	Ore Milled or Shipped	Gold
	Tons	Oz.	Tons	Oz.	Tons	Oz.	Tons	Oz.	Tons	Oz.
1900–01[1]	....	....	....	....	....	....	....	....	16,988	5,421
1902–03[1]	....	....	4,663	2,658	....	....	....	....	4,663	2,842
1904–05	....	....	10,924	4,773	415	1,252	....	....	11,339	6,025
1906–07[1]	141	696	15,875	7,512	1,364	1,515	....	....	17,485	9,912
1908–09[1]	7,148	9,326	20,086	11,543	3,148	1,947	....	....	30,456	22,935
1910–11[1]	8,964	7,177	26,709	14,372	31	236	....	....	35,857	22,337
1912–13[1]	42,041	23,924	18,474	6,095	....	....	....	....	60,503	30,164
1914–15[1]	22,892	10,273	19,350	10,608	....	....	....	....	42,446	21,125
1916–17	....	....	2,060	860	....	....	....	....	2,060	860
1918–19[1]	....	....	56	8	....	....	....	....	93	18
1920–21	15,577	4,873	....	....	....	....	....	....	15,577	4,873
1922–23	5,645	2,293	....	....	28	170	....	....	5,673	2,463
1924–25[1]	....	....	....	....	....	....	....	....	4	15
1926–27	....	....	27	65	149	380	....	....	176	445
1928–29	2,008	1,807	1,756	229	282	538	....	....	4,046	2,574
1930–31	21,614	17,530	....	....	....	....	....	....	21,614	17,530
1932–33[1]	24,055	14,861	1,850	150	915	1,308	....	....	27,102	16,953
1934–35[1]	66,812	37,507	28,197	9,081	17,924	7,374	318	640	113,255	54,606
1936–37[1]	88,729	50,895	109,216	40,417	63,464	12,822	....	....	163,327	115,757
1938–39[1]	66,538	28,410	109,286	53,647	100,904	38,154	67,682	21,006	344,792	142,672
1940–41[1]	52,016	18,535	110,129	52,312	73,481	22,427	118,868	32,759	354,408	126,041
1942–43	1,949	2,062	85,680	35,572	28,760	10,293	70,145	25,404	186,534	74,331
1944–45	1,713	585	37,688	14,855	248	107	1	14	39,650	15,561
1946–47	1,303	685	48,029	13,924	564	148	....	....	49,895	14,857
1948–49	362	184	53,424	19,126	748	652	154	45	54,688	20,019
1950–51	110	97	15,846	5,203	468	261	170	116	16,594	5,677

SUMMARY

	Ore	Gold	Silver	Lead	Zinc
	Tons	Oz.	Oz.	Lb.	Lb.
Columbia, 1932, 1933	42	31	46	....	....
Fawn, 1915, 1935	74	131	13	....	....
Gold Belt	257,338	79,984	32,761	....	....
Kootenay Belle	292,893	109,937	37,153	....	....
Motherlode, Nugget, Reno[2]	429,667	231,932	184,502	....	....
Ore Hill, 1906, 1914–15, 1918, 1936–38, 1940	3,669	2,849	5,415	186,940	166,784
Queen and Sheep Creek[3]	719,320	303,711	100,182	....	....
Sumit, 1906, 1908, 1910–11, 1914, 1924, 1938	1,205	870	1,218	30,264	28,634
Vancouver, 1909, 1911–13, 1932–33	383	964	412	....	....
Yellowstone, 1900–02	16,989	5,606	3,091	....	....
Totals	1,721,580	736,015	364,793	377,568[4]	312,633[4]

[1] Total for year includes any production from the Columbia, Fawn, Ore Hill, Sumit, Vancouver, and Yellowstone.

[2] From 1906 to 1922 production was from the Motherlode and Nugget veins; from 1928 to 1938 production was mainly from the Reno vein; thereafter it includes production from Nugget, Motherlode, Bluestone, and Reno veins.

[3] From 1900 to 1938 production was from the Queen vein; thereafter it includes production from other veins mined by Sheep Creek Gold Mines Limited (*see* Table VII).

[4] The lead and zinc totals include lead, 143,033 pounds, and zinc, 92,625 pounds, recorded as recovered from 155,625 tons of ore from the Reno mine and minor quantities from Kootenay Belle, Sheep Creek, and the Nugget-Motherlode.

The figures in Table VII representing the production from individual veins are based mainly on records of company sampling of stopes and of ore sent to mills, and generally are somewhat higher than the figures for the mines. The latter figures (Table VI) account for metal in bullion and in ore shipped.

TABLE VII.—PRODUCTION FROM INDIVIDUAL VEINS

Vein	Company[4]	Tonnage Mined to Dec. 31, 1950	Ounces of Gold Produced to Dec. 31, 1950
Western Anticline			
Sumit		1,500	875
Ore Hill[1]	Sheep Creek Gold Mines Ltd.	3,500	2,850
57	Sheep Creek Gold Mines Ltd.	15,500	5,275
64	Sheep Creek Gold Mines Ltd.	2,000	700
68	Sheep Creek Gold Mines Ltd.	16,000	5,450
75	Sheep Creek Gold Mines Ltd.	30,500	12,725
76	Sheep Creek Gold Mines Ltd.	6,500	1,700
81	Sheep Creek Gold Mines Ltd.	167,500	80,700
83	Sheep Creek Gold Mines Ltd.	56,000	19,850
85	Sheep Creek Gold Mines Ltd.	6,000	1,575
92	Sheep Creek Gold Mines Ltd.	180,500	86,275
Queen[1]	Sheep Creek Gold Mines Ltd.	234,500	93,725
Yellowstone[1]	Sheep Creek Gold Mines Ltd.	17,000	5,600
Dixie-6600	Gold Belt Mining Co. Ltd. and Kootenay Belle Gold Mines Ltd.	33,500	11,725
8000	Gold Belt Mining Co. Ltd.	59,500	17,075
8200-Columbia[2]	Gold Belt Mining Co. Ltd.	41,000	10,050
2360	Gold Belt Mining Co. Ltd.	47,000	11,900
2590	Gold Belt Mining Co. Ltd.	150	60
3040	Gold Belt Mining Co. Ltd.	18,000	6,650
3050	Gold Belt Mining Co. Ltd.	300	650
3500	Gold Belt Mining Co. Ltd.	47,000	18,625
3900	Gold Belt Mining Co. Ltd.	17,500	5,175
Bluestone	Reno Gold Mines Ltd.	3,500	1,300
Reno	Reno Gold Mines Ltd.	261,500	146,725
Totals		1,265,950	547,235
Eastern Anticline			
Bonanza	Sheep Creek Gold Mines Ltd.	*Nil*	*Nil*
Alexandra	Sheep Creek Gold Mines Ltd.	3,000	540
Vancouver	Sheep Creek Gold Mines Ltd.	350	960
Black	Kootenay Belle Gold Mines Ltd.	45,000	15,475
B	Kootenay Belle Gold Mines Ltd.	32,000	9,150
A	Kootenay Belle Gold Mines Ltd.	204,000	84,300
Motherlode[3]	Reno Gold Mines Ltd.	108,000	51,475
Nugget[3]	Reno Gold Mines Ltd.	57,500	32,250
Fawn		75	130
Totals		449,925	194,280
Grand totals		1,715,875	741,515

[1] Includes production prior to ownership by the Sheep Creek Gold Mines Limited.
[2] Includes production prior to ownership by the Gold Belt Mining Company Limited.
[3] Includes production prior to ownership by the Reno Gold Mines Limited.
[4] *See* p. 75 for present ownership.

DIVIDENDS

Dividends paid from the profits of gold mines in Sheep Creek to the end of 1946 total more than $5,400,000. This sum includes $98,674 from the operations of the Queen mine 1902–07, $2,403 royalty from the Kootenay Belle in 1906, and $163,500 from the operation of the Motherlode, 1907 and 1915–16. Dividends paid in the period 1935 to 1946 amounted to $5,215,000 and include dividends paid by companies as follows: Gold Belt Mining Company Limited, 1940–42 and 1944, $668,595; Kootenay Belle Gold Mines Limited, 1938–41, $347,856; Reno Gold Mines Limited, 1935–39, 1942 and 1943, $1,433,640; Sheep Creek Gold Mines Limited, 1936–46, $2,765,625. Dividends paid by the Gold Belt (1944) and the Reno (1942 and 1943) companies include return of capital. The Sheep Creek Company has paid dividends since 1946, but it is considered that the payments to the end of 1946 fairly represent the dividends ascribable to operations of the company's gold mine on Sheep Creek. However, it should be noted that the revenue from which subsequent dividends were paid resulted from investing in other mines of money derived from the operation of the company's gold mine.

VEINS IN QUARTZITE

VEIN QUARTZ

Typical vein quartz is milky white and may or may not be banded parallel to the walls. Generally, but not invariably, the quartz can be distinguished from the adjoining quartzite by colour alone. Its coarse texture, its brittleness under the blows of a hammer, its own pattern of fractures, and its banding where developed, all serve to distinguish it from the wallrocks. Commonly the outlines of crystals are made apparent on broken surfaces of quartz by obscure cleavage planes that evidently are limited to individual crystals. The crystals are characteristically irregular, equidimensional to slightly elongated but with their length rarely more than twice their breadth. Elongation of the crystals, if developed, tends to be perpendicular to the vein walls. Locally crystals exceed 1 centimetre in length, but more commonly their size is measurable in millimetres or tenths of millimetres. In thin section the fabric is more clearly displayed. Crystals are commonly interlocking, in places with finely sutured boundaries like those of some particularly intricate jig-saw puzzle. The teeth of the sutures are not oriented in any one direction, as they would be had they been formed (as stylolites are believed to be) by solution of the quartz while it was being stressed under directed pressure. Most of the quartz grains in any one thin section are the same general size, but ill-defined bands generally a fraction of a millimetre across may be much finer grained. Although such bands may have been formed by cataclasis,* they do not exhibit the characteristic strain shadows and sutured boundaries. Indeed, except for some of the largest grains, very little of the quartz shows pronounced strain shadows. A preferred orientation of intermediate-sized grains in the vicinity of these large ones has probably resulted from the breaking-down of large individuals. Elsewhere preferred orientation is not conspicuous.

The contact between vein quartz and one of its walls is as a rule sharply defined by a fault surface; but the contact between quartz and quartzite of the opposite wall may be gradational across inches or even feet. In some instances solid vein quartz grades outward into a network of narrow white veinlets cutting darker siliceous rock and thence into quartzite in which the white veinlets are scarce or absent. In other places homogeneous white quartz merges almost imperceptibly with massive grey or white quartzite. Parallel mica-rich or clay-rich bands cutting through a light-grey or white siliceous rock apparently mark argillaceous beds and in many instances can be traced into unaltered argillite. Some off-white siliceous rock between the walls of the vein is seen under the miscroscope to contain more or less uniformly distributed flakes of muscovite having a strong parallel orientation. Sharply defined white veinlets of quartz cut across the micaceous bands and the off-white quartzite. The filling of these veinlets is regarded as introduced quartz, although it is not clear whether it is (1) hydrothermal quartz from some distant source, (2) dissolved from near-by quartzite and precipitated along minute fractures, or (3) quartzite recrystallized in place along the walls of such fractures. The off-white siliceous quartzite with the flakes of mica is regarded as quartzite from which some of the darker constituents have been removed in solution. The white or pale siliceous rock through which the mica or clay-rich layers can be traced is also considered to be recrystallized quartzite even though its light colour, its coarse texture, and its mineralization indicate that it is now part of the vein itself.

Vugs and comb structure are rarely seen in the veins. A few of the large elongated grains of quartz, which commonly are strained or broken, have a suggestion of crystal outline, and it is possible that comb structure once present has been partly obscured by later deformation. Some of the small irregular masses of pyrite apparently occupy

* White, W. H. (1943), pp. 518–520.

former vugs, and in the oxidized parts of the veins, where the pyrite has been leached away, vuggy iron-stained cavities are revealed; but even in these oxidized parts such crystal-lined cavities are not abundant. It would seem that only a small proportion of the vein matter, a fraction of a per cent to a few per cent, has developed by the growth of quartz crystals in open space. In some branch veinlets, on the other hand, vugs and comb structure are common, and it would seem that these veinlets, rarely more than an inch wide, were formed in large part by crystallization in the open.

The proportions of vein quartz developed by growth in open space, by growth under confinement, and by recrystallization of siliceous wallrocks are difficult to assess. As noted above, the amount of quartz grown in open space seems to be relatively small. Judging from the wide zones of quartz, particularly in branching parts of the veins, through which relic argillaceous beds can be traced, a high proportion of the vein in certain places has developed by recrystallization of quartzite. It should not be inferred that all the vein matter devoid of vugs and comb structure developed in this way. Some quartz, lacking vugs and crystal faces, occurs between walls of relatively unaltered argillite, and it is improbable that this quartz developed by removal of every constituent but the silica from the pre-existing wallrock. Probably such quartz was introduced in solution and precipitated in fractures that were so constricted that no crystal faces could develop. In the absence of such criteria as relic bedding, however, no satisfactory method of distinguishing introduced quartz from quartz formed by recrystallization in place is known.

Mineralization

Mineralization is largely confined to the vein quartz bounded on one or both sides by quartzite. Pyrite may occur in typical quartzite, but beyond the limits of the typical vein quartz its gold content is reported to be negligible. Physical rather than chemical differences between the quartz and quartzite seem to be responsible for the localization of mineralization. Relatively great stress is probably necessary to deform quartzite, and under deformation it apparently yields either by bending or by movement along discrete, relatively widely spaced joints. Vein quartz, on the other hand, is a brittle rock which breaks under stress along a myriad of closely spaced fractures favourable for the infiltration of mineralizing solutions. Where quartz and quartzite occur together, deformation is likely to be concentrated, if not confined, in the vein quartz. Where quartz and argillite occur together, deformation seems more likely to be concentrated along the contact between the two rocks, and the vein quartz may be so slightly fractured as to be unfavourable for mineralization.

The minerals found in the veins consist principally of the sulphides pyrite, galena, and sphalerite. Other minerals known to occur in minor amounts in the veins are calcite, sericite, scheelite, wolframite, chalcopyrite, arsenopyrite, marcasite, tetrahedrite, ruby silver, and gold. Such supergene minerals as limonite, malachite, anglesite, smithsonite, and tungstite are known to occur in minor amounts in the upper parts of several of the veins. Spectrographic analysis of some of the ore minerals indicates that the sphalerite commonly contains as much as 0.1 per cent indium and is locally associated with still greater amounts of this element.

Sulphides occur in the veins in four ways: as long streaks as much as several inches wide, paralleling the walls; in small fractures cutting obliquely across the vein; in more or less irregular masses rarely more than an inch across; or as individual crystals disseminated through the quartz. Pyrite may occur in any of these forms, but is most common in streaks and disseminations. Galena and sphalerite are commonly localized along oblique intersecting fractures that may be concentrated in one or more bands within the vein. Although pyrite and, less commonly, pyrrhotite or sphalerite may form nearly pure streaks, the combined sulphides rarely make up more than 10 to 20 per cent of the full width of the vein. Only locally do galena and sphalerite together make up more than a few per cent of the vein matter, and as a general rule they constitute from a fraction of a pound to a few pounds per ton of the ore.

The sequence of mineralization as established by M. C. Robinson* is as follows:—

(*a*) Introduction of quartz and scheelite.

(*b*) Shearing and fracturing of early vein filling.

(*c*) Introduction of sulphides, late quartz, and calcite.

The vein minerals were introduced in four stages:—

(1) Quartz, pyrite, and arsenopyrite.

(2) Pyrrhotite, sphalerite, and chalcopyrite.

(3) Galena, tetrahedrite, and ruby silver.

(4) Gold.

Robinson adds that "With the possible exception of pyrite and pyrrhotite, the periods of deposition of minerals of any one of the above stages do not overlap those of minerals of other stages."

The gold occurs as isolated particles, generally from a few microns to about 30 microns across. Particles of gold sufficiently coarse to be seen with the naked eye are rare. About one-third of the gold, according to Robinson, occurs within quartz, generally along boundaries between quartz grains. The rest of the gold occurs with sulphides, notably along quartz-pyrite contacts or, less commonly, along contacts between quartz and sphalerite, pyrite and sphalerite, or sphalerite and galena. A few grains have been seen completely enclosed in pyrite or in galena. A widely accepted generalization in the camp is that the parts of the vein relatively rich in galena and sphalerite are rich in gold. Although the gold is in the vicinity of these two sulphide minerals, it is not necessarily in contact with them.

Oxidation

Complete oxidation of the primary minerals has taken place to depths of a few hundred feet in several of the veins, notably the Reno, Nugget, Motherlode, and the A and B veins of the Kootenay Belle mine. The veins of the Western anticline, with the exception of the Reno, have undergone very little oxidation except at their outcrops. Many of these veins are sealed off from descending waters by a hood of argillites. Others were similarly protected until recent down-cutting by Sheep Creek and its tributaries in the latest erosion cycle breached the cover of Reno beds. The Reno vein, on the other hand, outcrops at a surface formed in an earlier erosion cycle and has thus been exposed to the influence of meteoric waters for a long period. The same is true of the Nugget vein in the Eastern anticline. The Motherlode and Kootenay Belle veins now outcrop on the relatively youthful slope of Sheep Creek valley, but conceivably they extended in the near past without interruption up to the erosion surface produced in the next to last erosion cycle, and certainly they have not recently been protected by any hood of argillites. Although sulphide-bearing ores occur in the Nugget mine at intermediate levels, some oxidation and leaching have been observed on 9 level, more than 1,300 feet from the nearest point on the present surface and about 1,500 feet from the outcrop of the vein directly above.

Although the oxidation has led to the removal of the sulphides from the vein, it may have had little or no effect on the gold values. Assay plans of the Reno mine show no significant change in the average grade of the vein that can be related to the lower limit of complete oxidation. Gold sufficiently coarse to be visible to the naked eye seems to have been more abundant in the upper oxidized part of this vein, but this may have been a characteristic of primary mineralization. Ore mined from the Nugget vein from 1907 to 1912 and from the Motherlode vein from 1906 to 1915 was almost completely oxidized, and mining activity on the latter vein ceased when about the last of the oxidized ore was stoped. It should not be assumed that decline in grades of ore at the lower limit of general oxidation was responsible for cessation of these operations. The cost of driving long low-level crosscuts to intersect the veins at greater depth discouraged further development at that time, and problems of milling sulphide ores may have contributed to the

* Robinson, M. C., unpublished M.Sc. thesis, Queen's University, 1949.

shut-down. A decrease is recorded in the grade of ore produced from the upper levels of the Kootenay Belle mine in the period from 1904 to 1909 from more than 2 ounces of gold per ton at the start of operations to less than 0.8 toward the end. This need not be interpreted as a decline in grade of ore at successively greater depths, for the initial production of this mine was entirely shipping ore and the later production was milling ore. Actual decline in grade with depth need not be attributed to the effects of supergene enrichment, for an erratic but general tendency for the gold content of ore to decrease with depth is noted many hundreds of feet below the surface, within the zone of primary mineralization.

