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Geology of the Whitewater and Lucky Jim Mine Areas

Slocan District

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By
M. S. HEDLEY

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SUMMARY.

This bulletin contains a structural analysis of the area between Retallack and Zincton and a detailed description of the Whitewater and Lucky Jim mines as well as of six smaller properties.

The area is in the slate belt, the basal part of the Slocan sedimentary series of Triassic age. The slaty rocks are cut by both granitic and lamprophyre dykes. The predominantly argillaceous rocks are in part slates but include phyllites and bands and single beds of limestone and quartzite. The regional strike is north-westward and the prevalent dip south-westward. The structure plunges westward west of Whitewater Creek and eastward east of that creek.

Other than a synclinal basin west of Zincton there is no major folding into anticlines and synclines, but there is a large and important drag-fold west of Whitewater Creek. This drag-fold is non-symmetrical and is highly irregular in form. It is localized at the reversal of regional plunge of the structure. There are many minor intricate structures in the area as a whole, none of which are symmetrical and few of which are continuous. There have been, in the Retallack area at least, two periods of deformation.

The intricacy of minor structures is such that geological mapping is difficult and must remain to some degree interpretive. Marked rock-flowage in many parts and brecciation in others testify that much differential movement took place. Some initial minor folding has been obliterated by the differential movement. Although this part of the Slocan series has not been thickened by isoclinal folding, it has been thickened greatly by minor structures; the amount of thickening, however, can not be measured.

The Whitewater mine is in and close to a large and irregular zone of thrusting. The lode in the upper part of the mine, between slate walls, contains silver-lead-zinc ore, with lead and zinc about equal in amount and with about 2½ oz. of silver to the per cent. lead. In the lower part of the mine the lode intersects the drag-folded Whitewater limestone close to its lower surface, and above the lode there are predominantly zinc-bearing replacement deposits with a zinc-lead ratio of about 5 to 1 and with a silver content of about 1 oz. to the per cent. lead. The replacement ore is dominantly in a siderite gangue, but a substantial tonnage consists of replacement in a lamprophyre dyke in which the gangue contains much magnetite and pyrrhotite. Minor structures are important in localizing the sideritic replacement ore, but projection is difficult owing to the irregularity of the lode and to the fact that the major drag-fold has reversals in plunge and has undergone a rotation of its axial plane.

The Lucky Jim mine lies within the Lucky Jim limestone, part of a member of banded argillites. The limestone is brecciated throughout much of its known extent and is partly bleached through hydrothermal agencies; the brecciation is pre-ore and is earlier than granitic dykes which are also pre-ore. The ore is a replacement of the limestone by sphalerite and pyrite and, in the upper levels only, galena. The structure is complex. The limestone and argillites are drag-folded and the limestone is greatly thickened locally, but the detailed outline of the deformation is not clearly defined. Brecciation, rock-flowage, and squeezing have destroyed the bedding of both limestone and argillites in many places.

The replacement ore is controlled by three major factors: vertical cross-fractures which cross the limestone at right angles, the direction of plunge of the folding, and vertical longitudinal fractures which are parallel in strike with the major structure. The cross-fractures provide the dominant control in the upper part of the mine, and the presence of galena in that part may be related to them; they are possibly related to domes or cross-warps in the drag-folding. The more general control follows the drag-folds, although ore is not strictly localized along limestone-argillite contacts. The plunge of the folding nearly parallels the line of outcrop of the limestone, and consequently the ore-zone is roughly parallel to the ground surface.

Neither the amount of brecciation in the limestone nor to what extent the brecciation has affected ore deposition is known. The bleaching, which is accompanied by introduction of magnesia, is closely associated with ore in one stope, but this relation is far from universal. Future study of the relation of ore to brecciation and bleaching may be of value to mine development.

INTRODUCTION.

The Retallack and Zincton areas are in the northern part of the Slocan mining district, on the divide between Kootenay and Slocan Lakes. The former is in Ainsworth and the latter in Slocan Mining Division.

Retallack and Zincton are stations 3 miles apart on the Kaslo–Nakusp branch of the Canadian Pacific Railway. They are also served by road. Retallack, on Kaslo Creek, is 18 miles by road from Kaslo, and Zincton, at the head of Seaton Creek, is 10 miles from New Denver. The pass followed by road and railway is at an elevation of 3,515 feet, approximately level with the siding at Zincton; Retallack siding is at an elevation of 3,340 feet.

Retallack is a post-office. There are a few residents other than those dependent on operation of the Whitewater mine; in some former years other mines near-by have been operated, and during the past few years cedar poles have been cut for the market. Zincton is populated only when the Lucky Jim mine is in operation.

There is a weekly train service between Kaslo and New Denver but no regular motor service. Buses are operated daily between Nelson and Kaslo, 42 miles; and between Nelson and New Denver, 68 miles.

A branch road to the upper Whitewater camp extends to the Charleston group, farther up Whitewater Creek. A road also leads from the upper camp to the Highland Surprise mine on Lyle Creek. A road from Retallack follows up Jackson Creek to the headwaters. There are a number of trails, most of which are badly grown over.

The country is one of steep but only locally precipitous slopes. The ground to the south rises to a maximum elevation of 8,200 feet in Reco Mountain at the head of Jackson Creek, and to the north to even higher peaks at the headwaters of Whitewater, Lyle, and Rossiter Creeks. Average slopes above the main valleys are for the most part between 25 and 30 degrees, and locally are as steep as 40 degrees. The greater part of the country has been burned over, the most destructive fire having been in 1910. Some patches of timber have been left, but much of the ground is covered by brush which forms locally a heavy cover. Weather is variable, with June and September customarily wet months. Snowfall is heavy in some winters.

Superficial deposits, largely composed of glacial drift, cover much of the area, including some of the steeper slopes. The valley of Kaslo Creek has been filled with drift through which the creek has cut a post-glacial channel into bed-rock between Retallack and the mouth of Whitewater Creek. The filling of the valley has also resulted in the formation of a stream-cut terrace about 225 feet above creek level in the vicinity of Robb and Rossiter Creeks.

Bear and Fish Lakes have been produced by a damming of the Seaton-Kaslo Creek valley by gravels brought down by Goat Creek and by slide material carried down steep tributary valleys. The depth to which the valley has been filled is not known, but bed-rock must lie at least 100 feet beneath the present surface, and the divide between Seaton and Kaslo Creeks must originally have lain farther east than at present.

Field-work on which the present report is based was done in 1944 and 1945. Plane-table mapping was done on the surface on scales of 100, 200, and 400 feet. The writer had free access to all maps of the companies' mine-workings, including geological plans and sections of the Whitewater and Lucky Jim mines prepared in 1930 by Peter Price. The use of this material vastly facilitated the underground work, and the writer makes grateful acknowledgement of the co-operation given him by V. McDowall, of Retallack Mines, Limited, and by H. E. Doelle and F. R. Thompson, of Sheep Creek Gold Mines, Limited.

The purpose of the work has been to study the mines and their structural setting. This involved detailed underground mapping and moderately detailed surface mapping in the immediate vicinity of the mines. The surface mapping was extended on a somewhat smaller scale in an attempt to elucidate the broader, surrounding structure. No attempt was made to cover the entire area systematically, a task which would take several years to accomplish.

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GENERAL GEOLOGY.

The area is in what may conveniently be termed the "slate belt," the more fissile basal part of the Slocan series.

The Slocan series is Triassic in age and consists principally of argillaceous rocks. Cairnes has estimated the total thickness to be 6,800 feet. It disconformably overlies greenstones of the Triassic Kaslo series, and is cut by Nelson granite and by many granitic dykes. The north-eastern or lower contact of the Slocan series crosses Lyle Creek a few hundred feet north of the border of Figure 2.

The sedimentary rocks are best referred to as slates. A number of distinct bands of limestone occur in them, as well as calcareous and quartzitic bands, but the bulk of the rocks are dark, highly cleavable rocks of argillaceous character. Some are typical slates with poorly defined bedding, others are even more fissile and are, properly speaking, phyllites; some sections show an alternation of hard and soft beds. They range in colour from various shades of grey to black and locally greenish.

No subdivision of the slates has been made other than to recognize an assemblage of banded rocks near Zincton, termed the Zincton member. This member consists of thinly bedded hard and soft argillaceous strata, as well as limy slates and several distinct bands of limestone.

The slates are overlain, west of Zincton, by thickly bedded, non-fissile argillites, a type of rock common in upper parts of the Slocan series. These are grey argillites, locally quartzitic and locally calcareous. They contrast sharply in appearance with the underlying slates.

Cutting the slates, usually in the form of sills, are many light-coloured granitic rocks. These vary widely in texture and composition, but types of the composition of

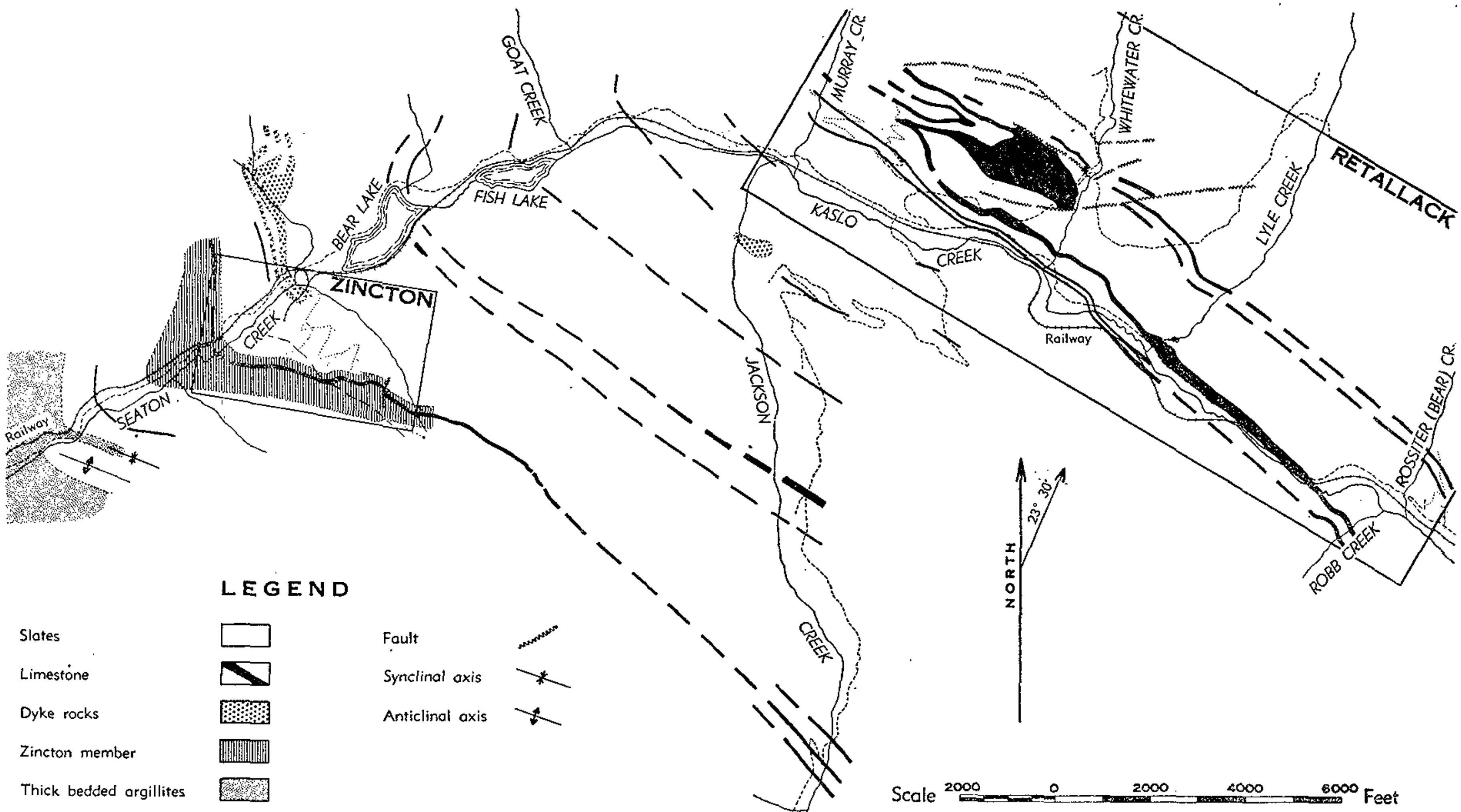


Fig. 1. Key map showing Retallack and Zincton areas and intervening ground.

granite, quartz syenite, and granodiorite are, according to Cairnes, the most abundant. These sills and dykes are most numerous near Zincton; a number are seen near the mouth of Goat Creek, and more isolated bodies occur elsewhere. Another type of dyke occurs in several places near Retallack and is encountered in the Whitewater mine; this is a porphyritic mica lamprophyre whose exact composition is uncertain. Dykes of this type are younger than the granitic dykes, according to Cairnes, but no evidence of their relationship was observed in this area. Most of the dykes and sills of all types are altered to a greater or lesser degree by carbonatization and sericitization. They are all pre-mineral.

The stratigraphy of the slates is not well known, because the lack of outcrops, variation in intensity of cleavage, and the intricacy of local structures make study difficult. Regionally, Cairnes has shown that the series is more sandy and less limy to the north-west, and this is borne out even in the present small area. Near Murray Creek, for instance, there is an abundance of finely granular, quartzitic strata which is not recognizable in equal quantity in the section provided by Whitewater Creek. Some other members, whether of thin, pyrite-studded paper-slates, banded argillaceous slates, or calcareous slates apparently do not maintain their thickness for more than a few hundred feet, and seem to change in character along their strike. Some of these changes may be the effect of minor structures, as will be discussed later, but some are undoubtedly due to rather rapid changes in sedimentation.

Bands of quartzite are rare, even though individual beds of quartzite are common in many sections. Two such bands, 15 to 30 feet thick, occur near Retallack and are of value as an aid in tracing the structure. Other bands which contain even a fairly high proportion of quartzite beds are difficult to recognize from one place to another.

There are several limestone bands from 10 to 60 feet in average width, as well as bands of calcareous slates which include numerous beds of limestone 1 inch to several inches thick. Limestone is an important rock, containing as it does replacement deposits of zinc and lead. It also provides the most reliable horizon-markers for the unravelling of structures.