Vein Widths

The widths of the veins in quartzite commonly range from zero to several feet. Many of the veins attain widths of 4 to 6 feet locally, but few of the veins commonly have such widths. The Queen vein, within the Western anticline, is notable for its width, commonly being more than 6 feet wide and locally much wider.* Other veins are persistently narrow; the Black vein, for example, is less than 1 foot wide for more than half its stoped extent and reaches a maximum known width of between 5 and 6 feet in only one part of the Kootenay Belle mine. Greater than average widths tend to occur (1) within the more favourable stratigraphic units, (2) where the vein fracture trends more nearly east than usual, (3) between the forks of a branching fracture, (4) where fault movement along the vein fracture is greater than average, and (5) in the lower parts of the veins.

The influence of wallrocks on the development of vein matter has already been noted.† Apparently because of appropriate composition and physical characteristics the Upper Nugget quartzite was the most favourable wallrock for the development of wide parts in the veins. Middle Nugget and Upper Navada beds are somewhat less favourable than the Upper Nugget quartzite, and Lower Navada and Upper Motherlode beds contain vein matter only locally. The Reno beds have yielded significant quantities of ore only in the Reno mine where the rocks of this formation were locally metamorphosed, apparently prior to vein genesis, to a spotted schist approaching in its competency that of the near-by quartzites.

The variations in strike of the vein fracture were very important in determining the width of vein quartz that was formed. Development of actual open space along the section of the vein fracture that strikes more nearly east than average as a result of right-hand fault movement has been generally considered to be the explanation of this relationship. Petrographic studies indicate, however, that relatively little quartz has been developed as open-space filling. A reduction in pressure across these parts of the vein fracture as a result of the fault movements may have rendered these parts more permeable to solutions, and adjoining walls may have been subjected to more recrystallization. Growth of introduced quartz during movement may also have led to development of a vein-filling without the presence of extensive open space at any time.

The distinction between influence of wallrock and influence of attitude is difficult to make, as the vein fracture tends to strike more nearly east in the more favourable wallrocks. However, the fact that the 92 vein in the Upper Nugget beds of the western limb of the Western anticline strikes about north 75 degrees east and has yielded much more ore than the same vein in the same beds of the eastern limb of this fold where the fracture strikes about north 60 degrees east shows, however, that attitude by itself may be an important control of ore deposition. That it is not the only control is, on the other hand, shown by the absence of ore in the Queen vein fracture within the Reno beds of 3 level west where the attitude of the vein is almost the same as that of its productive parts in the adjoining Navada and Nugget beds.

* The Queen vein is reported to be as much as 16 feet wide, and some of the old stopes on it are said to be as much as 25 feet wide. It is probable that the latter width includes two or more parallel veins separated by barren or sparsely mineralized quartzite.

† *See* pp. 50, 54, and notes on formations in Chapter III.

Between the forks of a branching fracture, vein quartz tends to be wider than in adjoining parts of the same vein. The quartz in such a locality seems to be largely, if not wholly, formed by the recrystallization of pre-existing quartzite, and such vein matter may or may not be as favourable for mineralization as introduced quartz in other parts of the vein. Quartz at the junction of the Kootenay Belle A and B veins is, as a rule, both slightly wider and slightly richer than in the adjoining parts of the vein. No examples are known, however, of oreshoots being restricted to the junction of two vein fractures.

A relationship between displacement on the vein fracture and width of vein quartz is apparent in many places. Thus the western orebody in the Kootenay Belle A vein shows a distinct increase in width between 6 and 10 levels that coincides with an increase in net slip from a few feet at the former level to 40 feet at the latter (*see* Figs. 7 and 11). However, although the net slip increases more than five times, the average thickness of the vein scarcely doubles. The orebodies of this same vein in the Upper Nugget beds increase distinctly in average width from 2 to 3 levels as does the displacement along the vein fracture. Below 3 level the average thickness changes little, and the displacement is nearly constant. From these and less striking examples elsewhere it would seem that other things being equal the vein widths vary directly with the amount of displacement along the vein fracture though not necessarily in a simple proportion.

A general tendency for veins to decrease in average width upward, irrespective of change in displacement, is apparent in at least the upper parts of some of the veins. Above a particular level the vein may be so narrow that mining is not profitable. Stopes above the 2 level on the 83 vein of the Sheep Creek mine were abandoned because the vein narrows at an altitude of about 3,750 feet, even though displacement along vein fracture increases upward and favourable quartzites extend for 350 feet higher. Decreasing widths of ore led to abandonment of stopes on the 81, 75, and 68 veins at approximate altitudes of 3,700 feet, 3,400 feet, and 3,200 feet respectively, although here, too, favourable quartzites extend to considerably higher levels. In the Kootenay Belle mine the veins pinch upward, and the Black vein was too narrow in the upper levels to be mined to the surface. It is probable that other veins of the Eastern anticline also pinched upward within the quartzite.

The pinching upward of the 75 vein cannot be explained by a change in displacement along the vein fracture. Movement has been greatest in the upper levels on this vein and might be expected, by itself, to lead to an upward increase in width. On the other hand, a change in the strike of this and other vein fractures might provide one explanation for the upward decrease in width. The tendency for the vein fractures to strike more nearly east at depth than at upper levels (*see* p. 40) might account for a gradual increase in width with depth, but scarcely serves to account for the relatively abrupt changes in the veins noted above.

Branching Veins

Branching veins in which one or both branches contain ore are known at various places in the camp. More important branching veins include the Kootenay Belle A and B veins, both of which contain ore, and the Nugget and Calhoun veins, of which only the former has yielded ore. The displacement along the branching veins may be distributed about equally in each branch, or nearly all may be concentrated in one of the branches. In general the branch with the greater movement is the more continuous and the one more likely to contain ore. Where both branches have approximately the same amount of movement, the right-hand branch strikes more nearly east and is considered the more favourable for the presence of ore. In some instances the one branch may have been followed and shown to be barren, but profitable ore may exist in the other branch perhaps only a few feet away in the wall of the drift. Such occurrences of ore in branch veins were found on 5 and 6 levels of the Reno vein, and on 7 level in the eastern part of the Queen vein. One branch of both veins proved to be generally unprofitable opposite the productive part of the other branch. The same has proved true for the 83 and 85 veins of the Sheep Creek mine and for the lower part of the eastern orebody in the Motherlode mine.

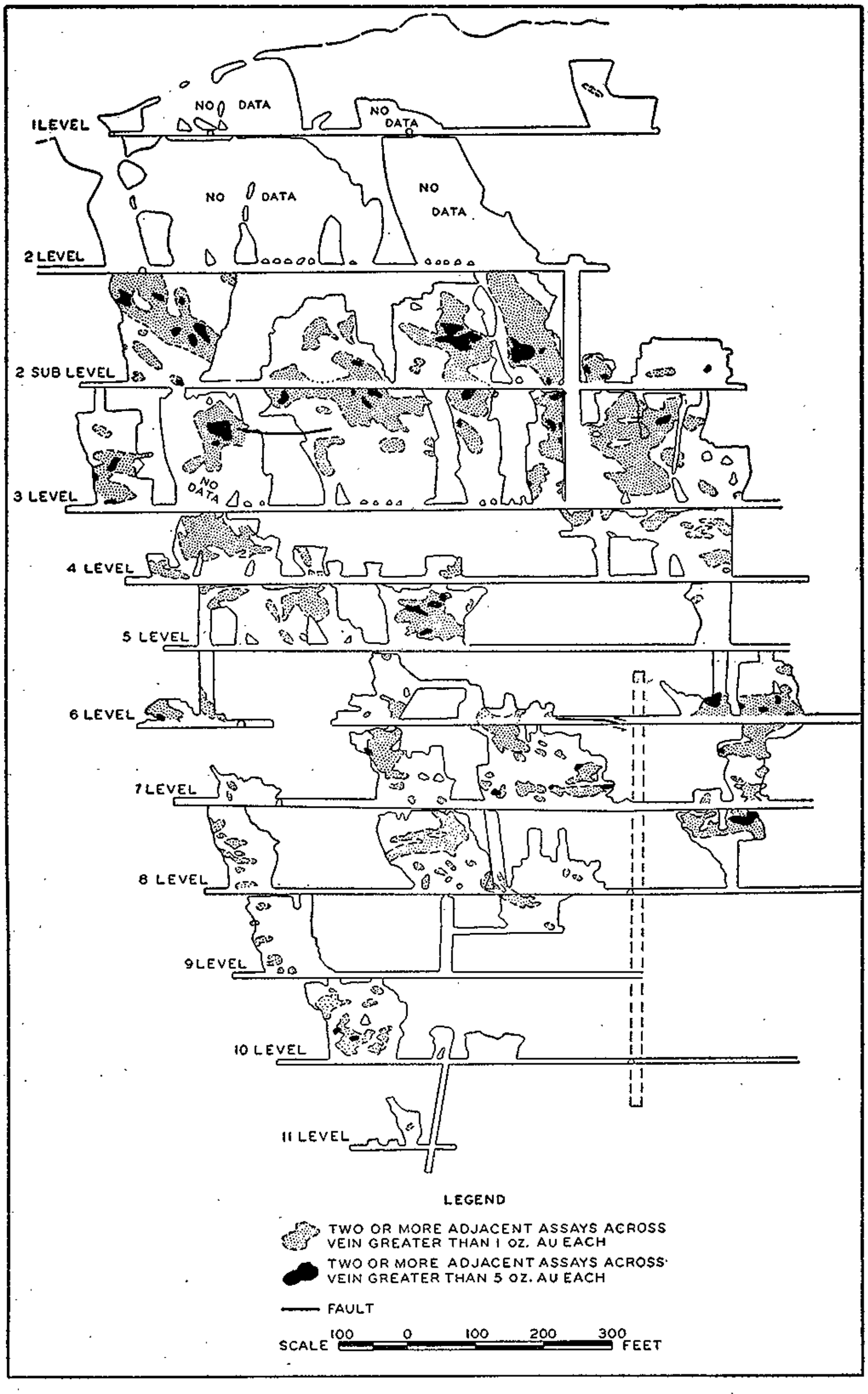

Figure 10. Longitudinal section of Kootenay Belle A vein showing distribution of gold values.

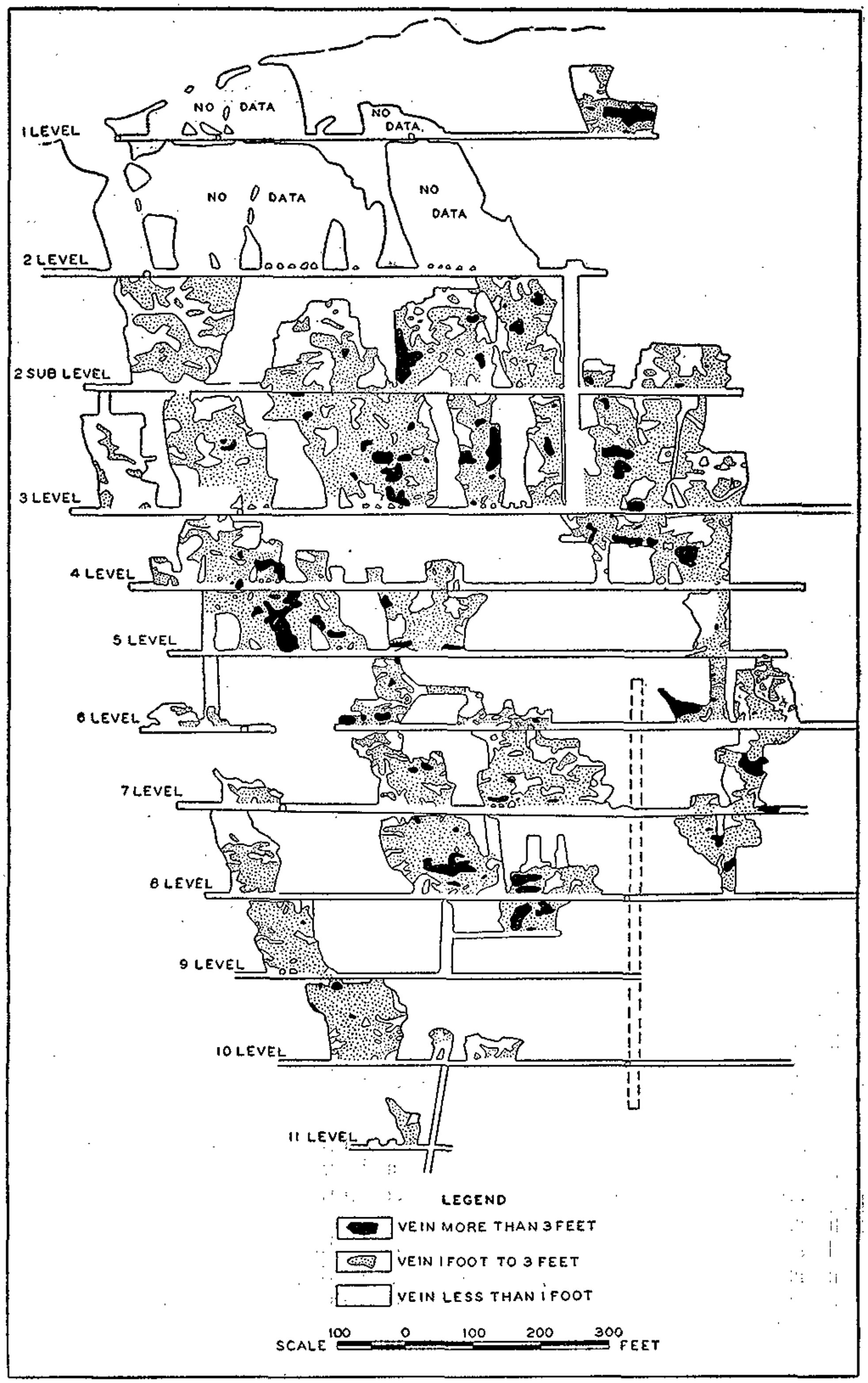

Figure 11. Longitudinal section of Kootenay Belle A vein showing variation of vein widths.

In other cases, however, oreshoots occur side by side in branching veins, as, for example, in the eastern part of the 75 and 76 veins of the Sheep Creek mine and in the A and B veins in the upper levels of the Kootenay Belle mine.

Mineral and Textural Changes with Depth

Changes in the veins with depth have been noted by various workers. Unfortunately, few of the changes could be observed in 1948 and 1949. McGuire (1942, p. 181) noted that some of the veins near the lower limit of oreshoots contained various hydrous, iron, lime, and aluminium silicates. Minor amounts of chlorite and of amphibole have been observed by the present writer in or close to the veins, but these minerals are not confined to the lower levels. Both chlorite and amphibole, for example, have been seen in thin section of vein material from 3 level in the Kootenay Belle mine. Changes in the character of mineralization with depth are widely recognized in several of the veins. A marked decrease with depth in the proportion of sulphides, notably of galena and sphalerite, and in the proportion of the vein that displays banding has been noted in both the Reno and Kootenay Belle veins, and similar changes are believed to occur in some of the veins of the Gold Belt mine. Geophysical studies of the vein minerals made at the University of Toronto using the pyrite geothermometer* and the decrepitation technique† did not indicate progressive changes with depth that could be used in identifying the levels from which any sample was derived.

Distribution of Ore

The characteristics of individual veins are by no means uniform. In some veins, such as the Queen, the width of vein quartz tends to be great throughout; in others, like the Black, only narrow widths of quartz are present in most parts of the vein. Some, like the Black, tend to be high in grade; others are persistently low in grade. Many vein fractures contain very little quartz, or quartz so sparsely mineralized that it does not constitute ore.

Distribution of Oreshoots within Veins.—Within the veins the ore occurs in shoots. Even the most productive veins, such as the Queen and Reno, had sections of considerable size that could not be mined profitably. In many of the veins, only about half the explored extent within favourable quartzite yielded ore, and in others only a very small fraction has been productive. The unprofitable parts of the veins are represented by nearly barren quartz that may be of average or more than average width, by a very thin band of quartz with or without mineralization, or in many places by a fracture devoid of vein matter.

The localization of oreshoots within a vein depends on a combination of factors that influence the width of vein-filling and the deposition of gold. No general statement can be offered to explain fully the localization of oreshoots in the veins of the Sheep Creek camp.

A special study was made of the distribution of gold within the Kootenay Belle A vein. Company data were used to prepare Figures 10 and 11, which show the distribution of gold and the vein widths within the stoped sections of the vein. Figure 10 indicates the distribution of patches containing an average of more than 5 ounces of gold per ton. These patches are irregular in outline and are as much as 30 feet in diameter. They seem to be distributed at random through lower-grade material. Locally the patches are elongated.

It is possible that day to day variations in discrimination between vein and wallrock by the sampler may introduce a pattern of assay results paralleling the backs of stopes as they were being developed. Nevertheless, the more irregular patches and those that plunge at moderate to high angles are believed to exist. Unfortunately, no wallrock structures have been observed that account for the distribution of the high-grade patches.

* Smith, 1947.
† Scott, 1948.

In places they coincide with narrower parts of the vein, in other places they coincide with the wider parts of the vein, and elsewhere they bear no relationship to vein width. A rather general decline in grade of the veins with depth is apparent notwithstanding the marked local variations. This decline is clearly indicated in many veins by production records as well as by assay sections. In the Kootenay Belle vein (*see* Fig. 10) patches of vein assaying more than 5 ounces of gold per ton are larger and more common in the higher part of the vein than at lower levels.

In the longitudinal sections of veins in the Sheep Creek camp it is apparent that stopes are within the limits of favourable stratigraphical units (*see* Figs. 3–8). The sections also suggest that within the favourable stratigraphic units the vertical distribution of oreshoots may have been subject to further control. Investigation of this possibility is extremely difficult because workings never expose a vein continuously throughout its vertical range and often expose very limited parts of the vertical range. Furthermore, the upper and lower margins of an oreshoot, if exposed, would probably be destroyed or obscured in the stoping operations, and finally the high cost of vertical workings limits the exploration of veins, particularly at depth. Because of the importance of the matter, the upper and lower terminations of oreshoots and the vertical ranges through which ore has been found are discussed in the following paragraphs.

Oreshoots that do not reach the ground surface may terminate upward (1) at the upper limit of quartzite, or (2) at various levels within the quartzite, by pinching to widths too narrow to mine profitably. These conditions are apparent in the Western anticline and presumably obtain in the Eastern anticline.

Pinching is characteristic of the more southerly veins of the Sheep Creek mine. Here the upper limit of ore is found at successively lower levels between the 92 vein on the north and 57 vein on the south (*see* Fig. 9). The southerly slope of this upper limit contrasts with the gentle northerly plunge of the fold axes between the same veins. From this fact may be drawn the inference that factors other than stratigraphic units have controlled the upper limit of ore in these veins, except that the upper margins of the stopes are below the Upper Nugget contact.