As mapped in Fig. 1 there are thirteen bands of limestone. The amount of certainty in their extent is indicated in the mapping. The bands vary in thickness as the result of folding and also of original sedimentation. Some bands are relatively pure limestone, some contain thin bands of slaty material, and others grade into calcareous strata of variable composition.

One of the most important is the Lucky Jim limestone-band which extends from Zincton to the bridge across Jackson Creek. This band is brecciated in all natural exposures, although in mine-workings the brecciation is not universal. It ranges in exposed width between about 16 and 40 feet, but locally underground it is much wider. It is part of the banded Zincton member. The amount of limestone in this member apparently increases to the south-east, although detailed mapping was not carried through the entire distance.

One band of limestone occurs above or south-west of the Zincton member and another a short distance below. Some limestone is also seen on the north side of the valley at Zincton, almost obliterated in the groin between two coalescing sills. Other bands of limestone outcrop on Bear and Fish Lakes, and are believed to be continuous with bands which outcrop on the Jackson Road. One of these shows an apparent width on the Jackson Road of nearly 100 feet, which may be partly due to folding. Smaller bands which outcrop on the lower Jackson Road and also at the mouth of Murray Creek are poorly exposed and are really more calcareous zones than distinct bands of limestone; some folding may here produce a repetition of strata.

The second important band is the Whitewater limestone, in which are the lower workings of the Whitewater mine. It is about 50 feet thick in general, but the thickness is greatly increased in a drag-fold of major size and importance.

Two bands lie south of and stratigraphically above the Whitewater band. The upper of these is almost as thick as the Whitewater band where seen in the bed of Kaslo Creek, but is narrower to the north-west. The lower of the two bands is not so clearly defined, being actually a part of a calcareous zone.

Below the Whitewater limestone to the north two bands range in apparent width from 30 to 100 feet. They are almost certainly continuous from Whitewater Creek to Rossiter (Bear) Creek. Other, less important bands of limestone are known to occur still lower in the section but have not been mapped.

STRUCTURAL GEOLOGY.

A knowledge of the geological structure is of great importance to both mining and exploration in this part of the Slocan. The study is not easy for a number of reasons. The present report does not pretend to solve more than a fraction of the problems, part of the material included is admittedly fragmentary, and some of the interpretation must await further work for verification. Some observations are tendered with the belief that they may prove useful when additional work is done. For that reason an outline of the major structure and a discussion of minor structural features and their cumulative effect are included.

General Structure.

The slates and associated limestones strike north-westward and dip for the most part south-westward. There is no folding of the series as a whole into anticlines and synclines of major size. One large and important drag-fold occurs west of Whitewater Creek, and there is much contortion of the beds in the valley of Kaslo Creek east and west of Retallack. These structures will be discussed in detail in the chapter on the Retallack area. There is a combined syncline and anticline passing through or near the mouth of Murray Creek, but exposures are so few in this area that it could not be studied fully; in any event, the structure does not appear to involve a very great thickness of sediments and is probably only of local significance.

The average observed dips in the section between Murray and Rossiter Creeks are steep, although the structure is far from uniform. West of Murray Creek as far as Zincton the dips are for the most part steep, with some local reversals and flattenings. West of Zincton on the abandoned Kaslo and Slocan Railway grade there is a small open syncline of the upper massive argillites before the south-westerly dip is again resumed. This syncline apparently dies out to the south-east and was not seen on the north side of Seaton Creek, where, however, the rocks are largely obscured by slides.

The fact that an area of low southerly dips at the east end of the Jackson Road switchbacks, south-east of Retallack, has no counterpart to the west may signify folding which is more marked to the east and fades out to the west.

The major structure is seriously complicated by numerous minor and local structures. It is further complicated by the fact that, at least in the Whitewater area, there have been two periods of deformation.

There are a number of faults. One of the most important, a curving thrust-fault which is occupied by the Whitewater lode, is a complex, branching zone of fracturing and shearing which is rudely parallel to the general structure. A steep, curved fault crosses Whitewater Creek and the Whitewater lowest adit and may swing into the bedding farther to the west; the vertical displacement is believed to be about 1,000 feet. Another fault of unknown displacement crosses Lyle Creek at the upper end of the canyon. Other faults on Kaslo Creek east of Retallack are probably relatively unimportant. In the Lucky Jim mine faults occur in the argillites in the foot-wall of the limestone and some in the limestone itself; most of these are strike faults whose displacements are not known. There are many minor faults and slices whose displacements may not be more than a few feet.

The faulting has more nearly followed the general structural trend in strike and dip than otherwise. In other words, the failure of the rocks by rupture has been along north-westerly trending planes. The brecciation of the Lucky Jim limestone has taken place along a longitudinal course and is not localized by transverse breaks or shears, and the same is true of the brecciation of many banded argillites in various parts of the area.

The regional plunge of the structure is westward in the western part of the area and eastward in the eastern part. Reversals of plunge are noticeable in many places, the most prominent of which are near Whitewater Creek. The average plunge from near Murray Creek to below Zincton is about 20 degrees westward, with many local anomalies; the average plunge east of Whitewater Creek is lower, and is probably less than 10 degrees eastward. Local observations on minor structures show plunges in either direction ranging between horizontal and vertical.

Discussion of Structural Detail.

The slate belt has undergone a great deal of deformation which has produced numerous minor and irregular structures whose individual appearance is commonly insignificant but whose net effect is important. Evidence of this minor contortion is abundant on close examination, although the details of form and extent are not always discernible. The following discussion refers to slates and slaty rocks and not to limestones which will form the subject of particular attention in succeeding parts of this bulletin.

Folding in the slates is of an asymmetrical and incompetent nature. Parallelism or even similarity in structures is maintained over short distances only, and the effects of folds die out rapidly in relation to their size. Drag-folds and zones of rumpling and contortion formed locally during the initial folding, and although these were numerous they seldom involved more than minor thicknesses of strata. There is abundant evidence of this fact in the Slocan series as a whole, but in the present area there has been a more than ordinary amount of rock-flowage in rocks of less than average competency.

The " slates " all possess a marked slaty or flow cleavage. Some of them are typical slates, but many are lustrous rocks which may be more properly classed as phyllites. In such rocks bedding can only be seen where there is an alternation of beds of markedly different character (principally of hardness), and in some sections of uniform rock-type the bedding has been obliterated.

The slaty cleavage is for the most part parallel to the bedding or very nearly so, but it was not formed initially as a bedded feature, since it cuts across elements of local folds. In other words it is a cleavage produced by rock-flowage on a regional scale, and the parallelism with bedding is largely fortuitous.

This last statement needs amplification, because this type of cleavage as developed in many parts of the world bears a symmetrical relation to the major folding and is frequently termed axial plane cleavage. Actually such cleavage is parallel to the axial plane only in the central part of a fold where differential movement, however slight, has taken place across the bedding, and becomes laterally more nearly parallel to the limbs of the fold where differential movement has been at a maximum and has taken place largely as a slippage between beds. In the slate belt differential movement has been great, and the general parallelism between cleavage and bedding is perhaps to be expected. In the lower part of the Slocan series differential movement has been localized in a belt of thin-bedded and relatively incompetent strata, between overlying thicker bedded argillites and underlying Kaslo greenstones.

In detail the cleavage cuts across the bedding in zones of minor folding. It is parallel to the axial planes of the folds in many instances, as where the individual folds are symmetrically developed with respect to the average regional dip. The relationship is not ideal because the original folding was not as a whole symmetrical, and the relationship is obscured by a second period of deformation which has affected both cleavage and bedding.

In some places there are two cleavages, one determined by rock-flowage and one by bedding-planes. In softer rocks the flow cleavage is dominant, but in some harder, well-bedded rocks the bedded cleavage is locally the stronger. The intersection of the two cleavages produces rod-like fragments, and the presence of these in slide material may sometimes be the only evidence that the bedding and flow cleavage are not parallel.

In some places flow cleavage follows bedding through the most intricate of minor rumpled structures, a fact which suggests initial parallelism and subsequent folding of both bedding and cleavage. In still other places both cleavage and bedding are folded along unrelated axes. The cleavage faces of most of the finer and more highly cleaved sediments are finely rumpled or plicated, with as many as ten plications to the inch (Plate III., B); these plications are the product of some additional (cross) strain to which the cleavage-plates were subjected after their formation.

All of this evidence points to the fact of a second period of deformation which has affected the folded strata. The clearest and most unmistakable evidence is to be found on the railroad-track below Retallack, opposite the mouth of Lyle Creek. Here limy slates have locally been isoclinally folded and axial plane cleavage has been developed in them and, at some later time, the already doubled beds have been folded in such a manner as to bend the original axial plane of folding through 90 degrees. The later folding has taken place by bending of and adjustment between the planes of the secondary flow cleavage and not the planes of the primary, bedded cleavage.

Symmetrical folding on a small scale, with clearly developed axial plane cleavage, was seen on the Highland Surprise Road. The cleavage and bedding show ideal relationships, but a false bedding developed parallel to the cleavage in some parts of the folding seems to be extraordinary (Plate IV., A). The cleavage is vertical and the fold is unmistakable, but the vertical ribbing seen in the left side of the photograph so closely simulates bedding that at first sight it is hard to believe the contrary. The ribbing is conditioned by the cleavage and yet it is indistinguishable in the field from an alternation of very thin beds of slightly different character. The reason for stressing the occurrence of this psuedo-bedding is that the geologist, working with minute exposures, as very frequently he must, may easily mistake it for true bedding.

In some exceedingly complex folded structures on the hillside north of Retallack there is developed a series of plications whose axial planes dip south-westward (Plate V., B). These are actually incipient shears or fractures which demonstrate a tendency for the rocks to fail along planes which dip at moderate to low angles south-westward. This near-shearing is rudely parallel with known shearing and faulting in mine-workings on Whitewater Creek, and it may be an indication that many secondary structures were developed at about the same time as the faulting along which mineralizing solutions were introduced.

In some areas of banded rocks the bedding is unmistakable and, viewed as a whole, extremely regular. The banded argillites of the Zincton member are relatively well exposed in the neighbourhood of the upper levels of the Lucky Jim mine, and the structure is at first glance simple and uniform, but careful scrutiny shows that occasional beds are doubled over in close folds which can not be traced far. These folds can only be seen on surfaces which provide a cross-section, or when erosion has exposed a crest which stands out from the rest of the rock. One such individual fold is seen at the main portal of No. 4 adit (Plate VI., A) where there is otherwise a simple uniformity in the section; other examples may be seen throughout the map-area. The amplitude of these individual folds can not be measured and it is not known just how great a thickness of strata is involved in each.

A few minor drag-folds, properly speaking only flexures, near Whitewater Creek, indicate a reverse relative movement of the beds to that which is to be expected. On the limb of any structure the upper beds move relatively upward in normal folding, and any single bed is pushed up and over itself in normal drag-folding. In this section, however, strata are pushed up and under themselves, a fact for which there appears no ready explanation. Such folds may have been produced by underthrusting during the second period of deformation, but definite proof is lacking. The rotation of the major Whitewater drag-fold presents a similar problem (*see* Fig. 3).

Cairnes makes reference to a pseudo-conglomerate in parts of the Slocan, notably on the Lucky Jim property. This is a breccia produced by failure of banded argillites in which the harder bands have broken while the softer bands have flowed. The nearly equidimensional fragments of harder beds have become rounded and strewn through the rock-mass, with the longer dimensions oriented with the cleavage to produce a rock which closely resembles a conglomerate with sparse pebbles.

The "pseudo-conglomerate" breccia is significantly developed only in strata which contain an alternation of relatively hard and soft beds. In the case of more uniform rocks it is likely that adjustment took place by flowage in the softer ones and that the harder ones were competent to carry the strain without brecciation; in fact, in harder beds of some thickness there was less tendency for small drag-folds to form and, if formed, they were strong enough to retain their outlines. This breccia is well exposed at two localities close to the main road, one on the west bank of Goat Creek and the other on the rocky point on the shore of Bear Lake; in both these places the slates contain numerous thin and relatively hard beds. At some points the contorted beds are broken into progressively shorter lengths and pass into breccia (Plate V., A), while at other points otherwise uniform slates contain "pebbles" which have no obvious relation to folds but are strewn across the cleavage to indicate the former position of the bedding. This breaking down and "strewing out" of bedding is seen locally in many successions of alternating hard and soft beds. The inference is that minor structures and rumplings were exceedingly numerous during the early period of deformation and that deformation progressed to the point of widespread rock-flowage which obliterated many of the minor structures. There was locally a rotation of elements of minor folds into positions more nearly parallel to the flow cleavage.

Plate IV., B, shows part of a small drag-fold involving a quartzitic bed between softer argillaceous beds. The cleavage, which dips steeply to the right in the photograph, has sliced the hard bed into irregular slabs between which the material of the softer beds has been squeezed, thus forming locally a sort of pseudo-bedding. The fact that the formation of this is directly related to the formation of pseudo-conglomerate is shown in Plate VI., B, in which bedding is seen to trend downwards to the right against cleavage oriented steeply downwards to the left; significantly, the harder beds play out and can not be traced farther to the right, and the inference is that they have been obliterated by differential movement.

A fact which makes field-mapping difficult is the occurrence of flexures in the dip of the bedding. A series of beds dipping at say 70 degrees may flatten to 45 degrees for a distance of perhaps 5 to 50 feet and then resume the normal dip, or the dip of the beds may be reversed locally. In one place on the Jackson Road an average dip of 70 degrees to the south-west changes to 60 degrees north-east for a sufficient distance along the course of the road to indicate, on one interpretation, folding of importance; farther up the road the south-westerly dip is resumed. Closer examination proves, however, that the north-easterly dip is caused by a broad flexure which by chance is followed by the road for several hundred feet in cross-section. Other examples of flexures which produce local overturning are to be seen at the mouth of Whitewater Creek.

The foregoing remarks make it plain that small, isolated outcrops are apt to give little structural information that can be relied on. It is only in areas which are relatively well exposed that the structures can be worked out. Compilation of cross-sections is difficult because of the asymmetrical nature of the folding and because of the many anomalous dips whose cumulative effect can not as a rule be estimated.

The drawing of any but the most general section is only possible where there are mine-workings or, rarely, where there are bluff exposures across the strike.

THE TOTAL EFFECTS OF DEFORMATION.

Although no obvious major folding into anticlines and synclines exists, a careful search was made for evidence of isoclinal folding in the two sections studied, namely on the road and railway and on the Jackson Road, but none was found. Isoclinal folding is difficult to detect in beds with such little diversity in character as the Slocan slates, and the limestone-bands are not sufficiently uniform along their strike to permit of positive correlation across the limbs of a postulated fold. Isoclinal folding would of course produce a great thickening of the section through repetition of strata.

It might be argued, for instance, that the Whitewater and Lucky Jim limestone-belts are one and the same, and that obvious differences in thickness of limestone could be accounted for by regional variations in sedimentation, but the geological sections of the two belts are stratigraphically so different that they can not be the same. Some rock units which contain a higher than average proportion of harder beds are recognized on Bear and Fish Lakes and also on the Jackson Road. If there had been a major doubling of the section brought about by isoclinal folding, it would be detected by a repetition of these units and of some limestone-bands, but none was seen.

It is concluded that no major isoclinal folding and no thickening of the section by wholesale duplication have taken place, but there is abundant evidence that the geological section has been greatly thickened by minor structures. The amount of thickening can not be measured.

RETALLACK AREA.

GEOLOGY.

This area, Fig. 2, and outlined in Fig. 1, includes the Whitewater limestone-belt between Murray and Rossiter (Bear) Creeks. Farther to the north-west outcrops are rare, much of the ground is covered by dense forest-growth, and extensive masses of glacial drift derived from the higher greenstone range cover the hillsides. The rocks north of the Whitewater lode are very poorly exposed and detailed mapping of them has not been attempted. Within the area itself exposures are not abundant, and it is only by virtue of the stream canyons and the cuts along road and railway that more than a cursory study is made possible. Many conclusions regarding the structure could not have been reached without the presence of mine-workings.

The slates are distinctly fissile rocks for the most part. There is a wide variation from argillaceous and graphitic types to calcareous and quartzitic beds, but on the whole the general similarity, the complexities of structure, and the poorness of exposure make detailed subdivision of them impossible. There is a tendency for the rocks to be more quartzitic to the west and for limestone to increase to the east. The softer slates are phyllitic and glistening and the cleavage surfaces are finely rumpled or plicated in many places. (Plate III., B.)

The distinctive horizon-markers are bands of limestone, some of the smaller of which contain an admixture of slate, and rare beds of quartzite. Only two bands of quartzite, more or less readily traceable and consequently useful as horizon-markers, were recognized; both are 15 to 30 feet thick. One is near the southern margin of the area and the other lies beneath the limestone members to the north.

There are five principal bands of limestone. The central one, about 50 feet thick, is referred to as the Whitewater band. It contains the replacement deposits of the Whitewater mine. Two upper bands, from 10 to 30 feet thick for the most part, are parts of a calcareous zone which appears to contain a variable amount of limy slate in

Fig. 2. Geological map of Retallack area.

different sections. Changes in sedimentation along the strike appear to account for the fact that on Robb Creek there is one band equal in width to the Whitewater band, with intervening slates and limy strata; the whole assemblage at Robb Creek, including the Whitewater band, is about 300 feet thick. Two other limestone-bands, 30 to locally 100 feet thick, occur beneath or north of the Whitewater band; they have not been traced positively from Whitewater to Rossiter Creek and on the east they are much farther separated from the Whitewater band than on the west.

No granitic dykes have been mapped, although some are associated with a small stock east of Jackson Creek, and some are reported to occur near the east end of the area. A lamprophyre dyke occurs in Whitewater canyon and extends south on the Metlakahtla claim. Another dyke of the same composition closely follows the Whitewater lode, and others occur west of the mouth of Murray Creek.

Apart from the large Whitewater drag-fold the structure is not well understood. The prevailing dip is south-westward with many complications in detail. A synclinal structure of relatively small amplitude passes through lower Murray Creek, but it is poorly exposed and could not be traced along the strike; on upper Murray Creek the dips are steep to the south-west.

Whitewater Creek canyon provides a good cross-section. In the upper part the rocks are nearly vertical, in the central part they are involved in drag-folding, and in the lower part they dip on the average between 50 and 60 degrees south-westward. At the mouth of the creek there is a local reversal in dip produced by underfolding of the strata.

On Lyle Creek the steeply dipping rocks at the mouth flatten to an average dip little more than the gradient of the stream. At the upper end of the canyon rocks of relatively low dip are faulted against vertical strata. On the railway opposite Lyle Creek there are some low dips, but the structure is complicated by faulting and by repeated deformation.

On Rossiter Creek the strata dip steeply for the most part, and on Robb Creek the dips average 60 degrees south-westward. Throughout the area there is local contortion and many anomalies, more frequently in dip than in strike.

The Whitewater fold is a warped, asymmetrical drag-fold which displays reversals of plunge. There has been much thickening of the principal band of limestone and, by inference, of the associated slaty sediments. The Whitewater limestone, as exposed from Retallack to Bear Creek, is about 50 feet thick, but on the Pauper's Dream and Hazel claims it is drag-folded in such a way as to produce an outcrop showing an apparent width of about 1,200 feet, being somewhat exaggerated by the slope of the hillside.

Fig. 3 shows this fold in diagrammatic cross-section. The surface outline and eight cross-sections illustrate its nature. No claim is made that the sections are strictly accurate.

The plan in Fig. 3 is drawn as the result of direct observation and some inference. Outcrops are not abundant on the thickly wooded hillside that locally is as steep as 40 degrees, and exact contacts can not be drawn with accuracy. On the western limbs of the drag-fold the position of limestone has been determined by zones of lime soil between actual outcrops of limestone, and in the major area mapped as limestone there may be narrow infolds of slate which were not seen on the ground. The general outline of the surface expression of the folding is nevertheless believed to be accurately represented.

The cross-sections A and G are the most certain. Section A could not be proved from underground study because the Hazel adit was inaccessible. Bad air was encountered in this adit 300 feet from the portal, and the full width of the outermost (south-western) limestone limb was not seen. Section A does show, however, the general outline of the folding, with only the depth of the synclines a matter of doubt. Section G shows the folding as known in the vicinity of Whitewater No. 14 adit, incomplete as to detail but certain as to general outline above the adit. The intervening sections are more hypothetical and are drawn to illustrate the changes in plunge and the rotation of

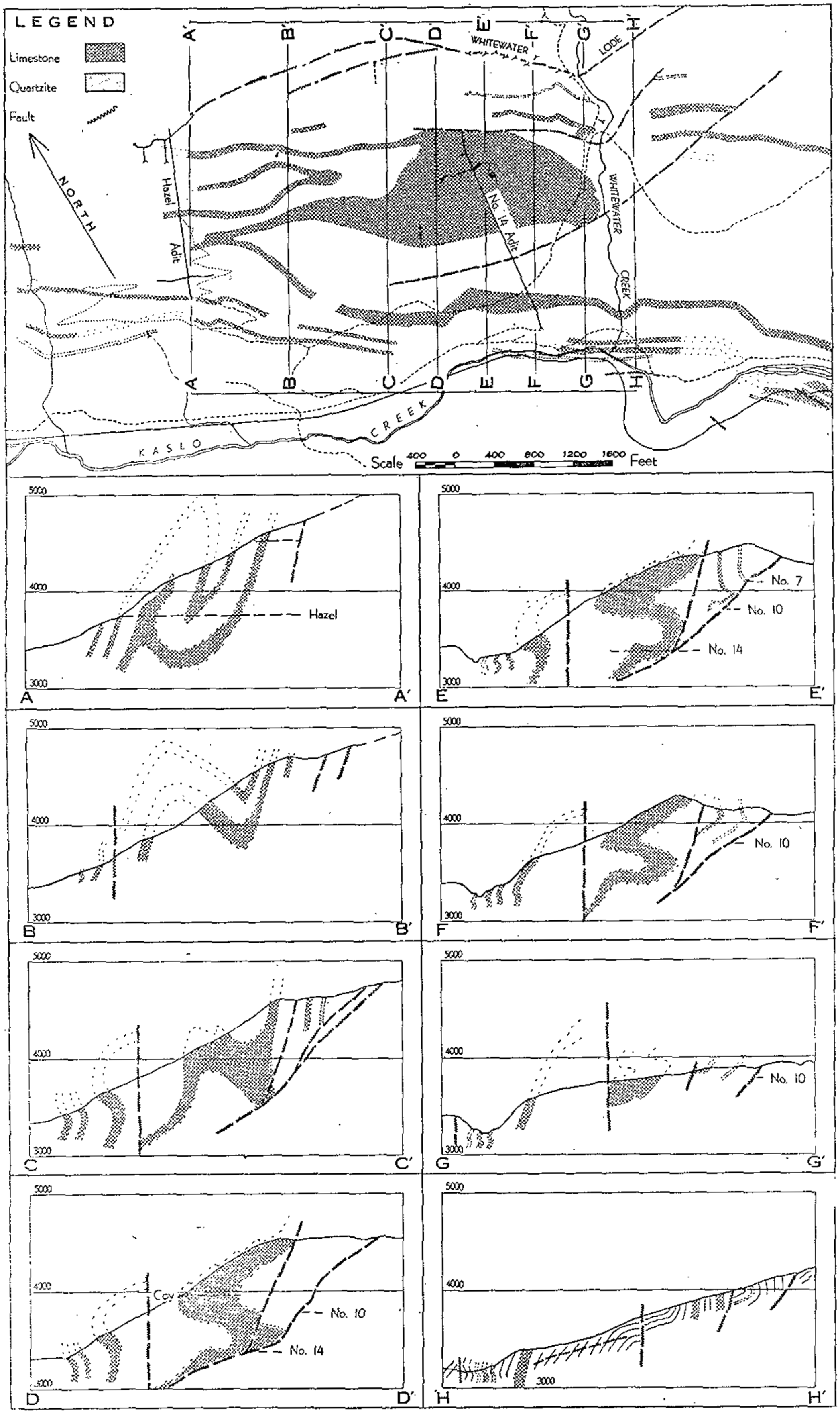


Fig. 3. Plan and diagrammatic cross-sections of the Whitewater drag-fold.

the axial plane of the folding. It is not known how much the limestone may be thickened by flowage and how much by rumpling and close folding.

The western continuation of the fold is obscured by drift, as already stated, and in any event is uncertain in the vicinity of Murray Creek owing to the fact that it is sliced by the Whitewater lode fault system. The eastern continuation of the folding is not apparent, as the lower bands of limestone are not, as far as can be determined in a heavily drift-covered area, involved in a comparable structure. This latter discrepancy may be explained by the fact that faulting on Whitewater and Lyle Creeks has brought different parts of the general structure to the present erosion surface in such a manner that the drag-folding is either hidden or has been removed by erosion; on the other hand, the effect of the folding may die out to the east. The folding can not be traced without the presence of marker horizons, as the slaty rocks can undergo much distortion, thickening, and thinning without the nature of the deformation being apparent in scattered outcrops.

The drag-folded Whitewater limestone does not cross Whitewater Creek. The thickened and warped synclinal " keel " of the fold is exposed on the west side of the canyon, where it plunges 35 degrees westward, about 20 feet above the creek-bed. At this point it is cut by a nearly vertical fault with a vertical displacement estimated at 1,000 feet. This fault cuts the lower bands of limestone and may cross the Highland Surprise Road in a prominent dry gully farther to the north-east. This fault crosses the No. 14 level adit and, farther west, slices the structure at an acute angle without producing a marked off-set; the exact westward course of the fault is not known.

The thrust-fault which is occupied by the Whitewater lode has a displacement on the dip of possibly 400 feet. It is rudely parallel in strike to the general structure and dips at varying angles to the south-west. On the east the dip is about 45 degrees, flattening to about 20 degrees at lower elevations; on the west it apparently steepens to about 85 degrees. It is a complex zone of breaking and shearing, with one prominent hanging-wall branch which has not been explored. There is a marked tendency for the main plane of the fault to follow the bedded structure, as can be seen in the cross-sections of Fig. 5, and it is only in the upper, eastern part of the Whitewater mine that the average dip of the bedding is cut at a large angle.

A segment of folded rocks lies between the Whitewater lode and the steep hanging-wall branch. The folding in this segment is observable only on the western bank of Whitewater Creek and is shown in sections F and G. Rocks which at the surface are vertical are folded into an irregular structure the lower part of which is not seen, but which probably represents a subparallel continuation of the main drag-folding. This folding is intersected by the Whitewater lode below No. 7 level, at the approximate lower limit of the main ore-zone in the upper levels of the mine.

The relation between the thrust and the nearly vertical fault is not known, nor is the relation of either to the fault at the head of Lyle Creek canyon. Other faults seen along the railway-track apparently are of minor significance. The rocks within the bend of Kaslo Creek immediately below Whitewater Creek are much sliced by faulting and quartz has been introduced into them.

A curving flat fault-zone follows close to the bottom of the lower part of Whitewater Creek canyon (Fig. 3, section H). The displacement on it is not believed to be great but it is important in being mineralized locally with small amounts of siderite and sulphides.

The known faulting with which mineralization is related on Rossiter Creek is not intense. Exposures above the canyon are so poor that the possibility of strike-faults in that section could not be investigated.

WHITEWATER MINE.

History.

The Whitewater claim was located in 1891 by J. C. Eaton, and 8 tons of ore was shipped from it in 1892, the first shipment from the district. Silver-lead ore, some of which consisted of carbonates, occurred at grass roots and the early owners opened up the mine at little capital expense.

In 1898 the Whitewater and Irene claims (and perhaps others) were acquired by an English company and a 120-ton concentrator was built. In the same year the Whitewater Deep ground, comprising claims lying south of the Whitewater, was acquired by another English company.

The original Whitewater company seems to have done little work, and there is no positive record that the concentrator was in use. Leasing of the mine is first mentioned in 1904. In 1905 J. L. Retallack and associates leased the property, and in 1907 modified the mill to produce zinc as well as lead concentrates. The property appears to have changed ownership twice between 1905 and 1922, although J. L. Retallack remained the moving spirit. The concentrator and camp were burned out in 1910 by a fire which swept the district, but the camp was soon rebuilt and silver-lead and zinc ore were shipped selectively. A number of subleases appear to have been granted during this period.