North of the Dixie vein, oreshoots terminated upward near the tops of the Nugget and Upper Navada in the Lower Navada and in the Reno formations. Except for the 8200 vein, the upper terminations of the oreshoots in the veins north of the Dixie are structurally controlled.

As mining progressed to deeper levels on the veins, it became apparent the various orebodies were being bottomed. In the Queen mine, between 2 and 7 levels, about 50 to 60 per cent of the length of the drifts within the limits of the Quartzite Range formation yielded ore; but east of the projected position of the Queen fault only 350 feet of 1,060 feet of vein exposed in the 8 level drift was stoped, only 65 feet of 770 feet of vein on 9 level, only 130 feet of 780 feet of vein on 10 level; and none of the veins was stoped along 440 feet of drift on 12 level. In the eastern part of the mine, therefore, the vein became subcommercial downward somewhere between 8 and 10 levels. West of the Queen fault a similar change was noted, but there the vein was subcommercial below 7 level, and drifts having lengths of 710 feet on 8 level, 140 feet on 10 level, and 520 feet on 12 level disclosed no part of the vein that could be stoped profitably. It had been demonstrated by more than 3,000 feet of drifting that oreshoots on the Queen vein had bottomed under operating conditions. It is interesting to note that the orebody east of the Queen fault bottomed between 100 and 300 feet below the one west of the fault. At the time of ore deposition, prior to this faulting, the lower limit of the western orebody was level with or slightly below the lower limit of the eastern orebody.

In the Reno mine more than 80 per cent of the length of the vein zone on levels down to No. 8 had yielded ore. Levels 9 and 11, representing more than 2,000 feet of drifting in the vein zone, showed that only 20 to 30 per cent constituted ore; and 12 level, explored for a length of 410 feet, produced no ore. On 10 level the vein zone was explored for a length of about 500 feet, in which a length of 250 feet was stoped. That was superior to the proportion of ore length to total explored length on 9 and 11 levels but was much inferior to the results obtained on the higher levels, both in the proportion of ore length to total explored length and in the actual length of ore. Thus exploration of all four of the lower levels showed much less ore than in higher levels.

Exploration on 10, 11, and 12 levels of the Motherlode mine, along the 750- to 800-foot length of vein within the Middle and Upper Nugget beds, yielded an aggregate stope length of 355 feet, 270 feet, and 50 feet in successively lower levels. At the same time, work on the lower levels of the Kootenay Belle mine on A vein demonstrated that only a relatively small proportion of this vein constituted commercial ore. A small amount of exploration on the Nugget vein disclosed no ore on 10 and 9 levels, but a stope 100 to 150 feet long was developed above 8 level. The levels at which the orebodies bottomed in these veins in the Eastern anticline lie not more than a few hundred feet above the lower limits of ore along the strike of the veins to the southwest in the Western anticline.

The distribution of oreshoots in the veins of the mines of the Sheep Creek camp is indicated in the longitudinal sections of several veins (*see* Figs. 3–8) and in the vertical sections along the two anticlines (*see* Fig. 9). If a surface is imagined running through or below the bottoms of the lowest known oreshoots in the different veins of the Western anticline, disregarding oreshoots that bottom considerable distances above it, the surface could be thought of as a plane that from the Reno vein as far south as the Queen vein slopes gently southward.

Exploration on the Yellowstone and 2360 veins below their known orebodies did not find additional orebodies at depths that are 500 feet and 300 feet respectively above the plane linking the bottoms of the orebodies in the Reno and Queen veins.

Exploration has been done as much as 250 feet below the bottoms of the lowest stopes on several veins, and the Queen vein (*see* Fig. 7) was explored at greater depths below the bottoms of oreshoots rich enough to repay the cost of exploration as well as of mining. However, it should be recognized that few veins have been explored exhaustively on the lower levels or explored at all at more than a limited depth below the lowest known oreshoots.

In the Eastern anticline the distance from north to south in which veins have been productive or have been explored is less than in the Western anticline. The bottoms of orebodies in the three main veins in the Eastern anticline were reached in 1940 to 1941, and work on the veins at lower levels was abandoned. However, it should be recognized that in the Nugget and Motherlode veins (*see* Figs. 4 and 5) non-productive intervals ranging from 300 to 450 feet occur between the bottom of one stope and the top of the one below it in the same formational unit.

The idea that the veins of the Sheep Creek camp may be productive only above a fairly regular limiting surface was conceived as an explanation for the disappointing results obtained in the lower drifts on several veins. No physical characteristics of the wallrocks or veins and no distinct changes in the character of mineralization have been recognized as marking the lower limit of ore. After the concept that veins were reaching their lower productive limit had gained acceptance, operators were reluctant to undertake further exploration on the lower levels or at greater depth. Figures 3 to 8 show the extent to which several of the veins have been explored in the various favourable formations. Veins remain strong on the lowest levels, but grades are low. However, as barren vertical intervals separate oreshoots in several veins, the development below known orebodies cannot be taken as proving that ore may not exist at still lower levels. The suspension of operations in the period 1937 to 1941 and in 1951 was caused by decline in grade of ore with depth, and by exhaustion of known ore, combined with rising costs. It must be concluded that beneath the bottoms of known oreshoots there are bodies of vein material that could constitute ore, at least under a markedly higher price for gold or markedly cheaper costs.

The greatest vertical range through which any vein has been stoped is 1,600 feet on the Kootenay Belle A vein. If the 3040 and C veins of the Gold Belt mine are parts of a single fissure, it has been stoped in the highest and lower parts of a vertical range of 1,590 feet. The Reno, Nugget, and Motherlode mines have had productive ranges of 1,490, 1,360, and 1,350 feet respectively. No other vein has yielded ore through a vertical range of more than 1,200 feet.

Distribution of Ore in the Camp.—The production from different veins varies markedly (*see* Table VII, p. 52). The greatest production has been obtained from the Reno, Queen, 92, 81, and Kootenay Belle A veins, each of which has yielded more than 80,000 ounces of gold. A concentration of production around two centres, one at the Reno vein in the northern part of the camp, the other immediately south of Sheep Creek and including the Queen, 92, 81, and A veins, is apparent, but the explanation of the concentration is less obvious.

The limitation imposed by the length of vein in favourable quartzite is important. The Gold Belt veins in general have been less productive than the veins of the Sheep Creek mine because the Gold Belt veins have distinctly shorter lengths in the favourable quartzites. However, this factor does not adequately account for the two concentrations of ore within the camp, neither does the amount of displacement on the veins. The displacement on the highly productive Queen vein is relatively large, but so also is the displacement on the much less productive Yellowstone vein, whereas on the most productive vein, the Reno, the displacement is moderate. However, it should be noted that vein fractures with less than 10 feet displacement tend to be limited in extent and for that reason are unlikely to yield large quantities of ore. The two centres of greatest production might be correlated with those parts of the camp in which the axial planes of the folds are bowed convex to the west in plan (*see* Fig. 2). Conceivably the stresses developed at the time of vein formation were localized by or even expressed in these two changes in strike, but such a relationship seems too tenuous to merit much weight. The extent to which the ground has been explored may offer a better explanation for the apparent concentration of ore in two parts of the camp, and if the ground between them had been explored more completely, the two local concentrations might be far less obvious.

Time of fault movement relative to time of introduction of vein-forming solutions is believed to have been important in controlling or making possible the formation of oreshoots. It has already been noted that fault movement on the vein fractures was not initiated simultaneously even in adjoining fractures (*see* p. 30). Similarly some veins have participated in late left-hand movements that did not affect others (*see* p. 42). The possibility that some fractures were not open at the time of introduction of quartz-forming solutions, and that immediately following this stage some veins were insufficiently fractured to admit entry of mineralizing solutions, may serve to account for tight northeasterly trending faults and veins of barren quartz, or quartz poor in gold. Unfortunately this explanation offers no help in predicting which vein fractures are likely to be richly mineralized.

VEINS IN LIMESTONE OF THE LAIB GROUP

Veins in limestone occur along the same set of northeasterly trending faults as do the veins in quartzite. The mineralization in the limestone is, moreover, similar though not identical to the mineralization in quartzite, and it can scarcely be doubted that both are derived from a common source. The gold and silver contents of oreshoots in limestone are similar* to those in the quartzites, but lead and zinc are far more concentrated in the former host. Mineralization in limestone commonly replaces the wallrock and consists of sulphides accompanied by minor amounts of quartz. Widths of high-grade mineralization are generally measurable in inches rather than in feet.

The total amount of ore mined from the two productive veins, the Sumit and Ore Hill, has been small† compared with the production for the camp, and it is highly unlikely

* Ore shipped from the Sumit ranged from about an ounce to as much as 14 ounces of gold to the ton. The very high-grade ore was very narrow. Ore of similar grade was mined from very narrow veins in quartzite on other properties.

† *See* Table VII, p. 52.

that the production to date has met the costs of operations and development. All the production from the veins in limestone has been made at levels fully 2,000 feet above the zone in which productive quartz veins occur in quartzite. The results of exploration in the limestone at lower levels have been disappointing.

CHAPTER V.—HISTORY OF DEVELOPMENT AND DEVELOPMENT POSSIBILITIES

HISTORY OF EXPLORATION AND DEVELOPMENT

In this discussion of the discoveries made and of exploration and development in the Sheep Creek camp, space has been given to the geological theories that have been held and have influenced exploration. It is felt that a knowledge of these theories will be useful in any consideration of past exploration and of the potentialities of the camp.

The earliest discoveries of the camp were the Yellowstone and Queen veins, staked July 18th and September 10th, 1896, respectively. Almost certainly ore outcropped in these two veins, for stopes were later extended to the surface in both veins. Thomas Bennett, a well-known prospector in the area, has been credited with the original discovery.*

The four original claims of the Queen group were staked along the strike of the bedding of the quartzite that is the host rock of the two veins. Presumably the claims were staked with the hope of finding other productive veins in the same wallrock. Parallel veins have since been found on these claims south of the Yellowstone and Queen but have not been productive at the surface. The quartzites are now known to outcrop, in that vicinity, only at the crest of an anticline and do not continue on surface far south of the Queen vein (*see* Fig. 1).

Later, attention was directed to a search for other shoots along the line of the two known veins, and for the next few years nearly all the claims located were either east or west of the two original groups. This search, however, was unsuccessful, and no orebodies have since been found on either vein on surface except at the original discoveries. It is doubtful, too, whether an extension of the Yellowstone vein west of Waldie Creek has been discovered to this day. The earliest known discovery of the Yellowstone vein in Kootenay Belle ground to the east was not until 1933.

The next three recorded discoveries were outside the quartzite belt. The first of these included the Galena Lady mineral claim, now lapsed, and the adjoining Joint and Double Joint claims. These claims were staked in or before 1897 and were all on the western slope of Nugget Mountain.

The Joint showings consist of an easterly trending quartz vein in limestone† containing galena, sphalerite, pyrite, oxidized streaks, and fair to spotty values in gold and silver. As far as is known, no ore has been produced from these claims. The Bluestone‡ claim was staked in 1899. The site of the original discovery is not known, but only Reno and Laib beds are exposed on this claim, and to date no ore has been produced. The Ore Hill, Sumit, and Snowstorm claims were staked in 1901 on the north slope of Mount Waldie, covering easterly to northeasterly trending veins that cut limestone and argillaceous rocks of the Laib group and Reno formation. Mining has since reached the surface, and ore can be assumed to have cropped out there.

The date of discovery of the Kootenay Belle veins is uncertain, though they are known to have been worked in the latter part of 1904. The veins are exposed on the southern part of the Yosemite claim, staked in 1898, presumably to cover the possible eastward extension of the Yellowstone vein.

Numerous discoveries were made in 1905. In rapid succession, claims were located on the Navada (6600 vein), Columbia (8200 vein), Motherlode, Nugget, Peggy (east of the Kootenay Belle ground), and Clyde veins, all in quartzite. It may be noted that the Motherlode group of claims was located along the line of the vein rather than along the line of the bedding, and the emphasis seems to have been on the exploration of a single vein rather than on the discovery of parallel veins in a belt of favourable wallrocks.

* British Columbia Mining and Engineering Record, December, 1911, and M. C. Donaldson, personal communication.
† O'Grady, 1932, p. 190.
‡ The Bluestone vein yielded 16,000 tons of ore in 1939 from the Rhomberg Fraction mineral claim; none of the stopes reached the surface.

In subsequent years some less promising veins were staked, the Fawn and the Golden Belle in 1906, the Eureka in 1907, and the Bonanza and Vancouver in 1908. Additional claims were staked from 1909 to 1910 chiefly, probably to consolidate and increase holdings. It was not until 1912 that the Reno vein was discovered. It was the last important surface discovery and turned out to be the most productive vein in the camp.

The underground development of the Yellowstone mine proved disappointing, for the third level, 350 feet below the outcrop of the one known oreshoot, yielded no ore. The underground development at the Queen mine for a time may have seemed equally discouraging. In 1902 the syndicate, which had undertaken work on the property and had mined 4,500 tons of ore worth $11 per ton, relinquished their bond. One of the owners, William Waldie, then undertook to operate the property, hoping to pay for the cost of development from the proceeds of mining. A tramway was built between the Queen portal and the Yellowstone mill, and with only a few hundred feet of drifting he disclosed and opened up the western oreshoot of the mine. For the next decade Waldie and his successors continued work on the western and central oreshoots of the Queen vein, reaching depths in 1915 of 400 feet below the lowest adit level and 610 feet below the outcrop of the oreshoot. Developing these oreshoots required no more than 150 feet of non-productive drifting on any level. The eastern oreshoot was first found on 5 level,* 225 feet east of the central oreshoot, and was developed to a depth of 290 feet below the lowest adit level before operations were suspended in 1916. Rising costs during wartime, labour troubles, and a cave-in in the shaft in July, 1916, were, at least in part responsible for the shut-down. A decline in grade of ore in the lower levels has also been cited as a reason, although it has since been established that a large quantity of ore averaging 0.6 ounce of gold per ton (worth $12 per ton in 1916) still remained in the lower part of the eastern oreshoot and that only 16 feet of drift was necessary to reach it from the eastern end of the lowest working. Once the mine was shut down it was allowed to flood, and it was not until 1934 that any serious effort was made to rehabilitate the old workings. The early operations of the Queen, although suspended in 1902 and 1916, demonstrated that valuable oreshoots existed in at least one vein in the camp, and that only relatively small amounts of exploratory drifting were necessary to prove these orebodies.

The Kootenay Belle veins had their first period of exploration and production between 1904 and 1911. In that period 5,100 tons of ore was won from shallow workings and yielded gold and silver to the value of $100,000. The mine was closed in 1911.

The original work on the Nugget vein was stimulated by the discovery of rich ore at the surface in the period from 1905 to 1907, and within a few years the vein was explored by four adits to a depth of 350 feet below the highest point on the oreshoot and 450 feet below the apex of the vein. During this period several additional subparallel veins were found on the property, and some drifting was done along two of them. Good values and widths were reported on one of these veins, the Calhoun, which at its western end converges on and joins the Nugget vein, but no part of it has been stoped. No blind oreshoots are known to occur in this part of the mine, although the Nugget vein was explored for several hundred feet on either side of the upper orebody. After yielding about $220,000 from 14,000 tons of ore, the mine was shut down in 1911 pending the driving of a lower crosscut and installation of new milling facilities, but it was not until the end of World War I that these developments came about.

The development of the Motherlode mine followed the success of the Nugget venture. Prior to 1910 a small amount of work, chiefly surface excavations, had disclosed the upper parts of two orebodies on the Motherlode vein. Work from 1910 to 1912 opened up these two orebodies to depths of about 500 feet below the surface, and drifts on 3 and 5 levels linking them disclosed a smaller, blind oreshoot. Oxidation extended to the full depth of this development, and it is reported that very little unaltered sulphide ore could be found even at the lower levels, although heavy sulphides did occur locally on 3 level.

* *Min. of Mines, B.C.*, Ann. Rept., 1910.

In 1911 it was announced that ore blocked out was sufficient to supply a mill of average capacity for three years. Accordingly a mill, of 100 tons daily capacity, was installed. It was operated slightly less than the predicted three years before visible ore was exhausted. The possibility of ore continuing to greater depths was considered, but a low-level crosscut to test the vein was not driven until 1939.

By the middle of World War I the camp had yielded about $2,500,000, mainly from three veins, and the more obvious geological controls of orebodies had been recognized. At least as early as 1915 work on the Motherlode vein had made it apparent that the vein is represented in schistose rocks by a tight fracture devoid of values, whereas on entering quartzite it widens out into productive oreshoots.* Underground work had been devoted principally to the development and stoping of exposed oreshoots, but, in the course of drifting on both the Queen and Motherlode veins, blind oreshoots had been discovered. Exploratory drifting had been carried on for distances of several hundred feet beyond the limits of known orebodies on both the Nugget and Motherlode veins, but without success. By 1915 all lateral exploration had ceased, and the managements of the different mines were reluctant to undertake further developments at depth in the face of high wartime costs.

At the end of World War I the Nugget vein was reached below the original adit levels by means of a long crosscut driven from No. 5 level of the Motherlode mine. The crosscut and the raise from it to No. 4 level of the Nugget mine linked the Nugget vein with the Motherlode mine, tram-line, and mill. The vein was stoped for 250 feet above the crosscut level, but no ore was located in the vein between the top of this stope and No. 4 level. Whether or not the exploration of this non-productive part of the vein was adequate, the inference was made that barren zones could occur within the veins separating a productive zone above from one below. One vein, moreover, was now known to have yielded ore through a vertical range of 900 feet. Had the price of gold and the cost of production been more favourable in the early twenties, these conclusions would no doubt have fostered the exploration in depth of many of the other veins, but such exploration was not to come until the following decade.

For several years after the closing of the Nugget mill in November, 1922, activity in the camp was limited to a small amount of exploratory work and to the shipment of a few carloads of ore from several of the veins. Development on the Reno property attracted the greatest interest and, by 1928, trenches, open-cuts, and about 1,000 feet of underground workings had exposed at least two orebodies. The vein itself had been traced for a length of 1,400 feet and through a vertical range of 700 feet; six other parallel veins had also been exposed. In 1929 a 30-ton cyanide mill was built to treat the output of the mine and was operated until February, 1932, when it was destroyed by fire. In that period gold worth more than $400,000 was recovered.

Following the fire, Reno Gold Mines Limited acquired the Nugget-Motherlode properties, including the old Motherlode mill. The old mill was reconditioned and was linked to the Reno mine by a 12,500-foot aerial tramway. In the meantime, work was continued in the Reno mine. The remodelled mill, with a capacity of 100 tons a day, began operation in December, 1932, and was operated on Reno ore until that mine was exhausted in March, 1939. In October, 1939, the mill was reopened to treat ore from the lower levels of the Motherlode mine and from the Bluestone vein. In 1941 the mill was operated mainly on ore from the Nugget mine between the 4900 level and the older workings at higher elevation. The mill was finally shut down late in 1941.

In the period from 1932 to 1934 the success and promise of the Reno mine, together with the rise in the price of gold, stimulated interest in the camp, and several of the old mines were reopened. Work began at the Kootenay Belle mine in the fall of 1932 under the direction of the Kootenay Belle Syndicate, and the following year a company was organized to promote large-scale development. A 50-ton mill was built at the property

* Galloway, 1915, pp. 156–160.

in the autumn of 1934 and was replaced by a new 100-ton cyanide mill in the autumn of 1936. The latter was operated until the mine closed at the end of 1942.

Gold Belt Mining Company Limited, formed in 1932 and incorporated the following year, explored ground west of the Motherlode mine on the north side of Sheep Creek. Work began on the property in June, 1932, and until the spring of 1935 was concentrated on the driving and developing of the two upper levels. North American Mines, Inc., then acquired a large interest in the company, and the lower levels were developed. The ultimate success in this venture led to the installation in the autumn of 1938 of a 150-ton mill, which was operated until midsummer of 1943.

A small amount of work was done on several of the properties south of Sheep Creek during 1932 and 1933. In 1934 these properties, including the Queen, Yellowstone, Alexandra, Vancouver, and Midnight, were amalgamated under the newly formed Sheep Creek Gold Mines Limited. Work on the Queen vein by this company led to the installation of a 150-ton cyanide mill, which was operated, with several interruptions, from May, 1935, until midsummer of 1950.

The operations in the various mines in the period from 1930 to 1943 yielded 547,890 ounces of gold, out of the total of 736,015 ounces credited to the camp in the period from 1900 to 1951.

Several geological discoveries made during the thirties had a marked influence on developments. Two of these stemmed from the examination of the unwatered Queen mine in 1934 by H. H. Yuill and his assistants. They recognized that the western orebody in the Queen vein was cut off in the lower levels by an important normal fault, and they predicted, correctly, that its continuation could be found at higher levels to the west of the workings then existing. They realized, too, that the quartzites in the vicinity of the Yellowstone and Queen mines lay at the crest of an anticline and had been exposed beneath the cover of Reno and younger beds by deep dissection in the vicinity of Sheep and Waldie Creeks.* Thus, in spite of the absence of these quartzites on the higher parts of the valley walls both north and south of Sheep Creek, it was then possible to predict their presence at depth in both areas. The first conclusion, regarding the presence of ore west of the Queen fault, was confirmed in the winter of 1934–35. The ore recovered from the Queen vein in the period from 1935 to 1937, inclusive, was chiefly from the lower end of the eastern orebody below the workings abandoned in 1916 and from the faulted part of the western orebody. It amounted to 113,000 tons, from which the gold recovered average 0.298 ounce per ton and was worth almost $1,200,000 (gross). The profit derived from this work was adequate to warrant the search for parallel veins in the quartzite farther south on the anticlinal structure. Two vein fractures had been exposed by surface work in the argillaceous quartzites overlying the Nugget quartzite, 800 and 1,700 feet south of the Queen vein, and it was proposed to intersect these in the quartzites at depth. Accordingly, in 1936, a crosscut was driven south from 5 level on the Queen vein. The first vein was cut at a distance of 800 feet and was drifted on for 600 feet with inconclusive results. Later the vein was reached by a crosscut on 7 level and was followed in a drift for 600 feet before a large high-grade oreshoot was encountered. A total of about 2,800 feet of level workings in quartzite was thus necessary to discover the main orebody of this one vein. The vein has since yielded 128,000 tons of ore assaying 0.55 ounce of gold per ton, worth almost $2,500,000.

The significance of the anticlinal structure in the Queen and Yellowstone mines had not been missed by others. It was essentially this new interpretation that led North American Mines, Inc., to invest in the Gold Belt Mining Company, in whose property the quartzites might also be expected to occur at depth. Prior to 1935 the work on this property had been confined to development on veins on the upper slopes of Nugget Mountain in the Reno formation, which there forms a hood over the quartzites.

At the instigation of North American Mines, several holes were drilled down from the 600 level (altitude 5,046 feet) in the late spring of 1935 to confirm the presence of

* This concept had previously been suggested by A. Lakes, but had either been discredited or overlooked.

the quartzites, and in the latter part of that year a long low-level crosscut (1850 level) was started from the lower slopes 1,000 feet north of and 400 feet above Sheep Creek to explore these favourable beds. By July of the following year this crosscut had been driven 3,150 feet from the portal and several veins had been intersected. Drifts totalling 945 feet on the 2360 vein, 425 feet on the 2590 vein, and 400 feet on the 3040 vein revealed no orebodies; with few exceptions the assays indicated subcommercial grade. After almost 5,000 feet of workings on the 1850 level had yielded no ore, the management was reluctant to expend more money on exploration, but one other vein zone exposed in the crosscut was tested. This vein zone had been intersected 1,500 feet from the adit portal in argillaceous schists, and it would be necessary to drift westward for several hundred feet before favourable wallrocks would be encountered. The sole encouragement for this work was the fact that a small amount of ore had been recovered from surface workings (the Columbia adits) in what appeared to be this vein zone. The distance from the crosscut to the quartzites proved even greater than had been anticipated, amounting to slightly more than 850 feet, but a few feet beyond the eastern edge of the quartzites, on what is now known as the 8000 vein, the drift entered a low-grade oreshoot, and a few hundred feet farther west higher-grade ore averaging almost 4 feet in width was encountered. The results of development on this vein and on a parallel vein 200 feet to the north were so encouraging that another crosscut, the 2100, was driven to explore these veins 250 feet lower. This crosscut intersected another vein, the 6600, which had been prospected in the early part of the century, and which had yielded a few tons of ore from the Navada adit. This vein* was later to yield 11,700 ounces of gold, worth more than $400,000, from the Gold Belt and Kootenay Belle holdings. The 8000 vein at the 2100 level contained three orebodies, but the work on the 8200 vein disclosed only subcommercial grades.

The productive depth of veins had been repeatedly increased by continued underground work throughout the history of the camp until 1937. Mines had been closed previously, but in each instance the fall in profits that led to the closure stemmed more from rising costs of labour, equipment, and supplies than from a decline in the grade of the ore. In view of the erratic distribution of values within the veins of the camp, it is doubtful if before 1937 any over-all decline in assay values with depth had been proved. With the added profit margins given in the early thirties by the rise in the price of gold and the fall in operating costs, the possibilities of production at greater depths were viewed with optimism. The levels at which the Queen vein was producing, 2,500 to 2,800 feet above sea-level, were regarded as ones to which other veins might be worked. With the Reno vein then producing at altitudes of 6,000 and 7,000 feet, such a concept made the future for the Reno mine look promising indeed. In 1937, however, when the lower part of the Queen vein was being developed, a diminution in the amount of ore present was clearly demonstrated. Vein widths persisted but grades declined with depth, and at successively lower levels a smaller and smaller proportion of the vein could be mined commercially.

The decreasing proportion of ore with depth,† first fully established in the Queen vein, was to be observed also in the Reno in the following year (1938). The exploration of the lower part of the Reno vein, though not as exhaustive as in the Queen, nevertheless showed a similar bottoming of commercial ore within the vein. These facts made it necessary to discard the idea that all veins could be worked down to the altitude of the lower stopes on the Queen vein. It was realized also that oreshoots on veins between the Queen and Reno might bottom at intermediate altitudes, and this concept served not only to explain the absence of ore in veins at the lower levels of the Gold Belt mine, but also to give promise of better grades at higher levels. This idea had been expressed at least as early as July, 1939, and from that time on development in the Gold Belt mine was conducted with the view of exploring the veins between an upper limit of quartzite and a lower

* On the Kootenay Belle ground the vein was explored and stoped from the Dixie adit.

† *See* pp. 61–62.

limit of commercial grades. The 2360 and 3040 veins, which had been barren of ore on the 1850 level, proved to be productive at higher levels, as had been predicted, and two other veins, the 3500 and 3900, were found to contain orebodies which bottomed at levels somewhat higher than in the veins to the south.

Experience in mines along the Western anticline between 1937 and 1939 indicated that a lower limit of oreshoots had been reached in the Queen vein, in several veins in the Gold Belt mine, and in the Reno mine. In the same period, operators came to believe that the commercially productive sections of veins lay above a gently southerly sloping surface (*see* pp. 61–62). This depth concept influenced subsequent exploration and to a degree restricted exploration to ground that, on the basis of this belief, was thought to be potentially favourable. In 1940 and 1941 the bottoms of commercial oreshoots were reached in the mines of the Eastern anticline. At that time the possibility of discovering orebodies large enough to pay for the cost of exploration on the Motherlode, Nugget, and Kootenay Belle A veins seemed so remote that work at lower levels on them was abandoned.

Attention was paid to the possibility of finding new orebodies in branch veins. Exploration on branches of the veins on 5 and 6 levels of the Reno mine had been successful in finding ore, but an extensive programme of diamond drilling for branch veins in 1936 and 1937 did not locate any significant new orebodies. Crosscutting in the Sheep Creek mines disclosed orebodies in branching or subparallel veins of a single fault zone (*see* pp. 57, 60).

Geophysical surveys were made in 1938 of the area between the Reno and Nugget mines by Hans Lundberg for Reno Gold Mines Limited. Details on the cost, procedures, and results are not available. It is reported, however, that one of the major anomalies led to drilling and the discovery of the Bluestone vein, which was completely buried by overburden. Relatively small amounts of mineralization exist in the vein on the uppermost level, and stoping was abandoned above the second level at a point 150 feet below the surface. It seems, therefore, that geophysical studies could be used to advantage in areas covered by overburden to locate relatively shallow orebodies. So far as is known, however, no geophysical work has been done in other parts of the camp.

GEOLOGICAL CONCEPTS THAT HAVE INFLUENCED THE SEARCH FOR ORE

In summary it should be noted that some of the developments in the early days of the camp and virtually all later development was guided by several conclusions on the geological factors localizing orebodies. The conclusions which follow were based on mining experience and were generally accepted within the camp. They are:—

1. The ore is confined to a series of roughly parallel northeasterly to easterly trending fault zones. Even though mineralized quartz has been found in at least one northwesterly trending fault, no ore has yet been found in any of them.

2. Orebodies are localized within the northeasterly to easterly trending zones where one or both walls consist of quartzite. The Upper Nugget quartzite is, as a rule, the most favourable wallrock, other things being equal, but in some localities, as for example in the northern part of the Western anticline, the Upper Navada quartzite may be more favourably situated. Drifts driven on the productive veins have been concentrated within the quartzite units and, in recent years, have generally been stopped on reaching the top of the Quartzite Range formation or, in some instances, the top of the Upper Nugget member. It should be noted, however, that under some circumstances ore or potential ore may be found where the northeasterly trending fractures intersect limestone as in the Sumit and Ore Hill veins.

3. Orebodies tend to be wider where the strike of the vein fracture is more nearly east than usual. By careful mapping of the vein zone at points exposed on surface and at intersections with drill-holes and crosscuts at depth, it is possible to indicate areas where the vein has a trend that is favourable for the occurrence of ore.

4. In the quartzites, orebodies have been found through a vertical range of not more than about 1,600 feet in any one vein. Higher parts of the vein tend to be too narrow for profitable mining development, and the lower parts tend to be too low grade. Development to greater vertical ranges has in recent years been avoided where it was thought that the vein lay outside the limits of the productive vertical range. It has been recognized that some veins, for reasons which may or may not be apparent, yield ore from only a fraction of the maximum known vertical productive range.

5. The productive parts of the veins are found at successively lower levels as the southern part of the camp is approached. Thus the Reno vein, in the northern part of the camp, has been productive between altitudes of 6,900 and 5,400 feet; the Kootenay Belle A vein, in the central part of the camp, has been productive between altitudes of 4,300 and 2,700 feet; and the 75 vein, in the southern part of the camp, has not been productive above the 3,300-foot level. Exploration for orebodies has, therefore, been concentrated within the range in altitude that for the particular part of the camp has been found to be favourable. It should be noted that the Sumit and Ore Hill veins have yielded ore from limestones at altitudes of 5,100 to 5,600 feet. It seems, therefore, that the favourable limits of depth for ore in quartzites are considerably lower than those for ore in some other type of rock, and that failure to find ore in a particular vein cutting quartzite above a certain level should not necessarily discourage exploration in limestone at higher levels. The failure, to date, to obtain large quantities of ore from limestone in the northeasterly trending fault, should, on the other hand, discourage very large expenditures in development in this rock at any level.

6. Orebodies may occur in one or both forks of a branching vein. If a branch is encountered in drifting, an accepted rule is to follow the " strongest " branch, that is the branch with the most gouge, the widest zone of shearing, the most drag, or the greatest displacement. If the two branches are of nearly equal strength, the right-hand branch trends more nearly east and is regarded as the more favourable, but ore may occur on both branches.

EXPLORATION POSSIBILITIES

Veins in Quartzite

On a broad scale, exploration of the Sheep Creek camp is incomplete, and even within the most extensively developed parts of the camp possibilities remain of finding ore. As a rule, drifts have been driven at vertical intervals of not less than 100 feet, and bodies of ore of smaller dimensions could be missed. However, it is questionable whether the expense of more drifts at smaller intervals would be justified by the additional ore they might disclose. Diamond drilling or crosscutting for ore in branching or subparallel fractures in an explored vein zone have likewise been spaced at too wide intervals to establish the absence of all such ore. Blind drifting, drilling, or crosscutting is not to be recommended in an effort to rectify these omissions, but careful study and utilization of geological information can, almost certainly, disclose more ore and lessen the cost of mining development.

Despite a history of exploration extending over more than fifty years, no simple criteria have been recognized by which a vein fracture that contains little or no ore can be distinguished from one that may be highly productive. The only known way to determine whether or not a vein contains profitable concentrations of ore is by thorough and costly exploration in underground workings.

The writer of this bulletin is impressed by the indication of a favourable depth range or depth zone (*see* items 4 and 5, above; *see also* pp. 61–62 and 69–70). The upper and lower limits of the zone are not marked by recognized structural or other geological features, but the known orebodies in the Western anticline and, to a less definite degree, the orebodies in the western limb of the Eastern anticline may be said to lie within a zone or within a limited vertical range. Unfortunately no characteristics of vein or wallrock are known that assist in predicting the relationship of a vein exposure to the upper and lower limits of this vertical range. Veins become too narrow for profits as they approach the upper limit. At the lower limit the veins are as wide as, or wider than, average and are not barren, but under the conditions of the past fifteen years too little of the vein matter is rich enough to return any profit after allowing for the cost of exploration and mining. If the demand were high and other conditions were favourable, it might be possible to mine siliceous flux below the favourable zone from parts of veins already developed. It may also be inferred that under conditions more favourable than those now existing further exploration and development below the lower limit of the " favourable zone " might be profitable, costly though such work would be.

The following observations and suggestions relate to development and exploration possibilities within the camp mainly in the more intensely developed parts.

Any future development in the Sheep Creek camp might be either (1) a search, conducted with a minimum of capital expenditure, for shipping ore on the extension of known orebodies or in branch veins within explored vein zones, or (2) expensive exploration for new bodies of milling ore and for new veins within and beyond the area now opened by mining. To be successful economically, the second would require the discovery of enough ore to warrant equipping the property for production.

No very large tonnage of shipping ore should be anticipated within easy reach of the present workings. Small-scale development, such as could be carried on by lessees, should be conducted as early as possible to take advantage of existing facilities, pipelines, tracks, timbers, and the workings before they deteriorate beyond hope of easy repair. Development, for the same reason, should be restricted to the vicinity of existing and accessible workings.

Pillars and sills adjoining known orebodies are obvious and readily available sources of ore, and have provided a considerable proportion of the material so far recovered and shipped by lessees.

Other sources of ore may be found around the margins of existing stopes. Examination of mine records and particularly of assay plans of stopes may be of great assistance in locating such extensions of orebodies. Careful study of the vein in the backs and ends of stopes may also reveal ore which had previously been left unmined. Low-grade vein material, averaging perhaps 0.3 ounce of gold per ton, could be treated profitably during the period of greatest activity in the 1930's when mining and milling facilities were available, providing the ore width was adequate. Approximately three times that average grade was required in 1949 to meet the cost of mining and shipments of ore to the smelter. Stopes which had been abandoned in the thirties as low grade offer no hope of becoming sources of shipping ore. However, those which had been abandoned because of the narrowness of vein material may be a potential source for shipping ore if sufficiently high in grade. It had been a common practice in the thirties to mine stopes to a minimum width of about 3 feet, even where the vein was much narrower, and to accept the resulting dilution of the ore. A vein which assayed 2 ounces per ton in gold could not, however, be mined economically in this way if its width were much less than about 6 inches, and many stopes advanced in high-grade vein material were abandoned if the vein became too narrow for economical mining across 3-foot widths. Some such high-grade portions of the vein can be mined profitably in very narrow stopes yielding, with a minimum of dilution, material of sufficient grade to bear shipment costs. Inasmuch as the veins tend to be both narrow and high in grade in the upper part of the productive zone, search for recoverable ore of this type should be concentrated in the higher levels of the mines.

The discovery of ore in the walls of veins already developed can be facilitated by careful search for branch fractures, particularly those branches in which a considerable proportion of the fault movement of the vein zone has been concentrated. A section of a previously developed vein fracture that has an abnormally small fault movement compared with the movement in adjacent sections of the same vein to the east and west, or above and below, is one that should be scrutinized for important branch or parallel fractures that might have localized not only part of the fault movement, but also much of the ore. Where such evidence indicates that previous development has locally been off the principal fracture of a productive vein zone, a few short drill-holes or short crosscuts are justified in a search for more ore. Sections of the vein zones where the absence of parallel oreshoots has already been established by drilling should, of course, be avoided for such exploratory work.

Inasmuch as the present pattern of orebodies cannot be fully explained by the known ore controls, the location of additional orebodies within a partly developed vein cannot be predicted. Elements of luck still exist to lure the miner into exploring farther along the extensions of the vein, and such efforts are occasionally rewarded. However, experience in the mines has proved that such blind drifting into sections of the veins in which favourable conditions for ore are not specifically indicated is, in the long run, unprofitable.

Any new extensive development programme in a search of new veins is almost certain to be very expensive. The easily discovered orebodies, those which extended to the surface, have probably all been located and mined. Other orebodies may be concealed only by overburden, but very detailed surface prospecting or geophysical surveys coupled with diamond drilling or underground work will probably be necessary to demonstrate their presence. Still other orebodies, like those in the southern part of the Sheep Creek mine and in the northern part of the Gold Belt mine, may have their apices many hundreds of feet below the surface, and these would be located only by underground work.

The ground offering most certain prospects for the discovery of ore in the Sheep Creek camp is in the parts of the Western anticline and of the western limb of the Eastern anticline in which productive veins have been found. Whether veins as rich as the Queen and Reno remain to be found in the vicinity of the present mines is not known, but smaller veins, comparable with the 75, 8000, and the 3500, can almost certainly be anticipated. Northeasterly trending faults are known to occur at the surface or at shallow depths at several places between the Gold Belt workings and the Reno mine, and from the Sheep Creek mine south to the saddle 750 feet south of Mount Waldie. It is a reasonable geological assumption that these vein fractures and others in their vicinity are potential sources of ore where they cut across favourable quartzites. Failure to find ore where such a vein is exposed on the surface or at some level underground does not necessarily prove that ore may not occur in the vein at another elevation.