The Whitewater Deep company drove Nos. 9 and 10 adit-levels and as early as 1899 considered driving a crosscut from near the level of the railway (now No. 14 level). Work on this low-level adit was resumed in 1908 and a connection was made by raise with No. 10 level by 1911. The two properties were amalgamated about 1911 or some time before, and the Retallack syndicate appears to have leased the upper part of the Deep ground as early as 1907. The Deep company encountered replacement ore relatively rich in zinc below 10 level, but did little or no work on it.

Whitewater Mines, Limited, was formed in 1922 and effected a final consolidation of the Whitewater and Whitewater Deep ground. The company started development of Nos. 11, 12, and 13 levels in 1923, but leasing operations in the old upper mine continued, largely by S. N. Ross. The replacement deposits in the new lower mine were opened up during the next few years and a concentrator was built in 1927. Operation by the company ceased in July, 1929.

Leasing continued until 1936, and in 1937 the company again operated, largely on ore from No. 1472 level, milling in that year 21,816 tons, under the management of S. N. Ross. The latest lease was granted in 1941.

Tailings from the old mill passed down Whitewater Creek and became partly reconcentrated on the Kaslo Creek flat. In 1925 Metals Recovery, Limited, built a 60-ton concentrator and, under the management of M. S. Davys, began mining the richer accumulations. Work was suspended in 1929 after a total of 37,800 tons had been milled, assaying between 2 and 2½ per cent. zinc, a fraction of a per cent. lead, and about 2 oz. silver to the ton.

In the latter part of 1929 and the early spring of 1930 a complete survey and examination of the lower mine was made by H. H. Yuill, the work being under the direction of Peter Price. At that time the old upper mine above 10 level seems to have been considered as worked out and in any event was largely inaccessible.

In 1943 Kootenay Belle Gold Mines, Limited, conducted a programme of diamond-drilling to explore extensions of replacement ore in and beyond the former workings. Following the closing down of the Kootenay Belle gold mine at Sheep Creek a war contract for sale of concentrates was obtained from metals Reserve Corporation, and a new operating company, Retallack Mines, Limited, was formed. Kootenay Belle Gold Mines, Limited, advanced the necessary funds for reopening the mine and furnished needed equipment under a profit-sharing agreement with Whitewater Mines, Limited, through the medium of the new company. Construction started late in 1943 on camp, power plant, and mill. The hydroelectric plant was augmented by the installation of Diesel engines, the capacity of the mill was increased to 300 tons per day, and accommodations for a larger crew were provided. Milling commenced in May, 1944, and continued throughout the year.

Ore was first obtained in 1944 in the south-eastern part of the mine between Nos. 14 and 1472 levels and, when that was almost exhausted late in the summer, ore was mined between Nos. 12 and 13 levels. A crosscut was driven from the existing face of No. 1472 level, 90 feet west of the 1472 raise, to get underneath ore explored by drilling beneath No. 13 level. The milling rate for the year was about 150 tons per day from the mine, with an additional 50 tons per day from the old dumps above No. 7 level during part of three summer months.

The Diesel power plant was completely destroyed by fire in May, 1945, and subsequent operations relied solely on hydroelectric power. After extraction of ore from a 20-foot winze below No. 14 level east, attention was again paid to the upper dumps during the summer. The main dump between the portals of Nos. 7 and 3 levels was mined by bulldozer at a rate of about 200 tons per day and the ore was trucked to the mill. Owing to a marked decrease in water-supply operations were suspended on September 19th, 1945.

Production.

The following table shows the over-all production of the mine from 1892 to the end of 1945. The tonnage figure is a little high because some custom ore is included, but since the actual tonnage and grade are not known the production officially credited to the Whitewater mine is given. The tonnage and metal content of shipping-ore is an approximation because the record does not show in all cases the source of ore, particularly when there was production from both the upper and lower parts of the mine, but the approximation is a close one.

The milling-ore from the upper mine is that treated during the years 1907 to 1910, and to this is added the metal recovered from tailings from the old mill, which were re-treated by Metals Recovery, Ltd. Some milling may have been done prior to 1900, but the amount, if any, was small. Although a mill was built in 1898 and supposedly was in condition to operate, the record shows that the average ore mined contained 30 per cent. lead and it may be that all of it was shipped.

The ore from the lower mine includes 5,250 tons taken from the old dumps of the upper mine. This is not listed separately because accurate figures of grade are not available.

Gross Metal Content in Ores and Concentrates.

	Tons.	Gold, Oz.	Silver, Oz.	Lead, Lb.	Zinc, Lb.
Upper mine—shipping-ore	23,426	459	1,756,934	14,317,509	2,607,335
Upper mine—milling-ore	70,587	512	951,881	7,873,313	6,868,651
Metals Recovery, Ltd.	(37,801)*	80	80,861	35,314	1,696,522
Total—upper mine	94,013	1,051	2,789,676	22,226,136	11,172,508
Lower mine—milling-ore	166,529	386	362,454	5,791,767	25,087,862
Grand total	260,542	1,437	3,152,130	28,017,903	36,260,370

* Tonnage of Whitewater tailings re-treated in the mill of Metals Recovery, Ltd., not included in mine totals, but the metal contents are included.

The table below, showing grades of ore, is reasonably accurate in the case of shipping-ore. In milling-ore from the upper mine the figures are estimates based on the average performance of gravity mills of the time, and the best that can be set for zinc is a minimum figure. The grade of ore from the lower mine is derived from the gross metal content of concentrates, assuming an average 85 per cent. recovery in milling and making an allowance for the inclusion of lower-grade material from the dumps. The figures of grade for the lower mine are possibly more accurate for silver and lead than for zinc.

Average Grade of Shipping-ore; Estimated Average Grade of Milling-ore.

	Gold.	Silver.	Lead.	Zinc.
	Oz. per Ton.	Oz. per Ton.	Per Cent.	Per Cent.
Upper mine—shipping-ore	0.02	75	30.6	5.6
Upper mine—milling-ore	......	20	8.5	10+
Upper mine—total ore mined	......	33.5	13.5	9+
Lower mine	......	2.2	2.0	9

The first 1,057 tons from the earliest workings returned 200 oz. of silver and 50 per cent. lead per ton. The silver-lead ratio in this earliest and highest grade of ore mined was 4 oz. of silver to the per cent. lead. The ore included carbonate material from the zone of oxidation, but how much is not known. In the upper mine as a whole the ratio was about 2½ oz. of silver to the per cent. lead. In 1920 shipments of 50 per cent. zinc ore are reported to have contained 15 oz. in silver per ton. In the lower mine the silver-lead ratio is about 1 oz. of silver to the per cent. lead.

It has been generally considered that the upper Whitewater mine was dominantly a lead mine which contained comparatively little zinc. This is only true in so far as the lead ore, with its high values in silver, was by far the more important commercially. The relative amounts of lead and zinc in the upper mine can now only be guessed, but they were probably about equal. This is judged from production figures and also from the fact that in ore milled from the main dump above No. 7 level, including waste trammed chiefly from No. 3 level, the zinc-lead ratio was between 3 and 4 to 1 and indicates, in view of past shipments, that the old stopes contained a considerable amount of zinc. The 70,600 tons of ore treated in early milling operations contained more zinc than lead, in terms of mill-head assays. In view of the zinc content of the dumps it is even possible that the 23,400 tons of shipping-ore was mined from ore-bodies similar in metal content to the milling-ore.

Initial shipments, made from grass roots, were of ore that was oxidized and contained a reported high proportion of carbonate material. As this was of relatively "clean lead" which was accompanied by silver in a ratio almost double that of ore in the upper ore-zone in general, enrichment in silver is indicated. Zinc was discarded in those days, but there may also have been some impoverishment in zinc in the oxidized zone.

Surface Workings.

There are few surface workings. Most of the exploration of the lode was by adits which were later connected throughout the mine. Perhaps strangely, there is practically no evidence that the eastern continuation of the lode across Whitewater Creek was ever prospected, although its approximate position on the bluffs east of the creek is clearly evident. Only one small open-cut is to be seen, and that is so old that nothing can be learned from it. Farther to the east the overburden is deep.

The Myrtle R. and Matheson shafts (Fig. 2) are steep and caved, and the dumps merely indicate sheared and partly mineralized slates. The former is probably on the foot-wall and possibly the principal branch of the lode, and the Matheson shaft is on the hanging-wall branch on which the Pringle raise is driven. Outcrops are very scarce in this area and there is no evidence that the lode was ever traced continuously across it.

The Coy, an old adit at an elevation of 3,960 feet, is completely caved and the dump is grown over. It was driven into and is inferred to have crossed the limestone. Old open-cuts for 250 feet up the slope from the portal show lead-zinc mineralization in limestone, following small fractures. This working is far in the hanging-wall of the Whitewater lode.

The Whitewater mine is opened up by 14 levels and several sublevels; all levels are adits except Nos. 8, 11, 12, 13, and 1472. The original Whitewater mine included No. 8 level and all those above. Part of No. 9 and the levels from No. 10 down were originally driven on ground held by the Whitewater Deep company.

A main raise extends in a straight line at a slope of 50 degrees from No. 14 to No. 10 level, above which there are many raises and stopes through the upper workings. A raise from the inner end of No. 7 level, known as the Pringle raise, extends to surface.

At the end of 1944 all of Nos. 14, 1472, and 13 levels were accessible and only the innermost faces on No. 12 were blocked. The eastern end of No. 11 was inaccessible from a point about 400 feet east of the main raise, and No. 10 was water-filled a short distance east of the raise. The only access to the upper mine from the surface was through No. 7 level, and a passage existed down to No. 10. The Pringle raise was inaccessible.

Only a small part of the mine above No. 10 level could be seen, and that not well. Most drifts were closely timbered and stopes inaccessible. As might be expected, after so many years of leasing operations, no ore was to be seen.

The portal of No. 14 adit-level is at an elevation of 3,370 feet, and No. 1 at 4,490 feet, a vertical range of 1,120 feet. The maximum length of drifting on the vein, on No. 10 level, is 1,900 feet. The Pringle raise, on the general course of which are driven several short sublevels, extends from the face of No. 7 level at an elevation of 4,095 feet to the surface at an elevation of 4,775 feet.

The general plan, Fig. 4, shows elevations and lengths of the other levels.

The mine is naturally divisible into two sections, the upper and lower. On the basis of type of mineralization the division is roughly at No. 11 level. On No. 11 (elevation 3,671 feet) and above the mineralization consists of silver-lead-zinc in a zone of shearing and fracturing in slates, while on No. 12 (elevation 3,580 feet) and below it consists of dominantly zinc ore replacing limestone.

Fig. 4 shows the stoped areas in the upper mine. These lie almost entirely above No. 9 level in an area about 1,000 by 700 feet in plan on a lode which has an average dip of 45 degrees. The stoped areas indicate the presence of one major ore-zone with a pitch of about 35 degrees to the south-east. Outside of this ore-zone very little ore appears to have been encountered. Numerous crosscuts and raises indicate a branching structure of the lode. These figures are taken from a map made in 1930 which represents the most complete information available regarding extent of the old workings.

The Whitewater lode in the upper mine has an average dip of 45 degrees to the south in its eastern part, and of nearly 60 degrees in its western part, west of the main raise. Just below the elevation of No. 13 level (3,505 feet) the lode flattens abruptly to an average dip of 18 degrees which is maintained to No. 14 level (elevation 3,378 feet). At and above the change in dip there are a number of subsidiary fractures, some of which are rudely parallel to the steeper part of the lode and a few dip northward.

The workings in the lower mine explore a zone of replacement ore which extends downward in an arc from the innermost face of No. 11 level (elevation 3,675 feet) eastward to the eastern part of No. 12 (elevation 3,580 feet) and southward to the south-eastern face of No. 14 level (elevation 3,380 feet). A large part of this ground has been stoped out, but the stopes are not shown in the general plan; some of the stopes are represented in section in Fig. 5.

The replacement ore in the lower part of the mine occurs in limestone in the hanging-wall of the Whitewater lode, and is localized by nearness to the lode and also by folded structures at or near the upper limestone-slate contact. Mineralization of

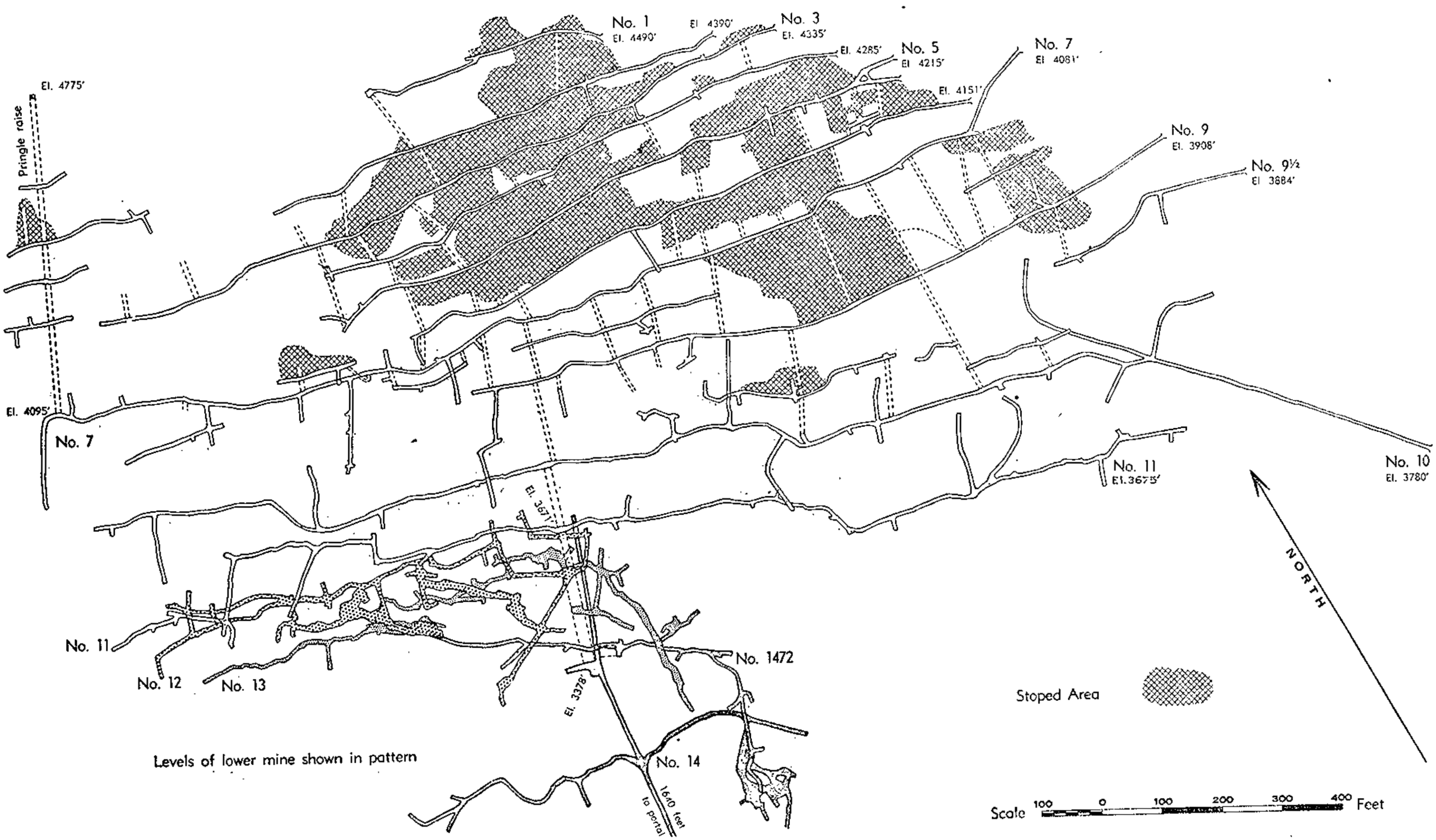


Fig. 4. Plan of Whitewater mine-workings.