Within the part of the camp that has been productive, the favourable quartzites remaining to be explored may be several hundred to a few thousand feet below the surface and could be fully tested only by crosscuts driven in appropriate positions. It would be necessary to test veins at different elevations and to test the favourable quartzites on both limbs of the Western anticline to avoid the possibility of missing such veins as the 8000, which is non-productive on one limb, or the 92, which is only sparingly productive on one limb. Crosscuts driven on opposite sides of the Queen fault would also reduce the problems of locating offset sections of the veins. Crosscuts driven along some clearly recognizable stratum may also be advantageous, inasmuch as the displacement of vein fractures which cut it can be determined with a minimum of drifting. Additional work could then be concentrated on those fractures which have moderate to large displacements and therefore probably have considerable lateral extent.

In considering the ground at depth between the Alexandra and Bonanza veins, it should be remembered that all the workings on the Bonanza veins are well above the elevations of the known oreshoots in the comparable part of the Western anticline. The amount of movement along the Bonanza vein fractures is large, and they can, therefore, be expected to extend to considerable depth, well into, if not beyond, the productive zone. Other vein fractures, hitherto undiscovered because of widespread overburden on the lower slopes of Waldie Creek valley, can be anticipated between the Bonanza and Alexandra veins. The Alexandra vein has, however, produced disappointing amounts of ore to date even though exploration has been concentrated within the projected limits of the productive zone, and there is no assurance that veins to the south would be more productive. Although exploration south of the Alexandra vein may not seem as promising as work done in the Western anticline, it would probably be no less favourable a gamble than the 1850 crosscut of the Gold Belt mine was in 1935. It could only be hoped that such a crosscut might be at least as successful as was, ultimately, the work done at the Gold Belt mine.

The Upper Nugget quartzite north of the Fawn mine does not merit underground development unless very detailed surface or geophysical surveys indicate the presence of ore-bearing veins. Exposures in this area are poor locally, but traces of auriferous float might be expected in the talus and soil below any potentially productive veins. Such traces have not been reported.

It may be of interest to note that the Kootenay Belle, Motherlode, and Nugget veins in the Eastern anticline and the veins of the Sheep Creek mine in the Western anticline have been productive in the Middle Nugget member, and that elsewhere little or no exploratory work has been done in this member, which generally lies well below the bottoms of the mines and in much of the area is below the 1,600-foot vertical range discussed on pages 61 to 63.

Another area that merits some study is the eastern limb of the Eastern anticline. To date only a few vein fractures have been located in this limb, and only one, the Eureka, has been explored underground. That the stresses responsible for the vein fractures farther west acted this far to the east is established. The small amount of material mined from the Eureka vein is not enough to show that the processes of mineralization were here sufficiently intense to form orebodies, but, on the other hand, it is not known that the Eureka vein has been tested at the most favourable level. Until this part of the area is shown to contain orebodies, the expense of crosscutting should be avoided, but some surface work, and perhaps even geophysical surveys, might well be conducted at different levels to expose and explore northeasterly trending fault zones within the Nugget and Navada members.

Extrapolation of the upper and lower limits of the productive zone eastward from the developed mines cannot be done with sufficient confidence to indicate the most favourable levels for exploration in the eastern limb of the Eastern anticline. Should it be proper to project the limits horizontally eastward, the lower northeastern part of Yellowstone Mountain and possibly the higher exposures of the Nugget beds north of Sheep Creek would lie within the extension of the productive zone. If the Weasel Creek fault is post-ore, the favourable zone would lie more than 1,000 feet higher on the east than on the west side of the fault, and conceivably this zone may have been completely removed by erosion north of Sheep Creek, and may lie at relatively high levels on the slope of Yellowstone Mountain south of Sheep Creek. The Eureka adit would, in this case, lie beneath the zone or low within it. If, on the other hand, the Weasel Creek fault is pre-ore, the zone would lie at relatively low levels east of Weasel Creek fault and the Eureka adit might be at or above the top of the zone. The tightness of the vein fracture in this adit and the presence of occasional small lenses of vein quartz favour the latter suggestion. Waldie Creek almost certainly lies above the zone on the eastern limb of this fold, and surface work at all elevations except perhaps creek level is likely to be fruitless.

Veins in Limestone

Some investigations of vein fractures in limestone at levels of from 2,000 to 3,000 feet above the productive zone in quartzite may be warranted, although the limited production from limestone so far fails to encourage large expenditures for exploration. So far ore has not been found in the limestone at the depths at which the veins have been productive in the quartzites. Whether any of the vein fractures extend into the limestone belt east of the Weasel Creek fault is completely unknown.

CHAPTER VI.—STATUS OF MINING

OWNERSHIP

The entire productive part of the Sheep Creek camp and much of the outlying area was held as Crown-granted claims in 1949.* Sheep Creek Gold Mines Limited owned thirty-eight Crown-granted claims between Sheep Creek and the west ridge of Yellowstone Mountain on the north and Mount Waldie on the south. This company also had five claims near the summit of Mount Waldie which were held by record, together with an option of ten Crown-granted claims making up the Bonanza group on the southwest slope of Waldie Creek valley. Gold Belt Mining Company Limited owned thirty-two Crown-granted claims and parts of two other Crown-granted claims along the Western anticline between Sheep Creek on the south and the southern slope of Reno Mountain on the north. This company also held a group of five Crown-granted claims on both sides of Sheep Creek east of the Motherlode mill. A total of nineteen complete Crown-granted claims and parts of two other Crown-granted claims, including the Nugget, Motherlode, and Reno mines, were held by A. Endersby, Sr., and A. Endersby, Jr., of Fruitvale, who acquired the property from Reno Gold Mines Limited in 1942. Holdings of Kootenay Belle Gold Mines Limited consisted of eight Crown-granted claims, all but one of which was on the northwest slope of Yellowstone Mountain. The Golden Belle group, owned by Myrtle I. and David T. Williams, and F. L. and J. S. Murdoff, consisted of ten Crown-granted claims on the north slope of Sheep Creek valley south of the Motherlode mine. Ownership of two surveyed but not Crown-granted claims had been allowed to lapse, the ground being open for location. Smaller holdings, mainly beyond the limits of the productive veins, were as follows: Silver Bell, a Crown-granted claim northwest of the Reno mine, held by J. G. McColeman, of Stayner, Ontario; Golden Eagle, a Crown-granted claim northeast of the Fawn mine, held by J. E. Bick, of Vancouver; Joint Fraction and St. Eugene Fraction, two adjoining Crown-granted claims, west of the Gold Belt property, held by C. A. Cawley, of Salmo; Iron Cap group (Iron Cap, Dew Drop Fraction, Bunker Hill, Yip Fraction, Fawn Fraction, United No. 2, Falls No. 2, and Gold Bug Crown-granted mineral claims), also west of the Gold Belt property, held by William Brown of Nelson, who also owned two near-by Crown-granted claims, the Collins and the Edward D.; Lucky George Crown-granted claim on the west ridge of Yellowstone Mountain, held by Soturn Oils Limited, of Vancouver; Eureka group (Rex, Pat, Keno, and Gem mineral claims held by record) on the north side of Yellowstone Mountain, held by R. G. Cameron and M. L. Craig, of Trail; Bremner group (Dome Fraction, Tea Pot, and Tea Pot No. 2 Fraction Crown-granted mineral claims) on the southwest side of Waldie Creek, held by A. and J. B. Bremner, of Ymir; Sumit group (Sumit, Independence, Gold Crown, Buster Fraction, Gold Crown Fraction, and Independence Fraction Crown-granted claims) west of Mount Waldie, held by McCuaig Red Lake Gold Mines Ltd., of Toronto; Fisher group (King No. 3, King, King Fraction, King No. 1, Emperor, and President Crown-granted mineral claims) near the head of Stoat Creek, held by Nettie H. and James Fisher, of Nelson.

Reno Gold Mines Limited was dissolved in 1952. Some claims and other assets of the company in the Sheep Creek camp were disposed of following the shut-down of the company's operations there in 1941. Claims that constituted the Motherlode and the Fawn properties, except part of the Golden Fawn claim, are now owned by A. Endersby, Sr., of Rossland, and A. Endersby, Jr., of Fruitvale. In 1952 the principal claims at the original Reno mine, and the claims that constituted the Nugget group, except part of the Nugget claim, were still recorded in the name of Reno Gold Mines Limited but were understood to be covered by an agreement between Reno Gold Mines Limited and Messrs. Endersby. Gold Belt Mining Company Limited acquired the following claims

* Changes in ownership since 1949 are noted in the second paragraph.

formerly owned by Reno Gold Mines Limited: Dandy, Curlew, Manhattan Fraction, Larkhall, Cassiar Fraction, Blackstone, Snowdrift, Bluestone, Cayote, Rhomberg Fraction, part of the Nugget, and part of the Golden Fawn. The claims acquired by Gold Belt Mining Company Limited include the Rhomberg Fraction, on which Reno Gold Mines Limited mined ore from the Bluestone vein. In 1951 Gold Belt Mining Company Limited, then a wholly owned subsidiary of North American Mines, Inc., was dissolved, North American Mines retaining ownership of the property. The 1952 tax records indicate that North American Mines then owned thirty-seven claims or fractions and also owned part of the Golden Fawn and part of the Nugget claim.

ORE RESERVES

The known ore reserves of the Sheep Creek camp were in 1949 almost entirely confined to the Sheep Creek mine. It was reported by this company on May 31st, 1949, that 50,578 tons of ore averaging 0.341 ounce of gold per ton was blocked out, enough for about two years' operation at current rates.* Virtually all the known ore in the Gold Belt mine had been extracted by 1943, when the mill was finally shut down, but a small amount of development work done in 1946 demonstrated the presence of an oreshoot at the west end of the 3500 vein between the 1400 and 1100 levels. This ore remains to be mined. The ore remaining in the Nugget vein between 6 and 5 levels has not been estimated, but this part of the vein constitutes the main reserve of the Endersby holdings. A section of the Fawn vein in the lower level and a part of the Calhoun vein are reported (A. Endersby, Jr., personal communication) to be of commercial grade, but lack of transportation facilities has prevented its being mined. The ore remaining in the Kootenay Belle mine is confined to pillars and small pockets at the margins of former stopes. No other ore is known in the camp at this time.

MINING FACILITIES†

Sheep Creek Mine

The Sheep Creek mine was the one mine in 1949 that was still fully equipped and in operating condition. However, by 1951 all known orebodies were mined, equipment was withdrawn, and the workings were flooding. The mill and surface plant were left intact.

Kootenay Belle Mine

The Kootenay Belle mine is flooded below 6 level, but nearly all the other workings are accessible. Natural ventilation is good, and tracks and air-lines are still available on 6 and 3 levels. The mill was dismantled and shipped to Retallack in 1943, where the company has treated lead-zinc ores. The compressor is still in operation. Mill building, compressor-house, several residences, and a few other buildings are in good order.

Gold Belt Mine

All level workings of the mine are accessible, although timber sills in the 1782w drift are in poor condition and may soon render higher parts of the 82 vein unapproachable. Natural ventilation has been good since the shaft on the 3500 vein linking the 1200 and 600 levels was completed. Rails and air-lines are intact, as is the hoist at the head of the 3500 vein shaft on 600 level. Most of the movable mine equipment has, however, been sold, and the remainder is on sale. The power-line was damaged by a snowslide in the spring of 1949, and other snowslides in this same year partly or completely demolished the mill, mill office, cook-house, and several other buildings. Most of the mill machinery had been removed prior to the catastrophe.

* Exploration at lower levels of the Sheep Creek mine in 1949 and 1950 disclosed little new ore, and continued rise in costs led to a slight reduction in ore reserves previously estimated. As a result, after 43,998 tons of ore had been extracted, the mine was shut down in the early part of 1951, and the workings have been allowed to flood.

† This section refers to conditions in 1949 unless otherwise stated.

Fawn and Cayote Mines

The Fawn and Cayote mines are fully accessible, but no tracks or air-lines are laid.

Bluestone Mine

The 3 level is flooded, and 2 level is caved at two points near the portal. The 1 level is fully accessible.

Reno Mine

The mine is completely flooded below 5 level, and 5 level itself is partly flooded by a cave-in 675 feet from the portal. Natural ventilation between 4 and 1 levels is good, despite the fact that the portal of 4 level is almost completely closed by caving. Air-lines and tracks were still available in several parts of the mine. The tram-line to the Motherlode mill has been dismantled between the Reno and Bluestone mines. As towers had collapsed at several places between the Bluestone mine and the mill, the tram-line is no longer in operating condition. Most of the buildings at the Reno mine, with the exception of the core shed, are in poor condition; many are completely broken down by the weight of winter snow.

Motherlode and Nugget Mines

The workings on the Motherlode vein are flooded below 10 level. Natural ventilation is good in the Motherlode mine and in the upper part of the Nugget mine. Lower levels in the Nugget mine are being ventilated by an artificial system which takes advantage of the air current on 10 level between the Motherlode mine and the surface. Most of the mine timbers in the Motherlode mine at and above 6 level and in the Nugget mine at and above 5 level were put in prior to 1922, and many of them would need to be replaced before any new mining activity could be initiated. The tram-line to the Motherlode mill-site was still in operating condition, but the mill itself was dismantled in 1943. The compressor, operated by water power, was still in good condition.

Ore Hill Mine

Most workings are accessible, although 8 level was partly caved and partly flooded. No air-lines or track remain. The bunk-house and a few cabins are still standing but in poor condition.

Bonanza Mine

All but the uppermost level are fully accessible, but no equipment remains.

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APPENDIX

MOVEMENTS ON VEIN FRACTURES

The following list of movements on vein fractures is made up mainly from the observations of the writer and the members of the party under his supervision, but some data have been taken from maps prepared by J. R. Johnston, C. C. Starr, and others.

Most of the observations have been made on displaced beds identified on opposite walls of the vein. In some instances, doubt existed at the time of observation regarding the identification of the beds and in other cases doubts were raised when the measurements of displacement later proved inconsistent with observations made near by on the same vein. Such cases in which the accuracy of the measurements is uncertain have been queried in the table. Some others of the computed net slips may be no more accurate. Axial planes of folds have been utilized in measuring movement on the vein fractures, but the data are, in general, less reliable or less accurate than those for offset beds. Identification of the same fold on opposite sides of the vein is less certain than identification of the same bed, and the determination of the average dip of the axial plane is not always accurate. Measurements of offsets on pre-vein dykes are noted in four instances. The average dip of the dykes, like those of axial planes, may not have been correctly estimated at least for the portions above and below the drifts, and the calculated displacements are also less accurate than those based on offsets of beds. In addition, the possibility of the dyke having been intruded after part of the vein movement was complete (*see* 2180E drift, p. 30) reduces the value of these data.

Net slip has been computed from the observed horizontal separation measured along the vein, of the two parts of the same bed, or axial plane (Ax. pl.) or dyke, using the formula $s = \frac{h(\sin d)}{\sin a}$ where s is the net slip, h is the horizontal separation, d the apparent dip of the bed (that is the dip of the trace of the bed) on the plane of the fracture, and a the angle between the trace of the bed and the direction of movement measured on the fracture plane. The direction of movement is here assumed to plunge 25 degrees west for all the vein fractures of the camp.

It can be shown that if the dip of the beds is in the same direction as the plunge of the movement and at a lower angle, the apparent displacement and the strike-slip are in opposite directions, and that if the trace of the bedding is either horizontal ($d=o$) or parallel to the direction of movement on the fracture ($a=o$), the equation is indeterminate. In all other cases the apparent displacement (h) and strike-slip are in the same direction; i.e., in the vein fractures of the Sheep Creek camp they are both right-handed. In most of the examples of the Sheep Creek camp the dip of the bedding on the walls of the fractures is steep, approximately 65 degrees to the east, and the plunge of the movement may be assumed to be 25 degrees to the west; thus the angle between the plunge of the direction of movement and the trace of the beds is $180-(25+65)=90$ degrees, and the equation could be expressed $s=h\frac{\sin 65°}{\sin 90°}=h(0.9)$ and s and h are seen to be not markedly different. In some instances, notably in the upper parts of the 8000 and 8200 veins on the eastern limb of the Western anticline, the dip of the bedding is gentle to the east, and in such circumstances $s=h\frac{\sin 20°}{\sin 45°}=h(0.4)$, or in other words the actual slip is less than half the apparent offset. Since gentle westerly dips are rare and very local, examples of offsets of beds in a left-hand direction, opposite to the strike-slip, must also be rare. In the writer's knowledge no example of a left-hand offset of this type has been recorded in any of the northeasterly trending faults (vein fractures) of the camp.