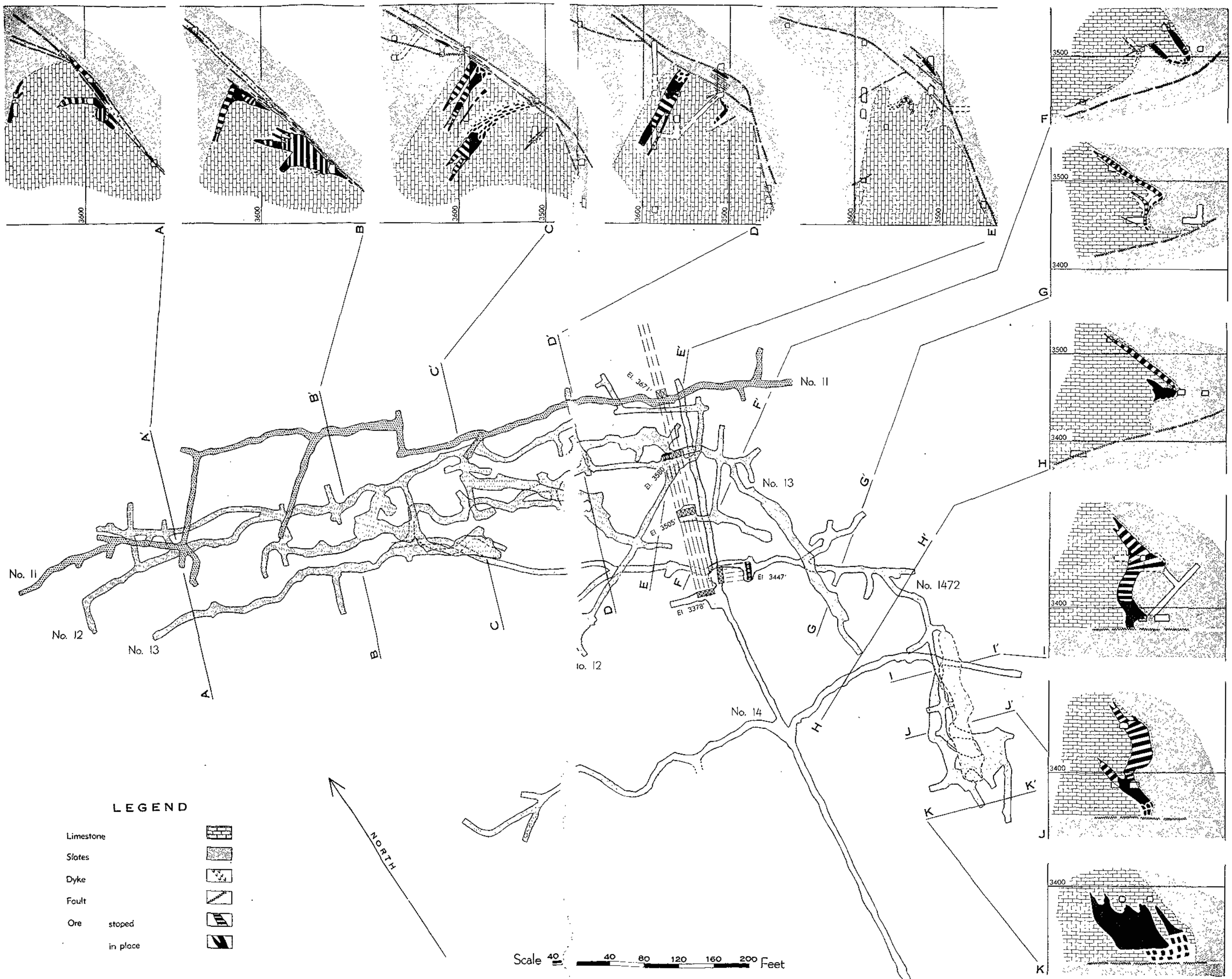


Fig. 5. Plan and cross-seons of the lower part of Whitewater mine.

similar type occurs within the flatter part of the lode itself, but nowhere has it been proved to be commercial.

The distinction between the upper and lower parts of the mine is based on structural grounds and on types of mineralization, and it might be well to emphasize that the division is not the same as that which formerly existed as a result of different ownership of Whitewater and Whitewater Deep ground.

Upper Mine Geology.

The Whitewater lode in the upper mine is an irregular zone of shearing and fracturing in slates. A band of limestone about 35 feet thick should be intersected by the vein at about No. 7 level, but its position underground was not seen. A dyke follows the lode on Nos. 11 and 10 levels and it is evident from the upper dumps that it must extend through parts of the upper levels. This dyke is a porphyritic lamprophyre, but its extreme alteration to carbonate, sericite, and locally to mariposite makes its identification difficult. It occurs as sheets and lenses within the lode and locally in the walls. It was intruded prior to mineralization and must originally have been a rather complex body, which now is much broken up by displacements along the lode.

The structure in the slates can only be inferred by projection of the general structure from the surface. In detail the structure cut by the lode in the lower levels is complex. In general, however, the strata are vertical above No. 7 level and strike roughly parallel to the lode. Immediately below No. 7 level the strata dip towards the lode, and somewhere above No. 9 level roll under and dip southward, in general parallel with or even flatter than the lode (*see* Fig. 3, section E). This general structure, complicated in detail by minor contortions, may very well control the occurrence and limits of the productive zone, which lies almost entirely within the area of steeply dipping rocks in the hanging-wall of the lode. The foot-wall rocks are so poorly exposed that the structure has not been worked out.

The lode in the productive zone above No. 7 level appears from old reports to have been a relatively simple break, although up to 20 feet wide in places, consisting of sheared and shattered slates. Below that level it is branching and not all of the splits seem to have been fully explored. Some of the workings on Nos. 10 and 11 levels west of the main raise are on a hanging-wall branch.

The Pringle raise appears to have followed a hanging-wall branch of the lode. The evidence for this statement lies chiefly on the relation of the collar of the raise to the line of outcrop of the lode.

Exposures above the highest adit are scanty and the vein can not be traced, but if the lode is the same as that encountered in the Myrtle R. shaft its line of outcrop can hardly pass through the collar of the Pringle raise.

Another branch lies farther in the hanging-wall of the lode. (Fig. 3, sections C to F.) The point of juncture with the lode is not certain as it has never been explored, but the branch forms scars on the hillside above the creek and has produced some offset. The relative movement is the same as the main fault, but much less in amount.

The ore consists of galena and sphalerite, with small amounts of grey copper. There is some pyrite and chalcopyrite. The gangue is chiefly siderite but some quartz occurs. Early reports on the highest levels refer to a concentration of as much as 5 feet of siderite on the relatively even foot-wall, above which lay the ore minerals, and much of the remainder of the lode seems to have consisted of rock matter in which mineralization occurred more or less irregularly. The ore occurred as streaks, lenses, and irregular pod-like masses attaining a maximum width of nearly 40 feet below No. 7 level (Cairnes, Mem. 184, p. 263). The topmost levels are in the zone of oxidation and the earliest shipments included some "carbonate ore"; most of the galena seems to have been of the normal variety, but some steel galena occurred. Besides the ordinary brown sphalerite there is a black, exceedingly dense variety, as well as a light brown variety of horn-like consistency. A small amount of cadmium is present in the sphalerite.

The productive zone extended down to the eastern end of No. 9 level, and one small stope was mined above No. 9½ sublevel. No productive sections were encountered on Nos. 10 and 11 levels, although masses of siderite occur at a number of places, particularly the eastern part of No. 10 and the western part of No. 11.

The former productive zone is largely inaccessible but appears to have been almost completely worked out. Splits in the lode west of and below the productive zone have not been completely explored and minor ore-bodies may exist, but the section in general does not appear favourable. The productive zone was in a relatively flat section of the lode but the lode is steeper to the west. It is thought that the structure in the hanging-wall rocks, already referred to, was of importance in the localization of ore, but the flatter dip of the lode was probably also important.

Lower Mine Geology.

The Whitewater lode flattens abruptly below No. 13 level from an average dip of about 60 degrees to one of less than 20 degrees. The foot-wall rocks are all slates, but in the workings of the lower mine the hanging-wall rock is limestone. West of the main raise the ground in the angle between the flat and steep parts of the lode is much broken; there are steep splits in the lode system and a few fault-planes with northerly dips.

The rocks dip for the most part northward towards the lode at from flat to steep angles. The local appearance of slate beneath limestone above the lode, and of limestone lenses amongst the slates between branches of the lode, indicate that the flatter part of the lode follows closely the lower surface of the major fold (*see* Figs. 3 and 5).

It might be argued that the Whitewater lode does not flatten from 60 to 20 degrees but has been cut off by a flat post-mineral fault on which there is drag-ore. The locus of intersection of flat and steep dips has not been explored by the workings, and there may be a flat continuation into the foot-wall of the steeper lode as a sort of tear or branch, but the two nevertheless are believed by the writer to be parts of a single complex break. The abrupt change in dip is probably conditioned by the large drag-fold which deflected the course of the faulting. Mineralized fissures in the bed of Whitewater Creek near-by demonstrate conclusively the existence of other flat "feeder zones" of the same general attitude in the mine area.

There are three types of ore in the lower mine. One is, by inference, much the same as that in the upper mine; it occurs as masses and lenses within the lode, typically in the "J" stope, now inaccessible, a short distance west of the main raise (elevation about 3,510 feet). This ore has not so far proved important as regards tonnage, and nothing is known of relative mining grades.

The principal type of ore consists of relatively massive replacements of limestone by sphalerite accompanied by much siderite. It constitutes the bulk of the ore in the lower mine, and is termed "spathic" ore. Galena occurs in this ore, disseminated or in local masses, in a proportion of about one-fifth that of the sphalerite. Pyrite is rare and chalcopyrite even rarer.

A third type, of a peculiar variety, will be referred to as "magnetic" ore. It is replacement ore consisting of sphalerite and a little galena in a gangue of magnetite, pyrrhotite, pyrite, and some silicate minerals. It occurs in relatively large bodies between Nos. 14 and 12 levels, below an elevation of 3,600 feet (*see* Fig. 5, section C), and also in narrower widths within the lode itself in the western parts of Nos. 12 and 13 levels. This ore replaces dyke rock, part of the irregular lamprophyre intrusive which extends through the mine.

The magnetic ore is mostly if not all a replacement of dyke rock. In some parts the replacement is gradational and in others it is sharply bounded by extremely altered dyke; in still others it grades into or cuts sharply across silicified zones which may originally have been part of the dyke or its wall-rock.

Magnetic ore is typically dense and dark in colour, and consists of magnetite and pyrrhotite in varying proportions in which brown sphalerite occurs as masses, stringers, or scattered grains. Pyrite is locally a prominent constituent, particularly within or closely associated with magnetite; a very little chalcopyrite is associated with the pyrrhotite.

The pyrrhotite is of moderately fine grain size, but the magnetite is extremely fine grained and dense. Both minerals are cut by stringers of quartz, carbonate, and epidote. Some margins of the ore are siliceous, with local fine quartz crystals and tiny vugs, and grade into silicate rock which probably represents completely altered dyke. In most instances the ore grades into rock which, although consisting almost entirely of carbonate and sericite, as a rule retains its igneous texture and is recognizably porphyritic underground. In some places the magnetic ore grades into spathic ore.

Most of the magnetic ore occurs in a wedge between the lode and a vertical bounding slip on the south, and attains a maximum width of about 40 feet and a length of 250 feet. It has been largely mined out on the west end by No. 13 " big " stope, which extends from the lower apex, up to irregular prolongations above No. 12 level (Fig. 5, sections B and C). The body plunges eastward and only fragments of ore extend as high as No. 12 level, 250 feet west of the main raise. In its eastern part the lower apex of this ore-body reaches to within about 20 feet of No. 1472 level. The eastern and central parts were diamond-drilled between Nos. 12 and 1472 levels in 1943, and the intersections showed a rather irregular distribution of ore, dyke rock, and some limestone in the general zone of the ore-body.

Magnetic ore occurs also within the lode to the west of this large ore-body as far as the western faces of Nos. 12 and 13 levels; some also occurs within the lode in the central part of No. 12 and a little in No. 11 west. Neither the dyke nor the replacement reaches as great a width in these places, although a width of 10 feet is attained locally on No. 12 level. The dyke is much wider in the main magnetic ore-body, and for the most part elsewhere exists as sheared remnants within the lode.