Table VIII.—Computed Net Slip on Veins

Vein Fracture	Location	Feature Offset	Apparent Dip	Horizontal Separation on Vein	Computed Net Slip
Veins of Western Anticline			Deg.	Ft.	Ft.
Sumit	3S level, west end	Bed	70 E.	12	11
	4S level, 160 ft. in	Bed	70 E.	12	11
	4S level, 245 ft. in	Bed	70 E.	12	11
Ore Hill	Surface at top of Reno	Bed	85 E.	10±	10±
South branch	6 level at top of Reno	Bed	85 E.	15±	15±
North branch	Surface and 6 level at top of Reno	Bed	85 E.	10±	10±
Adit, 5,546 ft. (1,000 ft. S. 80° E. portal of 8 level, Ore Hill mine)	Top of Reno	Bed	65 E.	6	5
44 vein	5 level S., Sheep Creek mine	Bed	55 E.	3	3
57 vein	7 level, 9505E[1]	Bed	55 E.	7	5.5
	7 level, 9645E	Bed	55 E.	0.2	0.2
64 vein	9 level, 9730E	Bed	55 E.	25	19
68 vein	2 level, 9570E	Bed	50 E.	0.2	0.2
	4 level, 9250E	Bed	30 E.	23?	13?
	4 level, 9390E	Dyke	80 W.	12	14.5
	4 level, 9570E	Bed	60 E.	9	8
	5 level, 9360E	Bed	45 E.	20	15
	5 level, 9670E	Bed	70 E.	9.6	9
	5 level, 9730E	Bed	70 E.	7	6.5
	7 level, 9820E	Bed	60 E.	1.5	1.3
	9 level, 9720E	Bed	50 E.	11	8.5
75 vein	2 level, 9495E (incl. 76 vein)	Ax. pl.	80 W.	60+	70+
	5 level, 9790E	Bed	65 E.	41	37
	7 level, 8870E	Bed	70 E.	17	16
76 vein	2 level (*see* above)	....	....	....	....
	5 level, 9830E	Bed	65 E.	25	22.5
81 vein	2 level, 9560E	Ax. pl.	80 E.	25	25.5
	2 level, 9770E	Bed	65 E.	38	34.5
	4 level, 9890E	Bed	70 E.	30±	28±
	4 level, 10010E	Bed	65 E.	10±	9±
	6 level, 9530E	Bed	30 E.	75	45
	7 level, 8840E	Bed	75 E.	65	63
	7 level, 8940E	Bed	70 E.	65	61
	7 level, 9740E	Bed	60 E.	54±	47±
	9 level, 9360E	Bed	35 E.	47	31
	9 level, 9410E	Bed	55 E.	48	40
83 vein	2 level, 9570E	Ax. pl.	90	44	48
	5 level, 9540E	Bed	50 W.	25±	45±
South split	9 level, 9990E	Bed	65 E.	6	5.5
	9 level, 10030E	Bed	55 E.	7	5.8
North split	9 level, 10040E	Bed	55 E.	12	10
85 vein	2 level, 9610E	Ax. pl.	90	60	66
	5 level, 8830E	Bed	90	20	22
	5 level, 8890E	Bed	85 E.	20	23
	5 level, 8910E	Bed	90	19	21
	7 level, 9000E	Bed	70 E.	35	33
92 vein	2 level, 9690E	Ax. pl.	90	80±	87±
	5 level, 9690E	Ax. pl.	90	55	60
	7 level, 9870E	Bed	55 E.	61?	50?
	7 level, 9960E	Bed	70 E.	25?	24?
	8 level, 9690E	Ax. pl.	70 E.	30	28.5
	8 level, 9770E	Ax. pl.	90	25	27.5
Queen vein	3 level, 9200E	Bed	50 W.	35	65
	3 level, 9400E	Bed	55 W.	100	160
	3 level, 9800E	Ax. pl.	90	100?	110?
	3 level, 10340E	Bed	60 E.	100±	88±
	3 level, 10800E	Bed	55 E.	70	58
	5 level, 9450E	Bed	65 W.	110+	150+
	5 level, 9800E	Ax. pl.	90	210	230
	6 level, 9250E	Bed	80 E.±	113	115±
	7 level, 10340E	Bed	55 E.	100±	85±
	8 level, 9020E	Bed	60 E.	92	75
	8 level, 9850E	Ax. pl.	90±	280−	310−
	8 level, 10450	Bed	55 E.	92	75
Yellowstone	1 level, 10330E	Bed	60 E.	140	120
Dixie—6600 vein	Top of Reno, west limb	Bed	80 E.	17	17
	Top of Nugget, east limb	Bed	42 E.	25	18

[1] Sheep Creek mine co-ordinate of intersection of observed feature, bed, etc., with south wall of vein.

Table VIII.—Computed Net Slip on Veins—Continued

Vein Fracture	Location	Feature Offset	Apparent Dip	Horizontal Separation on Vein	Computed Net Slip
			Deg.	Ft.	Ft.
8000 vein	1975 level, 4700E[2]	Bed	10 E.	55	17
	1975 level, 5110E	Bed	40 E.	22+	17+
	2100 level, 4175E	Bed	85 E.	12?	12.5?
	2100 level, 4750E	Dyke	90	(23)	(25)
	2100 level, 4840E	Bed	35 E.	66	44
8200—Columbia vein	Surface, 3860E	Ax. pl.	65 E.	60	54
	Columbia No. 1 adit, 3845E	Bed	90±	40+	44+
	Columbia No. 2 adit, 3975E	Ax. pl.	65 E.	42	38
	1600 level, 3990E	Bed	90	85?	94?
	1725 level, 4275E	Bed	90	48	53
	1725 level, 4555E, north split only	Bed	22 E.	50±	27±
	1725 level, 4875E	Bed	20 E.	90	43
	1850 level, 4280E	Bed	90	22	24
	1850 level, 4785E	Bed	30 E.	35	21
	2100 level, 4920E	Dyke	75 E.	37	36
	2100 level, 5045E	Bed	40 E.	40	28
2360 vein	1600 level, 4860E	Bed	45 W.	12	25
	1600 level, 5630E	Bed	25 E.	26	14
	1600 level, 5720E	Bed	40 E.	26	17
2590 vein	1600 level, 5220E	Ax. pl.	60 E.	27±	24±
3040 vein	1400 level, 5275E	Bed	90	3	3.3
	1400 level, 5440E	Ax. pl.	55 E.	30±	25±
	1400 level, 5820E	Bed	25 E.	6	3.3
	1600 level, 5610E	Ax. pl.	90	25±	27±
3500 vein	600 level, 5100E	Ax. pl.	60 E.	15−	13−
	1100 level, 5130E	Bed	70 E.	16	15
	1100 level, 5200E	Bed	75 E.	16	15.5
	1100 level, 5540E	Ax. pl.	60 E.	50±	47±
	1400 level, 5200E	Bed	55 E.	8	6.5
	1400 level, 5475E	Bed	80 E.	90–5[3] (dyke)	87
	1400 level, 5840E	Bed	7 E.±	165	40±
	1600 level, 5500E	Bed	85 E.	31	32.5
	1600 level, 6030E	Bed	45 E.	60	45
	1600 level, 6080E	Dyke	90?	72	80?
3900 vein	1100 level, 5700E	Bed	80 W.	18	22
4600 vein	1100 level, 6215E	Ax. pl.	50 E.	79	63
4800 vein (no information)					
Cayote South	Top of Navada, east limb	Bed	20 E.	10	5
Cayote North	Top of Navada, east limb	Bed	20 E.	15±	7.5±
Bluestone	5700 level, top of Navada, east limb	Bed	25 E.	10	5.5
	5600 level, top of Navada, east limb	Bed	25 E.	16	9
Reno	1 level, 10745E[4]	Bed	45 E.	1	0.75
	1 level, 11040E	Bed	90	11	12
	3 level, 10275E	Bed	80 E.	18	18.5
	3 level, 10665E	Ax. pl.	70 E.	25±	24±
	3 level, 10825E	Ax. pl.	70 E.	25±	24±
	3 level, 11220E	Bed	55 E.	4	3.4
	4 level, 10320E	Bed	90	8	9
	4 level, 11160E, south branch	Bed	20 E.	2	1
	5 sublevel, 10230E	Bed	80 E.	8	8.5
	5 sublevel, 10410E	Bed	80 E.	13	13.2
	5 sublevel, 10590E, south branch only	Bed	55 W.	2	4.8
	5 sublevel, 11145E	Bed	30 E.	2	1.2
	5 sublevel, 11200E	Bed	25 E.	0	0
	5 sublevel, 11345E	Ax. pl.	55 E.	7	5.8
	5 sublevel, 11420E	Bed	50 E.	3	2.4
	5 level, 10445E	Bed	75 E.	−1[5]	0+[6]
	5 level, 10735E	Ax. pl.	70 E.	30±	25±
Middle (no information)					
Donnybrook	Surface, 11350E	Bed	55 E.	5±	4±
Lake (no information)					

[2] Gold Belt mine co-ordinate of intersection of observed feature with south wall of vein.
[3] Horizontal separation has been increased 5 feet beyond its original amount by the intrusion of a post-vein lamprophyre dyke 5 feet wide.
[4] Reno mine co-ordinate of intersection of observed feature with south wall of vein.
[5] Left-hand horizontal separation instead of right-hand offset seen in all other examples.
[6] Dilation or reverse movement.

Table VIII.—Computed Net Slip on Veins—Continued

Vein Fracture	Location	Feature Offset	Apparent Dip	Horizontal Separation on Vein	Computed Net Slip
Veins of West Limb of Eastern Anticline			Deg.	Ft.	Ft.
Bonanza South	4175 level, 11410E	Bed	70 E.	60?	57
	4175 level, 12250E	Bed	65 E.	71	64
Bonanza North	4175 level, 11480E	Bed	70 E.	78	74
Alexandra	3 level, 11910E	Bed	55 E.	7.5	6.3
	1 level, top of Mid Nugget	Bed	65 E.	33	30
Midnight	3 level, 11900E	Bed	70 E.	20±	19±
	7 level, 12500E	Bed	70 E.	10	9.5
Black	3 level, 10575E[7]	Bed	60 E.	12	10.5
	6 level, 10680E	Bed	55 E.	25	21
	6 level, 10800E	Bed	60 E.	21	18
	7 level—				
	10870E, south branch	Bed	60 E.	33	29
	10905E, north branch	Bed	60 E.	10	8.8
B vein	1 level, 10430E	Bed	70 E.	80	76
	2 level, 10140E	Bed	65 E.	15	13.5
	2 level, 10530E	Bed	65 E.	60	54
	2 sublevel, 10650E	Bed	60 E.	40	35
	3 level, 10240E	Bed	60 E.	30	26
	3 level, 10675E	Bed	60 E.	55	48
	7 level, 10585E	Bed	45 E.	15+	11+
B vein E (*see* A vein E)					
A vein	1 level, 10440E	Bed	70 E.	37	35
	1 level, 10500E	Bed	70 E.	40	38
	2 level, 10190E	Bed	65 E.	9	8
	2 level, 10515E	Bed	65 E.	28	25
	2 level, 10580E	Bed	65 E.	35	32
	2 level, 10670E	Bed	65 E.	25	23
	2 level, 10990E (incl. B)	Bed	65 E.	57	52
	2 sublevel, 10230E	Bed	60 E.	15	13
	2 sublevel, 10585E	Bed	60 E.	25	22
	2 sublevel, 10650E	Bed	60 E.	38	33
	2 sublevel, 11025E (incl. B vein)	Bed	60 E.	40	35
	3 level, 10665E	Bed	60 E.	27	24
	3 level, 10725E	Bed	60 E.	60	52
	3 level, 10885E	Bed	60 E.	65	57
	3 level, 11140E (incl. B)	Bed	60 E.	60?	52?
	3 level, 11200E (incl. B)	Bed	60 E.	85	74
	3 level, 11455E (incl. B)	Bed	60 E.	93	81
	4 level, 10365E	Bed	60 E.	30	26
	4 level, 10790E	Bed	60 E.	55	48
	5 level, 10410E	Bed	60 E.	35	31
	5 level, 10850E	Bed	60 E.	70	61
	6 level, 10320E	Bed	65 E.	2	1.7
	6 level, 10420E	Bed	70 E.	9	8
	6 level, 10745E, north branch	Bed	60 E.	10	9
	6 level, 10900E	Bed	55 E.	65	54
	7 level, 10670E	Bed	55 E.	45	37.5
	8 level, 10455E	Bed	50 E.	13	10
	8 level, 10775E	Bed	45 E.	38	29
	8 level, 11140E	Bed	45 E.	65	49
	9 level, 10525E	Bed	50 E.	39	31
	9 level—				
	10840E, south branch	Bed	45 E.	35	26
	10885E, north branch	Bed	45 E.	25	19
	10 level, 10580E	Bed	50 E.	50	40
	10 level, 10905, south branch	Bed	45 E.	38	28.5
Queen	2 level, 10205E[7]	Bed	65 E.	30	27
	7 level, 10815E	Bed	55 E.	30+	25+
Unnamed	Surface, 9950, west of 2 level portal, K.B. mine	Bed	65 E.	33	30
Yellowstone (no information)					
1500 zone	Surface at top of Navada	Bed	60 E.	20+	17.5
	Surface at top of Mid Nugget	Bed	65 E.	25±	23±
Clyde	Surface at top of Navada	Bed	65 E.	60±	55±
	5166 level at top of Nugget	Bed	65 E.	31	28
	5166 level at top of Mid Nugget	Bed	65 E.	15	14
Golden Belle	Surface at top of Nugget	Bed	65 E.	65±	60±
	Surface at top of Mid Nugget, north branch	Bed	65 E.	50±	45±
	Surface at top of Lower Nugget	Bed	65 E.	60	55
	5495 level at top of Nugget	Bed	65 E.	70	64

[7] Kootenay Belle mine co-ordinate of intersection of bed with south wall of vein.

Table VIII.—Computed Net Slip on Veins—Continued

Vein Fracture	Location	Feature Offset	Apparent Dip	Horizontal Separation on Vein	Computed Net Slip
			Deg.	Ft.	Ft.
	5274 level at top of Nugget, south branch	Bed	65 E.	25	23
	5274 level at top of Mid Nugget, south branch	Bed	65 E.	10	9
Motherlode	1 level, 11630E,[8] south branch	Bed	65 E.	28	25.5
	2 level, 11695E, south branch	Bed	65 E.	30	27
	3 level, 12080E	Bed	70 E.	50	48
	3 level, 12450E	Bed	70 E.	65	62
	3 level, 12680E	Bed	60 E.	60	53
	3 level, 13120E	Bed	65 E.	50	45
	3 level, 13205E	Bed	65 E.	35	32
	3 level, 13260E	Bed	65 E.	12	11
	5 level, 11800E	Bed	65 E.	48+	44+
	5 level, 12195E	Bed	65 E.	70	64
	5 level, 12530E	Bed	65 E.	65	59
	5 level, 12785E	Bed	60 E.	76	66
	6 level, 12150E	Bed	60 E.	70	61
	6 level, 12260E	Bed	60 E.	75	65
	8 level, 12105E	Bed	55 E.	65?	54?
	8 level, 12315E	Bed	60 E.	90	79
	8 level, 12395E	Bed	65 E.	90	82
	8 level, 12715E	Bed	65 E.	88	80
	8 level, 12950E	Bed	65 E.	90±	82±
	10 level, 12045E	Bed	60 E.	60	52
	10 level, 12150E	Bed	60 E.	63	55
	10 level, 12280E	Bed	60 E.	70	61
	10 level, 12865E	Bed	60 E.	56	49
	10 level, 13075E	Bed	65 E.	55±	50±
Unnamed, 100 ft. north of Motherlode	2 level, 11750E	Bed	65 E.	15±	14±
Golden West (no information)					
Nugget	4 level, 11955E (incl. Calhoun vein)	Bed	60 E.	12	10.5
	4 level, 12070E (incl. Calhoun vein)	Bed	55 E.	15	12.5
	4 level, 12365E	Bed	55 E.	15	12.5
	4 level, 12405E	Bed	65 E.	13	12
	4 level, 12455E	Bed	60 E.	12	10.5
	4 level, 12590E, south branch	Bed	75 E.	12?	12?
	4 level, 12610E, north branch	Bed	75 E.	3?	3?
	4 level, 12685E, south branch	Bed	60 E.	5?	4.3
	5 level, 12725E	Bed	65 E.	15±	14±
	5 level, 12860E	Bed	60 E.	16±	15±
	5 level, 13420E	Bed	75 E.	0.66	0.6
	5 level, 13435E	Bed	70 E.	0.50	0.45
	5 level, 13480E	Bed	70 E.	0.25	0.22
	9 level, 12815E, north branch	Bed	65 E.	1	0.9
	10 level, 12910E, north branch	Bed	65 E.	3	2.7
	10 level, 12740E, south branch	Bed	60 E.	4.5	4
	10 level, 12870E, south branch	Bed	65 E.	7.5?	7?
	10 level, 12920E, south branch	Bed	70 E.	5	4.5
	10 level, 12940E, south branch	Bed	70 E.	3.5	3.2
	10 level, 12980E, south branch	Bed	70 E.	1	0.9
Calhoun	4 level, 12380E	Bed	60 E.	4?	3.5?
Unnamed, 60 ft. north of Nugget at 5 level crosscut		Bed	65 E.	6	5.4
O'Donnell	4 level at top of Navada	Bed	65 E.	25	22
	4 level at top of Lower Navada	Bed	60 E.	24	21
Fawn No. 3 (no information)					
Fawn No. 2	2 level, 12450E	Bed	60 E.	40	35
	5 level, 12675E	Bed	60 E.	15	13
Fawn No. 1	3 level, 12405E	Bed	60 E.	15	13
	5 level, 13000E	Bed	45 E.	33	25
Fawn No. 4	5 level, 12765E	Bed	60 E.	16	14

[8] Reno mine co-ordinate of intersection of bed with south wall of vein.

Plate I. North slope of Sheep Creek valley, showing top and bottom of Quartzite Range formation and fold axes, 1949.

Plate II. View looking up Sheep Creek from the mouth of Waldie (Wolf) Creek, 1909.

Plate III. View looking south from Reno Mountain, showing the steep north-facing slopes developed on the Quartzite Range formation, 1949.

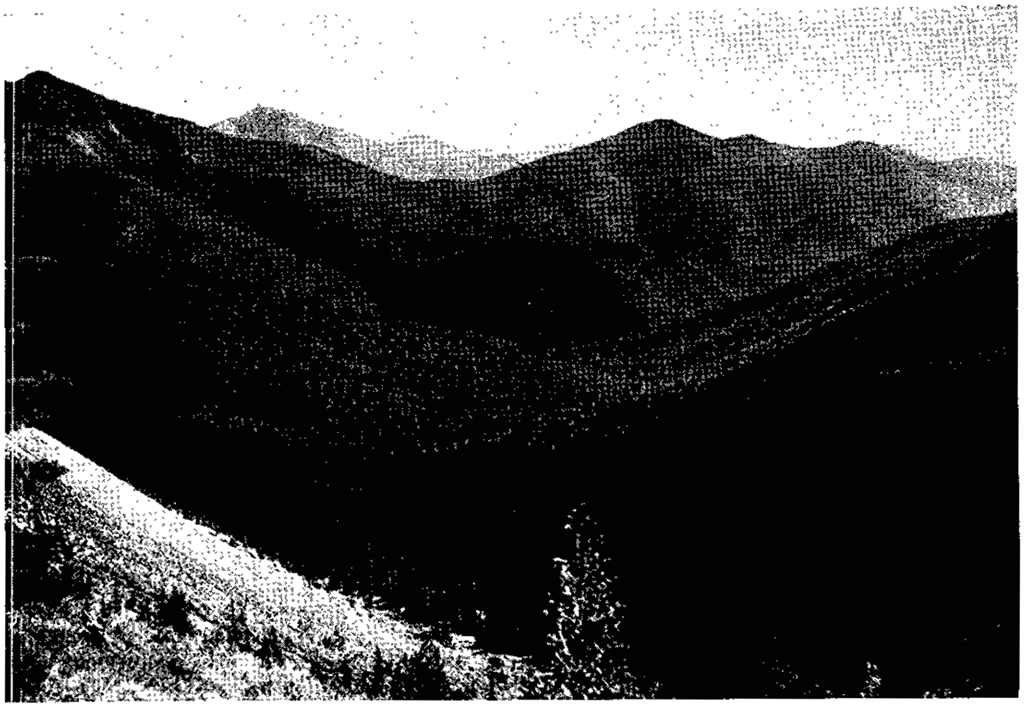

Plate IV. Fawn Creek basin from the Reno mine, 1949.


Plate V. Original Kootenay Belle mill, 1909.