The spathic ore-bodies as a rule follow the bedding of the limestone and become narrower and play out up the dip. The ore-bodies are characterized by the occurrence of siderite (spathic iron) in which sphalerite occurs irregularly and in varying amounts. The contact between siderite and limestone is sharp; a small amount of silicification is seen locally along the margins of some bodies, but is on the whole rare.

West of the main raise the spathic ore-bodies are almost invariably largest next to the lode and wedge out up the dip in one, two, or three tabular bodies. The foot-wall body in the central part of No. 12 level lies above an interband of slate within the limestone; this band is lenticular, up to 5 feet wide, and has evidently served to localize the ore-body.

Between Nos. 12 and 13 levels, west of the main raise, the limestone-slate contact is involved in a small drag-fold or crumple which has served to further localize the occurrence of ore in two small sublevels. This fold is well defined and swings in an arc with the major structure, plunging southward to and below No. 14 level at a distance of about 75 feet above the flatly dipping lode. This fold is shown in Fig. 5 in the successive cross-sections D to J; it is the dominant controlling structure which localizes the ore in this part of the mine. The ore occurs continuously for a distance of about 600 feet in the trough or " gutter " of the fold. The main mass of ore in the gutter reaches a cross-sectional area of as much as 40 by 40 feet, with the greatest volume extending from the lode below No. 14 level up to and above No. 1472 level. The ore extends up the upper limb of the fold for varying distances, and a second foot-wall prolongation extends locally upwards from the rim of the gutter.

Remnants of ore remain at many points in the lower mine but are mostly small or are difficult to reach from existing workings, many of which are no longer in good condition. The gutter ore-body, mined out above No. 14 level, is proved by diamond-drilling to extend below that level, presumably to the underlying lode (Fig. 5, section K). Other spathic ore is mostly mined out, as is most of the wider magnetic ore. Remnants of steeply dipping spathic ore remain in stopes above the western part of No. 12 level, as well as ore possibly of mixed type within the lode itself, but these stopes were not readily accessible in 1944. Spathic ore shows in small bodies in the innermost face of No. 11 level, representing the top of the general ore-zone which rakes upwards to the west.

Exploration between and west of the western faces of Nos. 12 and 11 levels should encounter more ore on the upward rake. The results of exploration for more than a few hundred feet beyond the present faces can not be predicted, because the outline of the major structure and its relation to the lode can not be foretold. Siderite occurs on No. 14 level in the inner part of the drift west of the main crosscut, in the hanging-wall of the lode. This was diamond-drilled late in 1944.

EXPLORATION.

Future exploration must take into account many factors, and before discussing them it should again be stressed that folding in the slate belt is of asymmetrical rather than of parallel or similar type. In other words, folds may die out rapidly in surrounding strata and may change greatly in cross-section along their strike. Minor irregularities of folding seriously complicate the larger structures.

Two reasons have been advanced for the occurrence of an important zone of silver-lead-zinc ore within slates in the upper part of the Whitewater lode. First, the relatively flat dip of the lode in this zone, and second, its occurrence within steeply dipping strata above a sharp fold in the hanging-wall rocks. The Whitewater lode is in a zone of thrust-faulting, and consequently flatter sections are more apt to provide openings (i.e., be relatively in a state of tension) than steeper. At the same time the dip does not steepen markedly at the lower limit of the ore-zone, so the dip is not perhaps the only controlling factor. The hanging-wall rocks in the ore-zone are essentially vertical, meeting the lode at an average angle of 45 degrees, while below the ore-zone they are rudely parallel to the lode; it may be that the bedded part of the lode is less favourable to ore deposition than the part which cuts the beds at a prominent angle. The eastward continuation of the lode across Whitewater Creek is marked by a prominent gully crossing the same general structure as in the ore-zone of the upper mine. There is no evidence of serious exploration across the creek, although a little digging may have been done in a cleft in the bluffs and record of it may have become obscured by slides.

The line of abrupt change in dip of the lode has only been explored where it has limestone in the hanging-wall, and it is possible that even where the hanging-wall is slate it might be a site of ore deposition, especially since the change in dip is accompanied by a greater general shattering of the rocks. The flat part of the lode has only been explored on No. 14 level, and at a few other scattered points where it closely follows the under-side of the major limb of limestone. Farther east, away from that structure and between slate walls, there may be a chance for silver-lead ore in the flatly dipping lode.

On the other hand, as there is a tendency for faults to swing parallel to the general attitude of the bedding under some circumstances of folding, the lode may have a different dip both to east and west of the mine-workings. The drag-folding which is presumed in part to have influenced the marked change in dip of the lode is a highly irregular structure localized at the point of reversal in plunge of the regional structure. Consequently, projection beyond the mine-workings is difficult, to say the least.

The lode will have both foot- and hanging-walls in slates at some distance below No. 14 level, where it passes through or beneath the limestone. Conditions at depth can not be foretold, but there appears to be no serious reason why silver-lead-zinc ore similar in type to that of the upper mine should not occur in the lode at greater depth in slates. The relation between the lode and the major steep fault that crosses No. 14 adit is not known; this relation would obviously be very important should exploration ever proceed to depth.

It may not be too much to point out again that the difference in mineralization between the upper and lower mine is primarily due to a change in geology and is not simply a function of depth.

By no means all of the limestone body has been explored for the existence of spathic ore, and actually only a very small zone contiguous to the lode has been investigated. It is known definitely that near the lode the presence of limestone-beds dipping towards the lode and of minor folds which have provided localization for ore-bodies are both favourable. Study of the generalized sections in Fig. 3 shows that similar conditions may exist at greater distances from the lode. Nothing that could be termed feeder zones to higher horizons in the limestones were recognized in the mine, but the presence of sulphides in surface working near the old Coy adit may be considered as proof that some such feeders to higher levels do exist. The fracture-zone which dips flatly southward in the bottom of Whitewater Creek canyon could undoubtedly act as a feeder, as it is mineralized locally and does not contain much gouge. Although this particular fracture possibly does not intersect the folded limestone, there is evidence of the existence of other similar fractures in the vicinity of the mine.

The south-eastern or " gutter " ore-body has been proved to extend below No. 14 level for a short distance. The present plunge of the structure would carry this ore-body southward, but a change in both strike and plunge is to be expected within a comparatively short distance.

Considerations regarding more extended exploration are more difficult. Ore may occur locally in any limestone-band in the general area, it must be agreed, but if it is of the same type and grade as the Whitewater spathic ore it must exist in quantity to be economic. Repetition of folding of Whitewater type, which involves a major band of limestone and has produced a great thickening of it, is hardly to be expected close to the present fold, but rolls in the dip of the limestone probably do occur beneath the general level of Kaslo Creek.

WELLINGTON MINE.

History.

The Wellington claim was located in 1892, and the early reports state that in 1894 350 feet of sinking and tunnelling was done on it. A " two and a half foot body of ore " was disclosed and 50 tons of silver-lead ore was shipped in the same year. In 1896, 400 tons averaging 173 oz. of silver and 30 per cent. lead was shipped and two adit-crosscuts were driven.

Little mention is made of the Wellington in succeeding years except that the A.Y. adit was driven 260 feet with the purpose of reaching the Hazel vein.

Wellington Mines, Limited, was formed in 1927 and additional claims were acquired, bringing the holdings up to ten Crown-granted and three located claims. In 1928 work was apparently done on the eastern Matheson adit on what was considered to be the continuation of the Whitewater vein, and work was started to advance the Hazel adit, then 250 feet long as the result of former work. The Hazel adit was stopped in 1929, and work on the Ivanhoe adit at a higher elevation in search of a continuation of the Wellington vein was stopped in 1930.

Exploration under a leasing agreement by S. N. Ross was carried out in the Hazel and Matheson adits between 1932 and 1935 and the company did a little additional work in 1937.

Production from the old workings, between 1892 and 1915, amounted to 787 tons containing 117,452 oz. of silver, 475,622 lb. of lead, and 100,402 lb. of zinc.

WORKINGS.

The Wellington property adjoins that of the Whitewater on the west. The following description refers only to the southern part of the property and to workings which investigated continuations of Whitewater structures. The older workings on the Wellington lode, which lies more than 1,000 feet in the foot-wall of the Whitewater lode, were not accessible.

Workings include the A.Y. adit, completely caved; the Hazel adit, largely inaccessible owing to bad air; three Homestake adits, of which two are caved; two Matheson adits, of which only part of one is accessible; and two I.C. shafts which are caved. There are a few open-cuts and shallow workings at scattered points, most of which are caved.

The Hazel adit, elevation 3,746 feet, was originally driven to intersect the Hazel lode, a line of quartz float and caved open-cuts along the hillside. For 170 feet from the portal the adit crosses fine-bedded, steeply dipping slate, of which much is quartzitic, and then crosses limestone for at least 120 feet, at which point bad air was encountered in 1944. The limestone strikes north 65 degrees west and dips at 50 to 75 degrees southward.

A drift on the hanging-wall of the limestone extends for 110 feet to the west, following a narrow quartzose zone on the contact. A second drift within the limestone, 250 feet from the portal, extends for 230 feet to the east and 485 feet to the west; one crosscut from the east drift and two from the west drift extend southward to the contact of the limestone. The drift follows a bedded fissure-zone along which there has been some but probably no major movement. The zone is locally mineralized with siderite, sphalerite, and galena, the best section being 20 to 90 feet east of the crosscut and as much as 18 inches wide. This is probably the Hazel lode, although at the surface the lode is not in limestone.

It has been reported that the Hazel adit is 2,350 feet long and that diamond-drilling extended for 240 feet ahead of the face, but the only map of the workings available shows a length of 1,775 feet in August, 1929. A drift 1,625 feet from the portal extends westward, and there is reported to be a raise driven from this drift on a " break."

Three old adits on the Homestake claim, at elevations from 4,180 to 4,265 feet, are reached by trail from the Hazel adit. The two lower adits are completely caved. The uppermost one is collared in and roughly follows a 30-foot limestone-band for 145 feet along the course of a mud-filled fracture-zone which dips from 20 to 45 degrees southward. If this fracture-zone represents a large fault it could complicate correlation of the surface geology with that in the Hazel adit, and might partly invalidate section A in Fig. 3. Near the face of the adit a 30-foot crosscut to the north exposes gently dipping underlying slates, whereas the limestone for the most part dips southward at moderate to steep angles.

Two caved shafts on the I.C. claim are at an elevation of 4,745 feet and indicate by their dumps nothing more than crushed rock and some evidence of mineralization; the slates dip steeply and it is inferred that the lode is more or less bedded.

Two adit-crosscuts at an elevation of 4,540 feet, some 500 feet south-west of the shafts, are known as the Matheson tunnels. The eastern adit is caved, but plans show it to extend as a crosscut for 275 feet and to continue as a drift for 400 feet eastward below the I.C. shafts. The lode is indicated by this relationship to dip very steeply to the south. The western adit is apparently collared just north of the projected lode. It extends as a crosscut for 120 feet to intersect a prominent shear-zone which has a steep northerly dip and strikes north 60 degrees west at a large angle to the supposed Whitewater lode. The shear-zone is followed for 35 to 40 feet to a caved face in either direction. A prominent band of limestone between steeply dipping slates is crossed by the crosscut. Several very old surface workings 300 to 700 feet east of the eastern adit, in limestone, show evidence of mineralization of no obvious significance.

METLAKAHTLA.

This Crown-granted claim, owned by M. J. Mahoney, one of the original prospectors in the area, is on the east bank of Whitewater Creek near its mouth. The claim is crossed by the Whitewater limestone as well as by the two upper limestone-bands, with intervening slates which are partly calcareous and contain several beds of limestone. The strata dip about 60 degrees to the south. Two inaccessible, short adits, one 25 feet lower than the other, near the bridge across the creek, were driven on a weak zone of fracturing about 20 feet wide that in part follows the bedding but in part crosses it at a somewhat flatter angle.

Both quartzose and replacement mineralization tend to follow the walls of the fracture-zone or lode and occur principally in beds of limestone and limy slate. The mineralization attains widths of from 1½ to 3 feet, and evidence of it can be seen on the steep hillside above the adits. It consists of siderite and quartz containing sphalerite, pyrite, and galena. A lamprophyre dyke about 8 feet wide, exposed farther north in the bed of Whitewater Creek, trends southward across the claim.

OHIO.

This old property is on the Highland Surprise Road. Cairnes (Mem. 184, p. 239) reports that a shipment of 10½ tons in 1909 averaged 160 oz. in silver, 2 per cent. copper, and $4.55 in gold, but there is no Provincial record.

Three short, caved adits on the roadside show by their dumps no more than that they were driven in lustrous black slates. Mineralized material on the dumps contains pyrite and a little chalcopyrite, and appears to have been chiefly quartzose although a little siderite gangue was seen.

Cairnes reports a fourth adit which was not seen but must lie below the road. He states that the lode strikes north 65 degrees west to due west and dips steeply to the south, and notes the presence of grey copper and galena in the ore.

DOHERTY.

The Doherty Crown-granted claim, known originally as the Iron Hand, is on Kaslo Creek at the mouth of Lyle Creek. It is owned by G. C. McCready and L. Garland, of Retallack. There is no official record of production from this property, although shipments are reported to have been made to the Hall mines smelter in early years. A trail (originally an old wagon-road) branches from the main road half a mile below Lyle Creek and follows a narrow bench along the property between 150 and 175 feet above the road.

The showings are lead-zinc and quartz-pyrite replacement deposits in the Whitewater limestone which outcrops in prominent bluffs along the road. The bluff exposure is a dip slope of about 60 degrees and several narrow infolded wedges of slates prove that the road follows the southern or upper contact. The dip flattens 50 to 75 feet above the road to as little as 20 degrees, and at the change in dip there is some drag-folding and contortion, the details of which can only locally be seen. The structure is as a whole roughly parallel to the ground surface, and the limestone is removed by erosion about 200 to 300 feet north of the road.

Mineralization occurs in irregular pod-like bodies conforming in general with individual minor folds. It occurs mostly in the upper part of the limestone-band and in part seems to be related to small folds and crumples above which the slates have been eroded away. The mineralization is largely restricted to a zone of contortion along the top of the bluffs, extending for about 1,000 feet south-east of Lyle Creek.