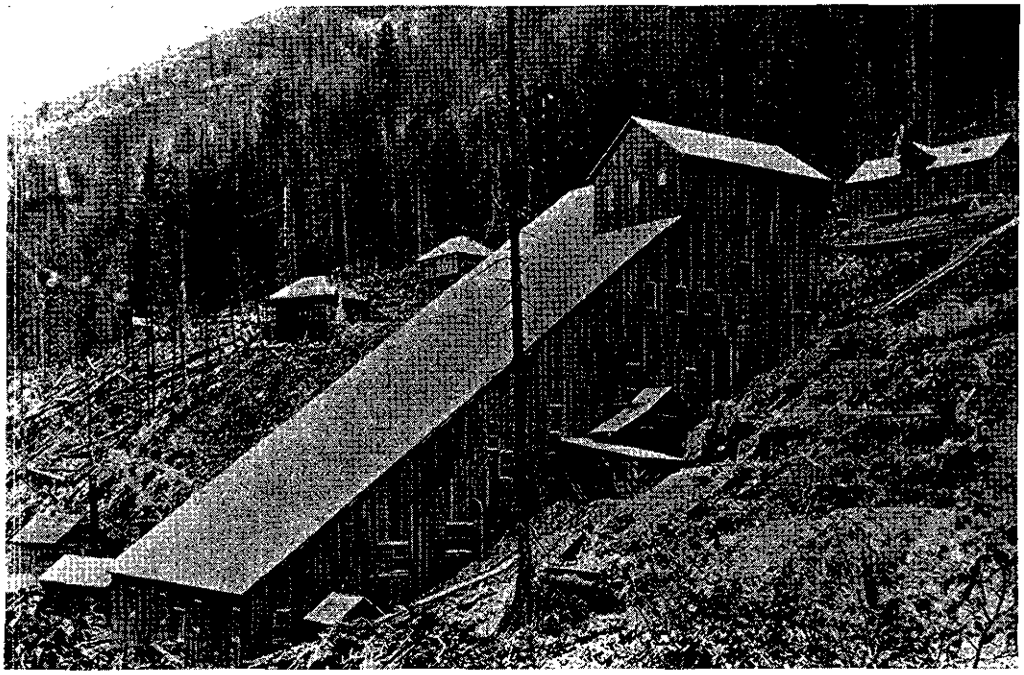

Plate VI. Motherlode mill, 1915.

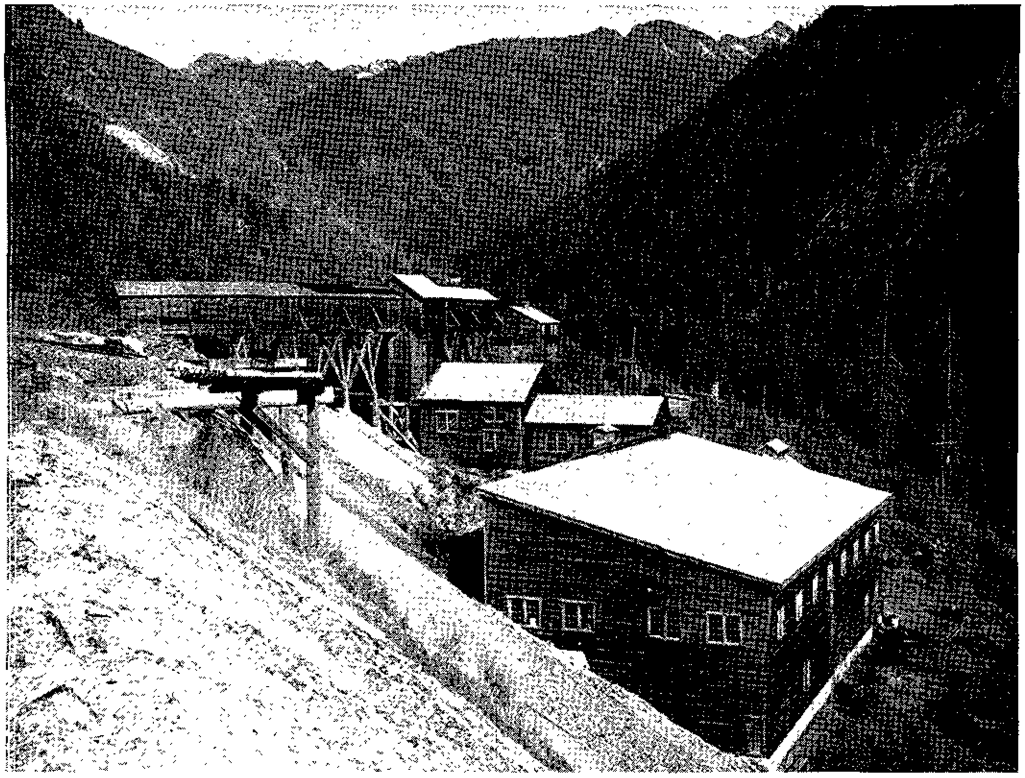

Plate VII. Gold Belt mill, 1945.

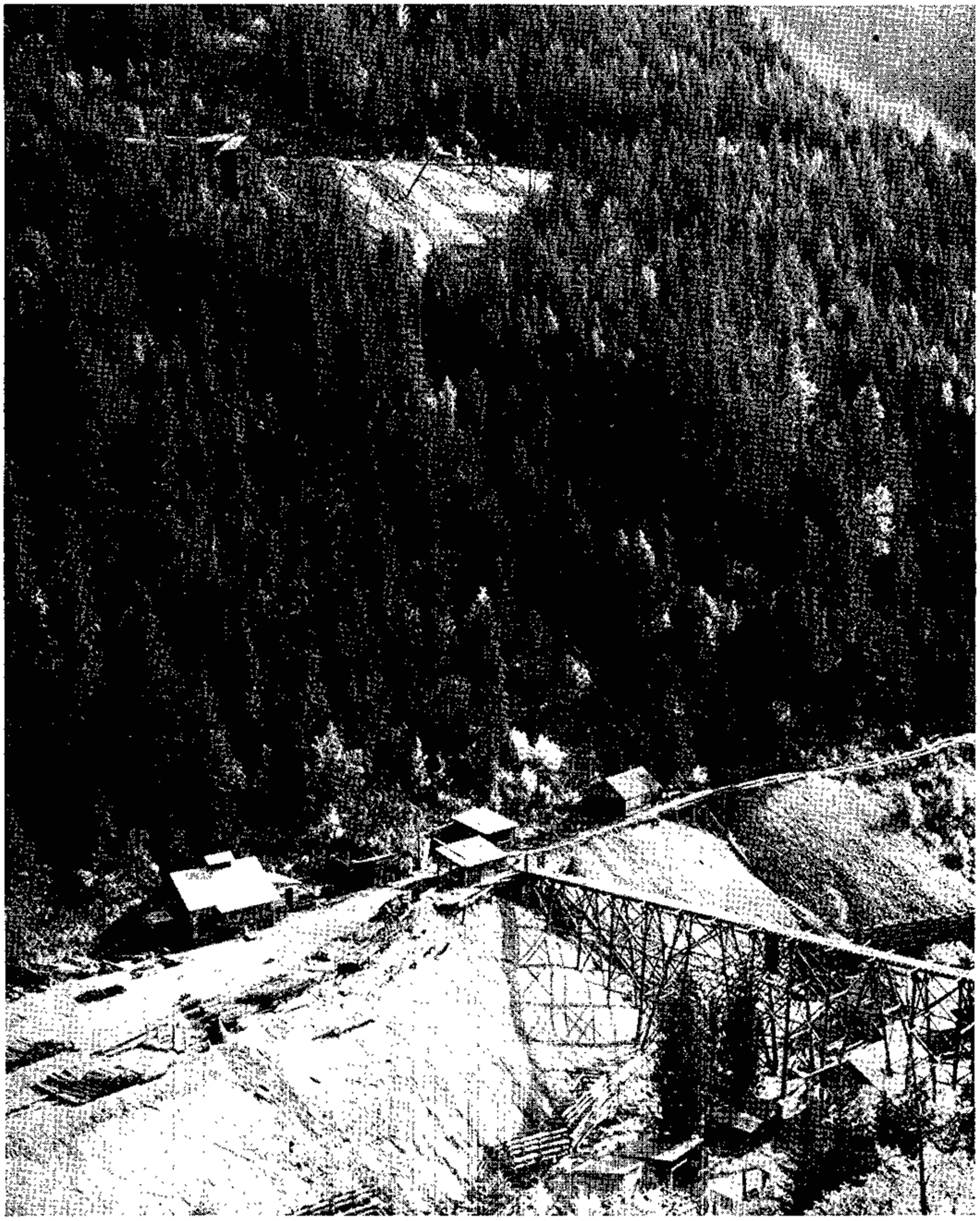

Plate VIII. Portals of No. 6 (below) and No. 3 (above) adits, Kootenay Belle mine, 1945.

INDEX

General Note.—Mines or properties have been grouped under the name of the company that held or operated them in the latest period of principal activity. Changes in ownership since that period are noted on page 75.

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1953

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FIG. I
GEOLOGICAL MAP
OF THE
SHEEP CREEK MINING CAMP
WEST KOOTENAY DISTRICT, BRITISH COLUMBIA

TO ACCOMPANY B.C. DEPARTMENT OF MINES BULLETIN 31
"GEOLOGY OF THE SHEEP CREEK MINING CAMP", BRITISH COLUMBIA, BY W.H. MATHEWS, 1953.

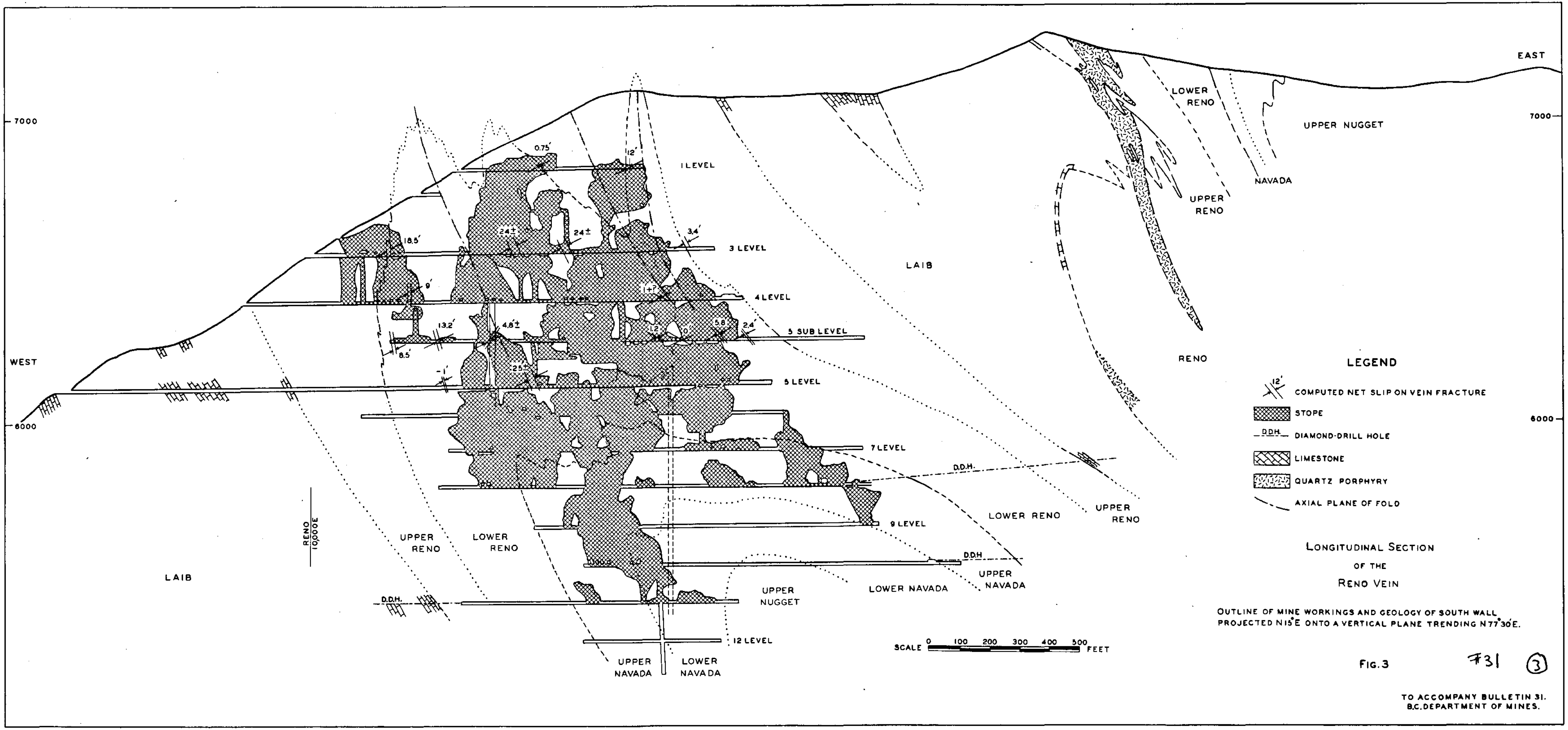
FIG. 2

COMPOSITE PLAN SHOWING

GEOLOGY OF THE PRINCIPAL WORKINGS

SHEEP CREEK CAMP

TO ACCOMPANY B.C. DEPARTMENT OF MINES BULLETIN 31 "GEOLOGY OF THE SHEEP CREEK MINING CAMP, BRITISH COLUMBIA, BY W.H. MATHEWS, 1953.



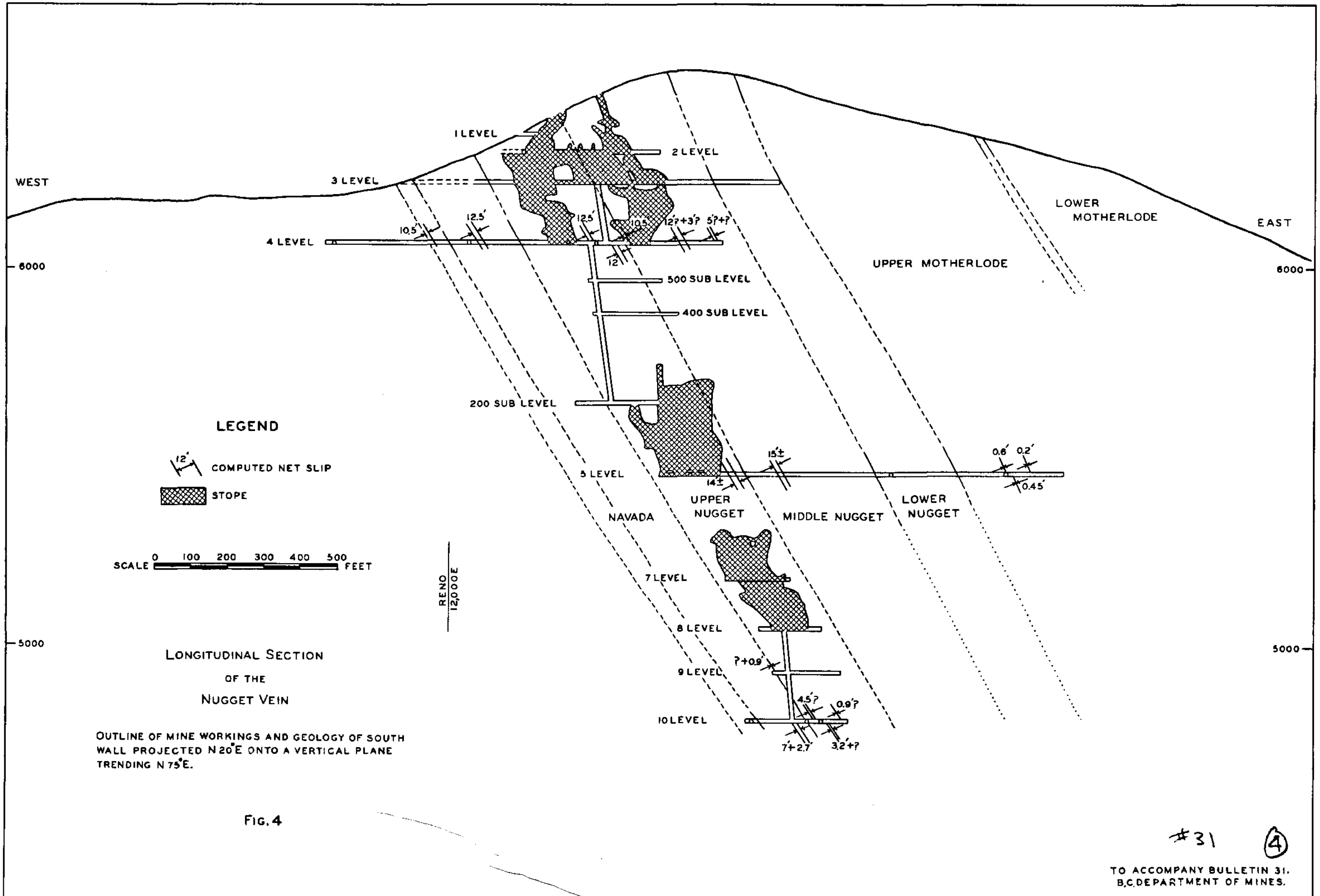
Longitudinal Section of the Reno Vein

Outline of mine workings and geology of south wall projected N15°E onto a vertical plane trending N77°30'E.

Fig. 3

F31 (3)

To accompany Bulletin 31.
B.C. Department of Mines.



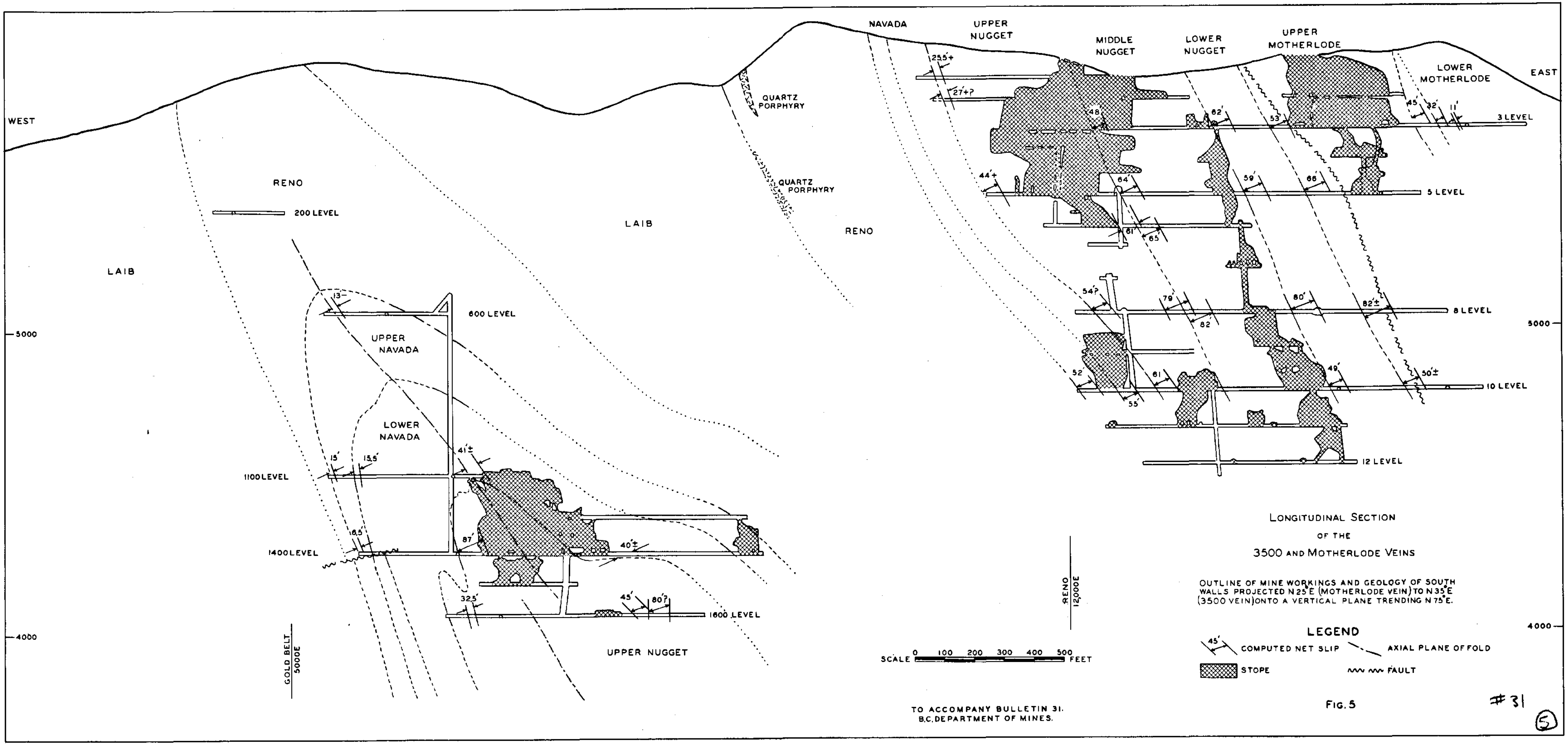
LONGITUDINAL SECTION OF THE NUGGET VEIN

OUTLINE OF MINE WORKINGS AND GEOLOGY OF SOUTH WALL PROJECTED N 20°E ONTO A VERTICAL PLANE TRENDING N 75°E.

FIG. 4

#31 ④

TO ACCOMPANY BULLETIN 31.
B.C. DEPARTMENT OF MINES.



LONGITUDINAL SECTION OF THE 3500 AND MOTHERLODE VEINS

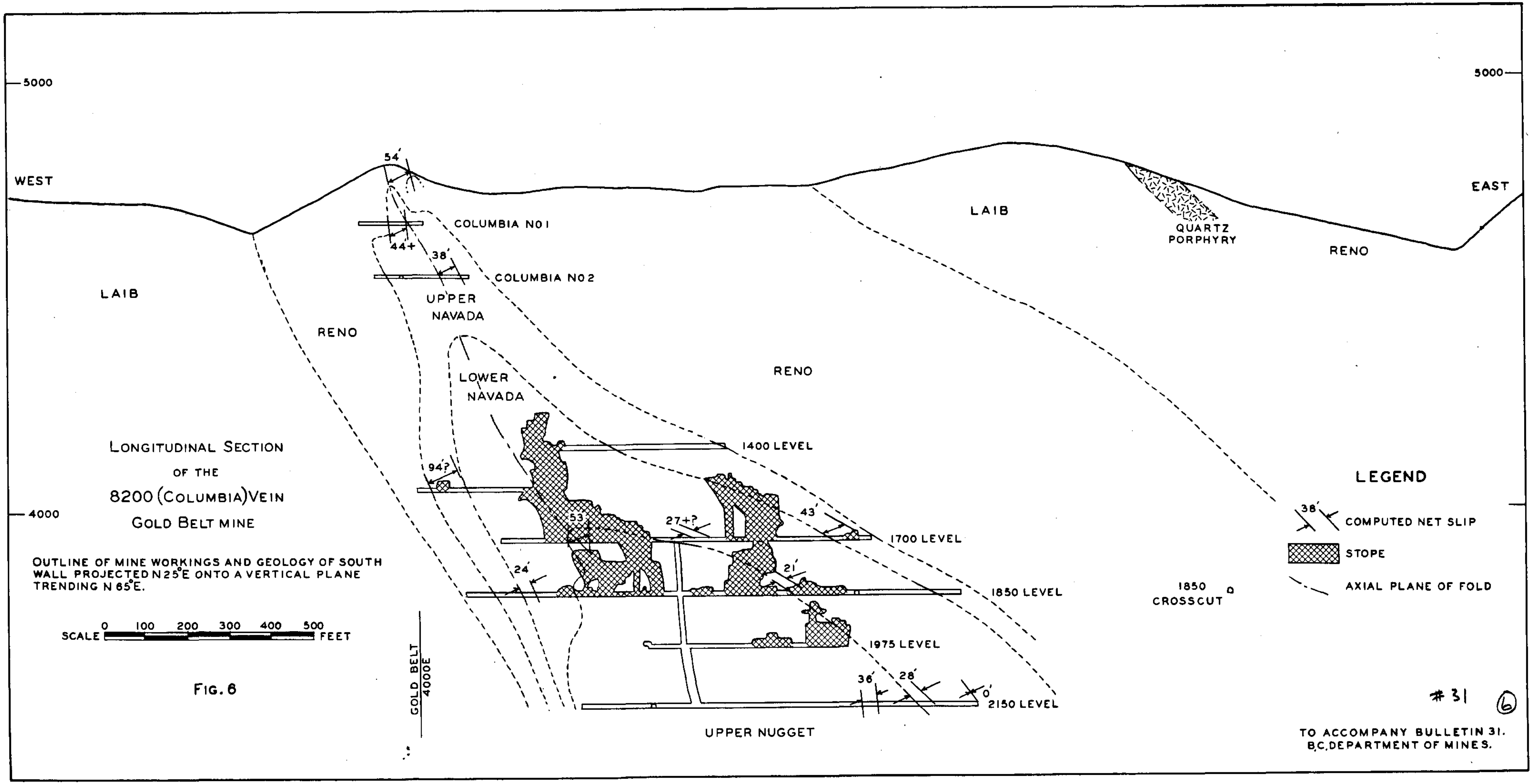
OUTLINE OF MINE WORKINGS AND GEOLOGY OF SOUTH WALLS PROJECTED N 25° E (MOTHERLODE VEIN) TO N 35° E (3500 VEIN) ONTO A VERTICAL PLANE TRENDING N 75° E.

FIG. 5

TO ACCOMPANY BULLETIN 31.
B.C. DEPARTMENT OF MINES.

#31

(5)

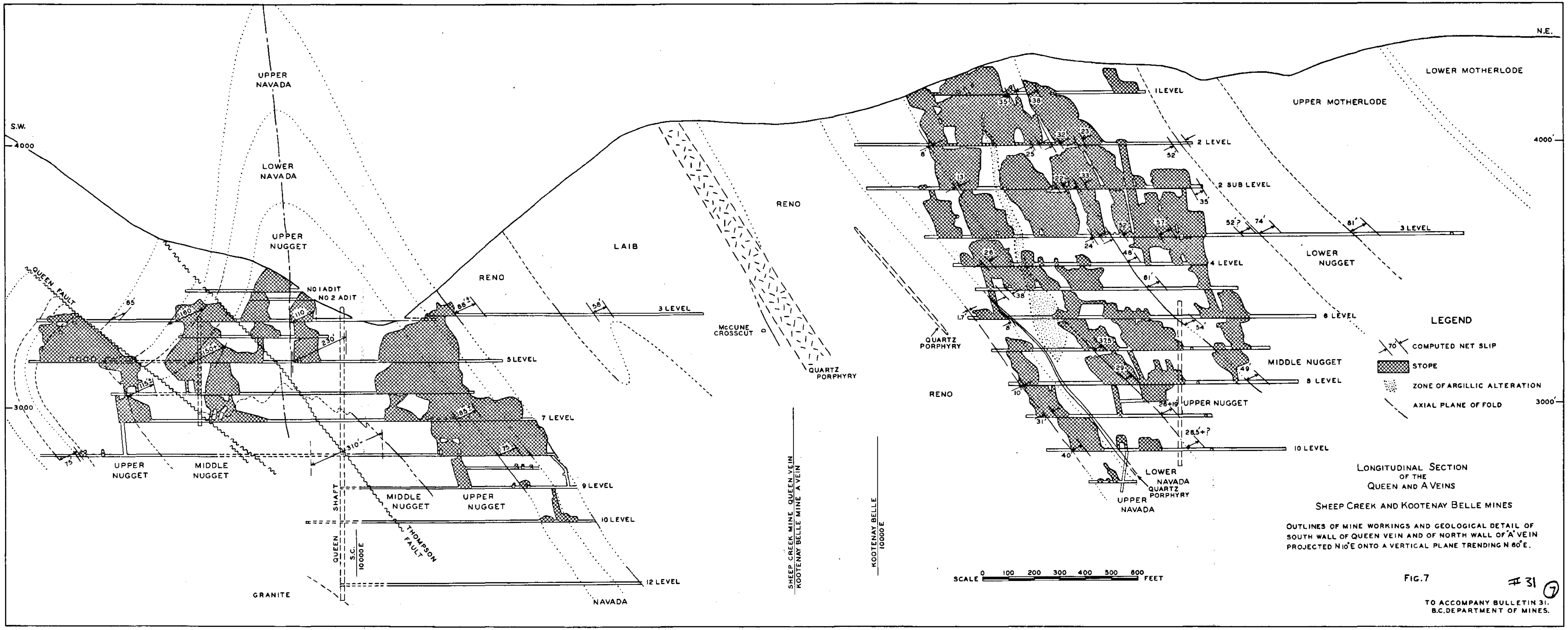


LONGITUDINAL SECTION OF THE 8200 (COLUMBIA) VEIN GOLD BELT MINE

OUTLINE OF MINE WORKINGS AND GEOLOGY OF SOUTH WALL PROJECTED N 25°E ONTO A VERTICAL PLANE TRENDING N 65°E.

FIG. 6

TO ACCOMPANY BULLETIN 31. B.C. DEPARTMENT OF MINES.



Longitudinal Section of the Queen and A Veins

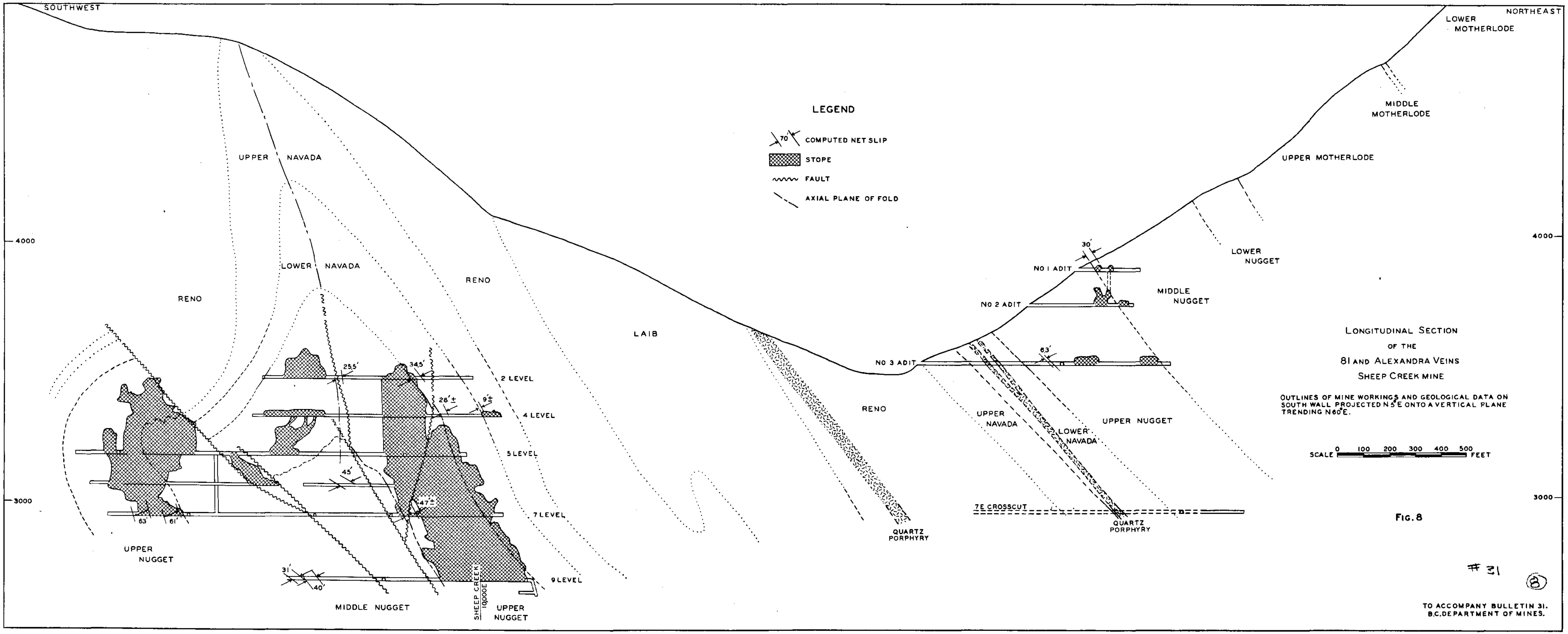
Sheep Creek and Kootenay Belle mines

Outlines of mine workings and geological detail of south wall of Queen vein and of north wall of "A" vein projected N 10° E onto a vertical plane trending N 80° E.

Fig. 7

#31

To accompany Bulletin 31. B.C. Department of Mines.



Longitudinal Section
of the
81 and Alexandra Veins
Sheep Creek Mine

Outlines of mine workings and geological data on south wall projected N 5° E onto a vertical plane trending N 60° E.

Fig. 8

#31

(8)

To accompany Bulletin 31.
B.C. Department of Mines.

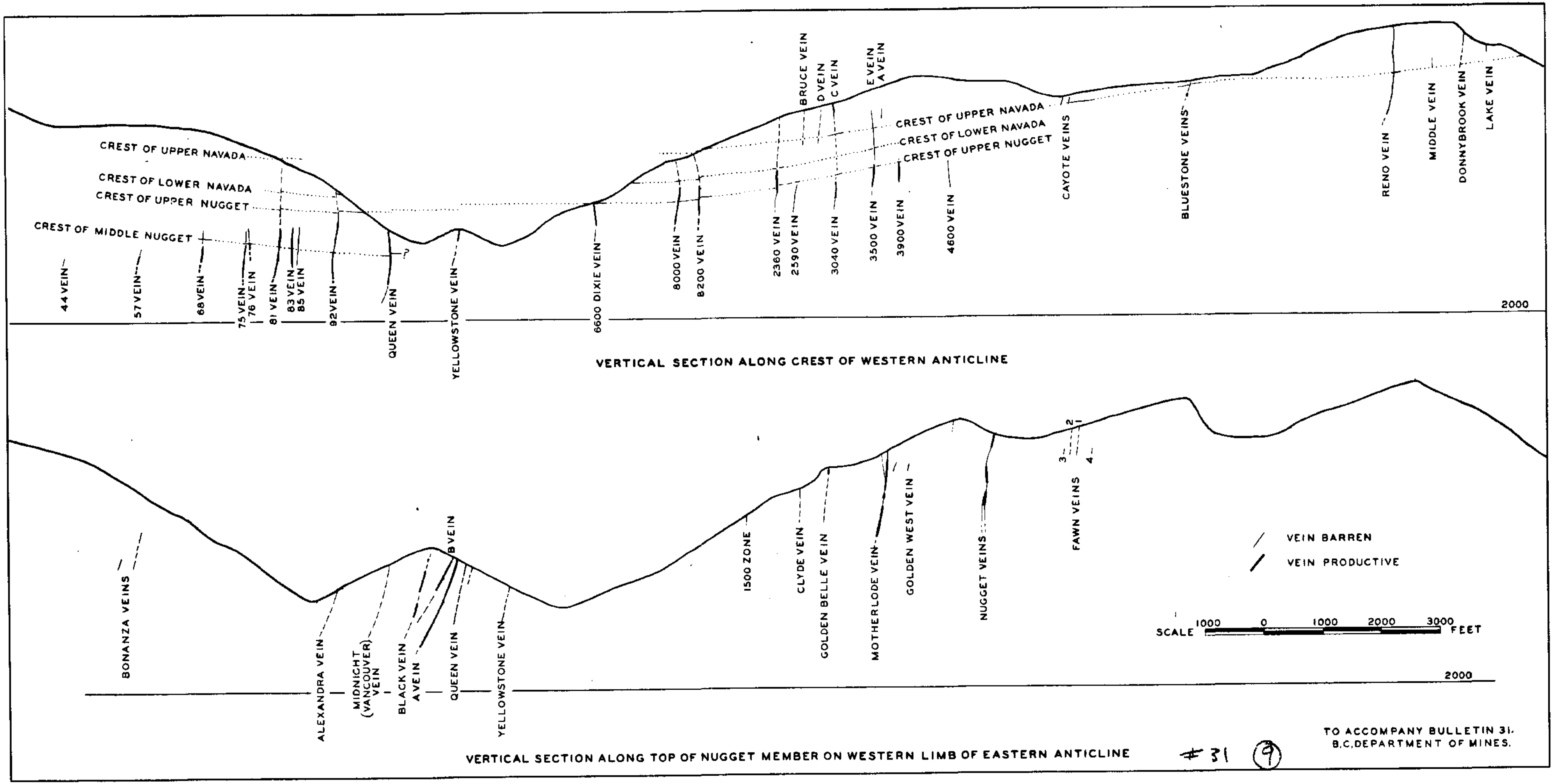

CREST OF UPPER NAVADA
CREST OF LOWER NAVADA
CREST OF UPPER NUGGET
CREST OF MIDDLE NUGGET
44 VEIN
57 VEIN
68 VEIN
75 VEIN
76 VEIN
81 VEIN
83 VEIN
85 VEIN
92 VEIN
QUEEN VEIN
YELLOWSTONE VEIN
6600 DIXIE VEIN
8000 VEIN
8200 VEIN
BRUCE VEIN
D VEIN
C VEIN
E VEIN
A VEIN
2360 VEIN
2590 VEIN
3040 VEIN
3500 VEIN
3900 VEIN
4600 VEIN
CAYOTE VEINS
BLUESTONE VEINS
RENO VEIN
MIDDLE VEIN
DONNYBROOK VEIN
LAKE VEIN
2000
VERTICAL SECTION ALONG CREST OF WESTERN ANTICLINE
BONANZA VEINS
ALEXANDRA VEIN
MIDNIGHT (VANCOUVER) VEIN
BLACK VEIN
A VEIN
B VEIN
QUEEN VEIN
YELLOWSTONE VEIN
1500 ZONE
CLYDE VEIN
GOLDEN BELLE VEIN
MOTHERLODE VEIN
GOLDEN WEST VEIN
NUGGET VEINS
FAWN VEINS
1
2
3
4
VEIN BARREN
VEIN PRODUCTIVE
SCALE 1000 0 1000 2000 3000 FEET
2000
VERTICAL SECTION ALONG TOP OF NUGGET MEMBER ON WESTERN LIMB OF EASTERN ANTICLINE
TO ACCOMPANY BULLETIN 31.
B.C. DEPARTMENT OF MINES.
#31 (9)

FIG. 9