A good cross-section of the structure is seen on the east wall of Lyle Creek canyon (Plate VII., B). The base of the limestone is exposed in the bed of the creek and infolded remnants of slate show at the brow of the hillside. A zone of gossan on the vertical wall of the canyon, as much as 35 feet thick and about 100 feet long, is inaccessible and has been partly eroded away, but is clearly seen to be controlled by drag-folding. A flat fault which penetrates to and then follows up the basal beds of the limestone complicates the cross-section. An adit driven 33 feet along the bedding of the limestone from the bottom of the canyon beneath this showing contains a few thin seams of bedded mineralization.

A short adit about 300 feet farther up the creek is driven on zinc mineralization in an isolated patch of limestone. An adit about 35 feet below the brow and 20 feet from the canyon rim is driven 84 feet north-eastward. The first 37 feet is in slate and slaty limestone and for the remaining distance is in limestone beneath a flat slip on which siderite 2½ to 4 feet thick contains sphalerite and galena; this is probably the fault previously referred to. Another adit at the same elevation and 250 feet to the south-east is driven 142 feet north-eastward through limestone to encounter slates in the face. Fifty feet south of this adit there is an open-cut on a slab of siderite containing galena and sphalerite. The slab is an erosion remnant probably 50 feet by 20 feet and 6 feet thick, but has been partly removed and is partly covered by the adit dump.

An area of gossan about 25 feet square is crossed by the trail 650 feet from the canyon, and a larger area about 200 by 120 feet in plan lies on the steep hillside 800 feet from the canyon. An adit 40 feet below the gossan and 60 feet above the road is 37 feet long and reaches the lower surface of the limestone; it contains no mineralization. This large area of gossan is irregular in outline, appears to wedge out to the east, and to be divided into two parts, which trend south-south-east, separated by limestone. The western part of the gossan, if continuous beneath detrital cover, is about 200 feet by 30 to 40 feet in plan and the eastern part is about 200 feet by 30 to 70 feet in plan. These two bodies are erosion remnants in downwarps in the limestone. Other small patches occur farther down the slope and 100 feet or so to the east.

Heavy oxidation masks the character of the mineralization, and vague boundaries and general lack of bedding mask its limits. In general it consists of two slabs, lying with the hillside, locally seen to be about 12 feet thick and probably as much as 20 feet thick in places. Relatively massive sphalerite at the south-eastern corner seems to be of local occurrence, and much of the gossan is composed of thoroughly leached siliceous material which contained principally pyrite and some sphalerite and galena. The relative amounts of sideritic and siliceous replacement could not be estimated. Some local continuation beneath the surface may be looked for, but the main bulk of the mineralization is right on the surface; small feeder zones from below are not likely to be mineable. Determination of the tonnage and grade of material amenable to flotation could be carried out by a relatively inexpensive programme of test-pitting and diamond-drilling.

MONTE CHRISTO.

This Crown-granted claim, owned by C. L. Aylard, of Victoria, is on the west side of Rossiter Creek, a short distance from the mouth. The showings are on the canyon wall at an elevation of 3,360 feet. Production has amounted to 21 tons with a grade of 22 oz. silver and 25 per cent. lead.

The mineralization is in the southern of the two main limestone-bands which cross the creek. It lies within a fissure-zone which has a strike of north 65 degrees east and a dip of 60 degrees south-eastward; there is no displacement of the 50-foot limestone-band. One main adit, now caved, follows the fissure in the limestone, and two others appear to have been driven a short distance below on the steep slope, but the portals have been obliterated.

A fourth adit, 75 feet south-west of the first and at the same elevation, is driven a total distance of 335 feet north. It is collared in limestone and limy slate and crosses the main 40-foot band of limestone 105 feet from the portal. At 260 feet from the portal a band of limestone is encountered that appears to be 10 to 15 feet thick, although it is folded and is cut by a slip dipping 40 degrees northward. Some oxidized material, evidently sideritic and containing sphalerite and galena, occurs at two points in the limestone. It may be localized by cross-fractures.

CALEDONIA.

This group of ten located claims is owned by Geo. E. McCready, of Retallack. Four claims lie west and north of the Monte Christo and the rest are on the east side of Rossiter Creek.

Production from the Caledonia in fourteen different years between 1914 and 1943 has amounted to 113 tons, with a metal content of 5 oz. gold, 8,516 oz. silver, 113,110 lb. lead, and 6,803 lb. zinc.

A recent discovery (1943) on the Mother Lode claim, 1,200 feet north of the road and 2,000 feet west of Rossiter Creek, consists of a fissure striking eastward and dipping steeply southward in poorly exposed slates which dip steeply. Several small open-cuts and one 22-foot adit which intersects the fissure at about 15 feet of depth show traces of mineralization and, above the adit, a slab of galena about 4 inches thick. Exposures are few in this area.

The Caledonia workings consist of three adits and a number of surface workings over a length of about 400 feet measured along the strike of limestone and slates. This is partly on the southern main band of limestone which crosses the creek and partly in a zone of slate which contains several smaller bands of limestone. A fissure-zone of apparently small displacement cuts the strata at an acute angle; the principal fissure has a strike of north 70 to 75 degrees east and a steep southerly dip. There is some contortion of the strata, and at the eastern end of the zone of workings there are some small drag-folds with a vertical axis.

Mineralization consists of galena and sphalerite with some siderite in fractures in slate and as replacements in limestone. There is some pyrite, calcite, and quartz in addition. Mineralization in the principal showings is in the fissure-zone, and elsewhere is in small cross-fractures which cut the limestone nearly at right angles. Arsenopyrite occurs at one or two points and is reported to be gold-bearing.

The main adit, 650 feet north-east of the bridge on the main road, is a crosscut for 140 feet, and then follows the fissure-zone for 100 feet west and about 250 feet east. There is one small stope just east of the crosscut from which a raise continues to surface, a total distance of 65 feet above the adit. The eastern drift-face is in limestone which is apparently the main band, and discloses some irregular replacement. Two short adits and some open-cuts above the eastern drift disclose two or perhaps three sub-parallel oxidized zones which locally contain masses of galena, but most visible mineral has been mined.

ZINCTON AREA.

GEOLOGY.

A division of the rocks in this area has been made with the chief purpose of outlining the Zincton member which includes the Lucky Jim limestone.

The Zincton member consists of argillaceous and calcareous rocks. The argillites range from soft, dark-coloured rocks to harder, quartzitic types, the harder beds being in many cases lighter in colour. There are many distinct beds of limestone besides impure limestones and limy argillites. The rocks are for the most part rather thinly bedded, and the variation in rock-type imparts a distinctive banded appearance to the member as a whole.

The banded argillites are not distinctive themselves except for the fact that they are banded. They are slaty rocks in which slaty cleavage is better developed in the softer argillites and is less apparent in quartzitic beds and in limestone-beds. The cleavage is parallel to the bedding for the most part, but where the rocks are contorted it cuts across the bedding while maintaining its general south-westerly dip. The banded argillites are locally brecciated.

Several calcareous units, about 10 to 50 feet thick and containing perhaps 25 per cent. lime, were mapped because they are obviously far more limy than the average of the member as a whole. The thickness and number of distinct limestone-beds in each unit varies along the strike and the units, apart from the one south-west of the Lucky Jim limestone, are not clearly continuous (*see* Fig. 6). The individual limestone-beds attain a maximum thickness of about 5 feet; 13 feet of limestone exposed in the gully below the portal of No. 3 adit probably represents the edge of a drag-fold of the Lucky Jim limestone.

Mapping of these calcareous units shows them apparently abutting the Lucky Jim limestone. Exposures are too imperfect to prove clearly the meaning of this truncation, but it is probably due to folding, the details of which in many cases can not be worked out. The stratigraphy of the entire member can not accurately be given, partly because of some lenticularity of bedding but mostly because of complex deformation which will be discussed below.

The Lucky Jim limestone is a dark rock about 30 feet in normal thickness containing a few discontinuous slaty beds. It is brecciated throughout much of its known extent, a distance of about 3½ miles, and is locally bleached. The true thickness is a matter of doubt because complex drag-folding accompanied by squeezing has greatly affected the thickness. It can be traced by rare outcrops from the mine area to the ridge on the Chickadee claim at an elevation of about 6,500 feet (Plate VIII., A), and is considered to extend from there to the bridge across Jackson Creek (*see* Fig. 1). It is not exposed on the north side of Seaton Creek valley, but the Zincton member is clearly recognizable about 2,000 feet north of the creek on the steep hillside, and one or two fragments of limestone breccia float were seen at the expected position of the Lucky Jim band. Regionally, the thickness of limestone in the main band, as well as that in the calcareous units, increases to the south-east.

Underlying the Zincton member on the north and east are slates of relatively uniform character, continuous across the strike to the central part of Bear Lake. The slates include at least three distinct bands of limestone up to about 25 feet in thickness, one or two small limy zones, and scattered beds and narrow bands of quartzite. On the whole, however, the slates show little variation from the average dark grey argillaceous rock with well-developed slaty cleavage. Pyrite-studded, dark grey paper-slates occur at the main portal of No. 9 adit-level.

The rocks overlying the Zincton member are dark-coloured slates and slaty argillites, for the most part soft and incompetent. They are thinly bedded and include harder, quartzitic beds, but are not typically banded like the Zincton member. They contain one band of limestone but the member as a whole is not calcareous. West of the area the slaty argillites grade upwards into stronger, more thickly bedded rocks and are overlain by thick-bedded argillites which do not have slaty cleavage developed in them.

Light-coloured granitic rocks intrude all of these sedimentary members but are most abundant in the slates underlying the Zincton member. The intrusive bodies are mostly sills and range from a few inches in width to a sill-sediment sheeted zone nearly 100 feet thick. Light-coloured sills are prominent in the bluffs above the two portals of No. 9 adit-level. Several sills in the Lucky Jim workings cut the limestone and follow more or less the hanging-wall. These sills, from a few inches to about 3 feet wide, split locally so that the number varies from place to place. Most of the sills are carbonatized and sericitized, although the largest zone of sills is relatively unaltered.

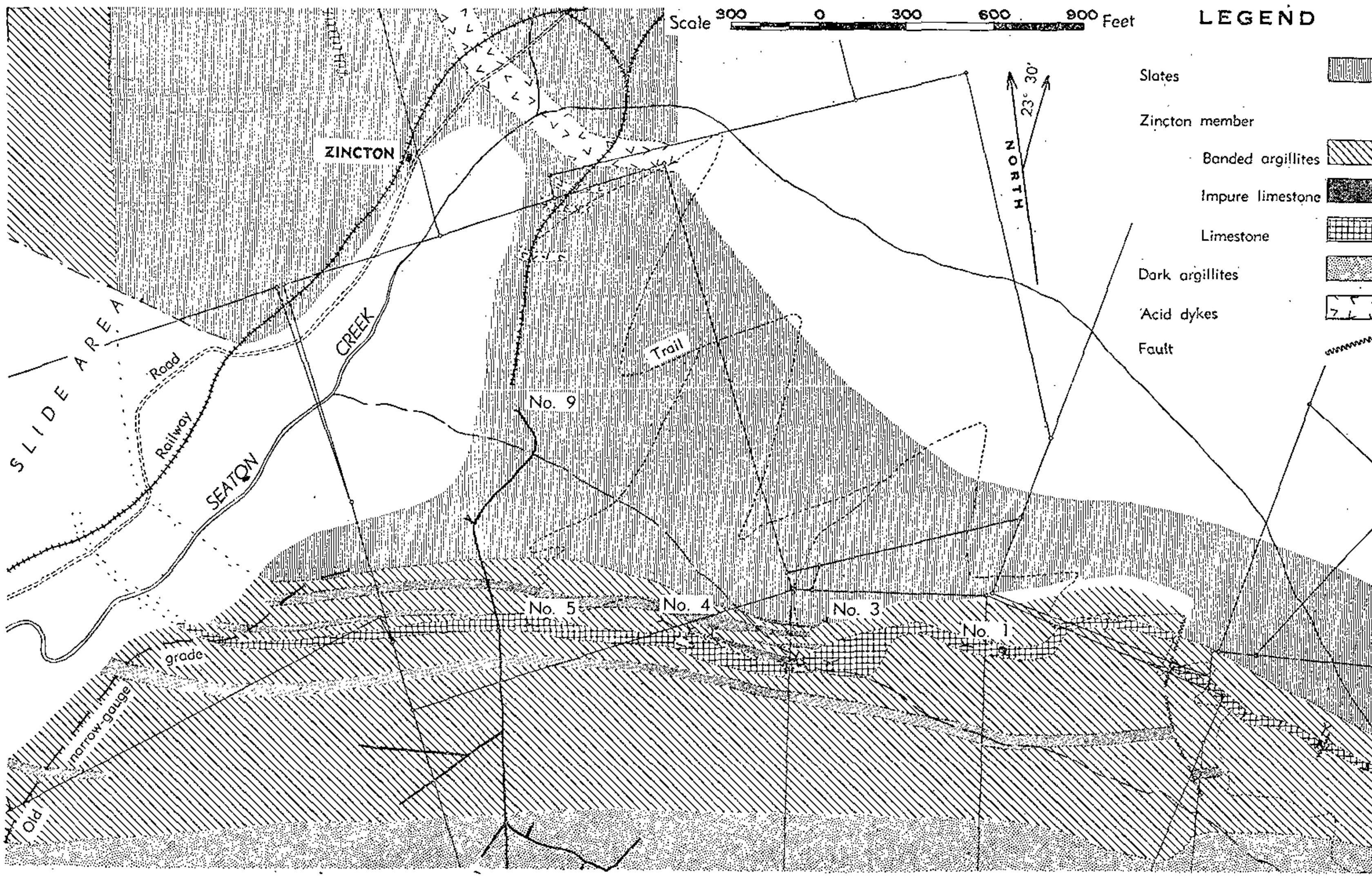


Fig. 6. Geological map of Zincton area.

STRUCTURE.

The regional strike is north-westward and the regional dip is south-westward. Surface mapping in general shows the rocks to persist fairly uniformly in strike. In detail, however, the rocks are profoundly deformed.

There is a synclinal axis 2,200 feet south-west of the area and the axis of a complementary anticline 2,800 feet south-west, crossing the old Kaslo and Slocan Railway grade (Fig. 1). The Zincton member is not exposed in either the syncline or the anticline. The regional plunge is west-north-westward at about 20 degrees and the synclinal basin rises in the higher ground south and east of Seaton Creek. This ground is heavily brush-covered and the structure was not traced up it, but there is a possibility that the syncline fades out on the ridge near the Chickadee claim, or at least becomes unrecognizable at that location, in a zone of local contortion.

Contorted zones immediately west of the mine area represent flats and even minor reversals in the general dip, and a flattening in the lower workings of the Lucky Jim mine probably marks the north-eastern edge of the synclinal basin. Much crumpling probably gives both the syncline and complementary anticline an irregular outline.

The dark slaty argillites overlying the Zincton member are locally contorted, but internal structures were not worked out. In the underlying slates bedding can not always be detected with certainty and, although bedding and cleavage appear generally to be parallel in the mine area, it is quite possible that much complex folding occurs in these rocks. There is no positive evidence of a second period of deformation such as exists in the Retallack area.

The internal structure in the Zincton member is better understood, partly because the banded nature of the rocks permits the tracing of bedding, and partly because of the cross-sections provided by mine-workings. It is better understood, but the knowledge of the structure is far from perfect. There has been local brecciation of the rocks and much drag-folding that is neither symmetrical nor continuous. Surface mapping does not do more than indicate the drag-folding, chiefly because the line of outcrop on the south side of the valley nearly coincides with the axis of plunge of the structure. The drag-folding can not be studied clearly unless it is seen in cross-section.

The character and effect of minor structures in the Slocan slate belt have been discussed previously (pp. 10–13). Fine plication of cleavage is not here so evident as in the Retallack area, but brecciation (the formation of "pseudoconglomerates" and the "strewing" of fragments of harder beds through the softer), drag-folding, and doubling up of strata have taken place throughout the banded argillites. Reference to Plate VI., A, shows that even in an area in which the rocks appear to be relatively undisturbed there is some close folding and duplication of strata. The photograph is of an anticline involving a single bed that stands out as the result of weathering, close to No. 4 adit; the continuity of this and similar folds is not known, nor the thickness of strata involved in them, since they can not be traced with certainty and can as a rule only be detected on a weathered, cross-sectional surface. Brecciation combined with flowage of the type illustrated in Plate VI., B, has in many places obliterated the bedding and consequently the folded structure of the banded rocks.

The anomalous behaviour, according to the mapping, of the calcareous units which pass along their strike into the Lucky Jim limestone is no doubt a product of the folding, squeezing, and brecciation that has affected the Zincton member as a whole.

The Lucky Jim limestone, originally a dark grey rock containing occasional discontinuous slaty beds, is brecciated throughout much of its observed extent and is partly bleached. Although the distribution of the breccia could not be accurately traced, nor the amount closely estimated, perhaps half to three-quarters of the limestone is brecciated in the Lucky Jim mine.

The breccia is varied in character. The fragments range in size from a small fraction of an inch to several feet in longest dimension. Characteristically, the fragments are lighter in colour than the matrix. The only fragments which are not limestone are rare slate fragments, and these are frequently slab-like. One rounded fragment was found that appeared to be coarsely crystalline quartzite and probably represented a pebble originally contained in the limestone. Cairnes (Mem. 184, p. 71) noted the presence of granitic dyke material in the breccia, but the writer did not see any. A limy conglomerate, stratigraphically above the limestone on the Chickadee claim, contains a few small pebbles of igneous rock, and it is possibly that to which Cairnes refers. Throughout the mine-workings at least, it is clear that the dykes were intruded later than the brecciation of the limestone.

The limestone was profoundly shattered throughout most of its extent and locally was ground to a fine rubble in which there are few fragments more than 2 inches in longest dimension. In some places there is an alignment of fragments in the fine or moderately fine phases of the breccia, which proves that differential movement took place during its formation.

Brecciation was not restricted to the limestone but affected other rocks of the Zincton member as well. Although not brecciated to nearly so great an extent as the limestone, the banded rocks are seen to be shattered and broken in many places. The brecciation of the banded rocks does not seem to have an obvious connection with the brecciation of the limestone, because in many places the contiguous banded rocks are unbrecciated whereas the limestone is. The presence of rare slate fragments in the limestone may indicate the fragmentation of slate interbeds or possibly of slates bordering the limestone, but it is also possible in some instances that they represent the shattered extremities of sharp drag-folds in slate which have been pinched off within the limestone; this last view is lent support by the occasional slabs of slate as much as 40 feet long which are seen in one or two stopes in the mine.

On the other hand, it is not thought that the brecciation of argillites and of limestone took place as the result of processes that differed either in age or character. The same widespread brecciating forces or agencies are believed to have acted differentially, in places affecting the limestone more greatly than the slates. A discussion of the salient facts of the case and a consideration of the factors involved follows.

The Zincton member, a succession of banded rocks including soft and hard argillaceous types and limestones, lies above a great thickness of relatively uniform slate and below several hundred feet of slaty argillites, both of which are much less competent than the Zincton member. The Lucky Jim limestone was, on account of its thickness and lack of banding, perhaps originally a relatively competent unit of the Zincton member. When the rocks were subjected to forces that produced the folding of the region there was much differential movement and many minor, irregular structures were formed. The banded rocks, on account of the banding, on the whole accommodated themselves to the stresses, but folded locally into complex and irregular minor forms, many of which finally ruptured under continued differential stress. The limestone was involved in precisely the same folding and irregular warped drag-folds were formed in it, accompanied by squeezing and flowage of the rock. It is believed that, with continued stress and differential movement, acting too rapidly for complete internal adjustment, the limestone failed by brecciation to a greater degree than the containing rocks which, on account of the thinness of bedding, were better able to accommodate themselves to the stresses by internal slipping between beds. In speaking of the relative competency of the limestone it is the competency of the band that is meant and not the intrinsic competency of the rock itself, because some of the harder argillites are much stronger than the limestone, and single beds of limestone in the banded rocks are not as a rule brecciated.

The foregoing hypothetical consideration seems to account for the brecciation of the limestone better than any other. Whatever factors were involved the forces acted along the strike of the formation and not along zones cutting across it. The action of bedded thrusts might be invoked to account for the brecciation but there is no positive evidence for them. If there were such thrust-planes sufficient in number to affect so great an extent of drag-folded limestone, some evidence of them should be seen in tabular zones of brecciation. Again, if brecciation were produced along thrust-planes these could not have followed the limestone exclusively, and brecciation of the contiguous argillites must also have taken place.

The fact that of the many bands of limestone in the region only the Lucky Jim is brecciated may possibly be accounted for by the different character of the enclosing rocks. The brecciation of the Lucky Jim limestone is in any event believed to have been a peculiar result of folding in which the rate of differential movement was such that complete internal adjustment was not brought about by folding alone.

There has been fracturing and faulting of the rocks, most of which appears to have taken place subsequent to the formation of the breccia. The faulting is for the most part more or less parallel to the general structure, and only one transverse fault with a horizontal offset of more than a few feet is known in the area. This is seen on the surface and at the face of No. 4 level, where the limestone is offset to the right along a northward dipping fault-plane.

Curving longitudinal faults are seen on several of the mine levels, some in limestone and some in slates. One on No. 5 level (Fig. 8) has produced an offset of perhaps more than 100 feet, but the movement on others is not known. Some steeply dipping longitudinal fractures on No. 9 level in the wide part of the limestone can not be classed as faults, because they are not seen to cut the slate walls and so the amount of offset, if any, is not known. They are possibly important in that they may in some instances have acted as feeder zones for the mineralization.

Cross-fractures, essentially vertical fractures normal in strike to the limestone, are common in the mine-workings and in some instances are mineralized. They have produced no noticeable offset in the bounding slaty rocks. They were long thought to have governed exclusively the localization of the ore and provided sole access to the mineralizing solutions. Cross-fractures are present throughout the known length of the limestone on the Seaton Creek slope.

A discussion of the form and extent of minor folding is best included in a description of the mine.

LUCKY JIM MINE.

History.

The Lucky Jim, together with other claims of the present group, was located in May, 1892, less than a year after the first discovery of mineral in the Slocan. The sum of $10,000 was spent on development during the first year, and in 1893 a shipment of 60 tons of 60 per cent. lead ore was made.

The first discovered ore contained masses of galena in addition to sphalerite, and more than 900 tons of sorted lead ore containing 1 oz. of silver to the per cent. lead was shipped by the end of 1898. Because of the difficulty of disposing of the zinc, which was predominant in the ore, the property then lay idle until it was bonded by G. H. Hughes in 1903 and shipments were again made the following year. The property was worked primarily for zinc from 1905 on, and $80,000 was paid in dividends in that year.

The property was well situated relative to the Kaslo and Slocan narrow-gauge railway, a comparatively short tram-line delivering ore to bins at the track. This railway was destroyed by extensive forest fires in 1910, but by 1912 the Nakusp and Slocan Railway, now a branch of the C.P.R., was built from Three Forks to Kaslo, utilizing the narrow-gauge grade from Zincton east.

In 1911 Lucky Jim Mines, Limited, was formed and a low-level adit known as No. 6 (now No. 9) was started about 30 feet above the K. and S. track. Shipments continued to be made, but the company got into debt. A. G. Larson, put in charge by the British Columbia Courts in 1915, succeeded in paying off much of the indebtedness by the end of 1916, during which year nearly 12,000 tons was shipped. Successively smaller shipments were made in 1917, 1918, and 1919 when work ceased.

In 1923 the property was acquired by A. G. Larson and associates, of Spokane, who formed the Lucky Jim Lead & Zinc Company, Limited. Development-work was done in 1924 and 1925, and production was begun in the latter year. The concentrator at Rosebery was acquired in 1925 but was found to be unsuitable for the Lucky Jim ore, and milling-ore was, instead, shipped to Trail for concentration and reduction. In 1926, 20,478 tons was mined, and in 1927 about half that amount. The ore was mined principally from Nos. 3 and 4 levels, including presumably the Larson stope.

In 1927 a large interest in the company was acquired by the Victoria Syndicate, and construction of a mill with a rated daily capacity of 200 tons was started in June. More than 44,000 tons was treated in 1928 at a rate as high as 225 tons daily on a mill-feed of 10 per cent. zinc, 1½ per cent. lead, and 1½ oz. of silver per ton.

In 1929 the Lucky Jim Lead & Zinc Company, Limited, with H. H. Yuill as president and managing-director and Peter Price as superintendent, ceased milling at the end of January and embarked on a search for more ore. Much drifting, crosscutting, and raising was done, including driving the main raise from No. 9 to No. 5 level and sublevels from it; 5,644 feet of long-hole drilling was done to test the ground within about 100 feet of existing workings. The Annual Report of the Minister of Mines, B.C., for 1929 states that at the end of that year "there was an indicated tonnage of from 150,000 to 200,000 tons of ore containing approximately 15 per cent. zinc, with very low values in lead and silver." All work was stopped at the end of January, 1930.

With a rise in base metal prices the Lucky Jim Lead & Zinc Company, Limited, renewed activity in the spring of 1937 and operated irregularly throughout the remainder of that year and again in 1938.

In 1940 the property was bought by Zincton Mines, Limited, a subsidiary of Sheep Creek Gold Mines, Limited, and the work of reconditioning mine and equipment started late in the year. This company, under the general management of H. E. Doelle and the local management of F. R. Thompson, milled 38,208 tons in 1941, 87,593 tons in 1942, 84,858 tons in 1943, 100,588 tons in 1944, and 63,322 tons in 1945, a total of 374,569 tons.

During the four-year period of operation, Zincton Mines, Limited, mined entirely below No. 5 level. A raise was driven between Nos. 9 and 8 levels and No. 850 sublevel was driven. Some crosscutting was done on No. 9 and a 20-degree winze 219 feet long was sunk below that level. More than 200 diamond-drill holes, with an aggregate length of 38,289 feet, were put down. The capacity of the mill was raised from 200 tons to about 320 tons, the Diesel power plant was augmented, and some new building was done. Exploration by diamond-drilling on the surface at an elevation of nearly 5,000 feet disclosed some interesting mineralization, including galena. A road was built in 1945 up to the old No. 1 adit preparatory to driving that adit ahead to explore the new discovery.

The present company first shipped zinc concentrates to the Anaconda Smelter at Butte, Montana, but in 1943 procured a war-time contract with Metals Reserve Corporation, of Washington, for disposal of their product. This contract ran out in June of 1945 and was not renewed. Following a shut-down on June 9th milling was resumed late in September, 1945, the zinc concentrates being shipped to the Trail smelter. F. R. Thompson became general superintendent of the Sheep Creek company, and J. S. McIntosh was made manager at Zincton.

Production.

Production from the Lucky Jim mine, from the first shipment in 1893 until the end of 1945, has amounted to 514,913 tons which contained, in ore and in concentrates, 51 oz. of gold, 303,203 oz. of silver, 4,369,957 lb. of lead, and 102,260,191 lb. of zinc.

The earliest production, from 1893 to 1904, when silver-lead ore only was shipped, amounted to 1,239 tons which contained 69,192 oz. of silver and 1,305,872 lb. of lead.

The ore mined from 1905 to 1945 averaged about 11½ per cent. zinc in terms of contained metal, assuming an 85 per cent. recovery in milling throughout the years. Mill-heads from 1941 to 1945 have averaged about 10 per cent. zinc for a total of

374,569 tons. Since 1937 mining has been almost entirely below No. 5 level, and no lead has been recovered.

SURFACE WORKINGS AND SHOWINGS.

The Lucky Jim limestone has been imperfectly traced from the K. and S. grade, elevation 3,530 feet, nearly to the ridge summit on the Chickadee claim, elevation about 6,500 feet, a horizontal distance of 7,000 feet (Plate VIII., A). The brecciated limestone is almost continuously exposed on the steep bluffs from track-level to No. 5 adit, and at intervals from there to the middle of the Snap claim. In the rest of the distance there are only four or five exposures.

The average slope of the line of outcrop is nearly that of the plunge of the axis of the main folding. The plunge is not accurately known, but appears to be about 20 degrees in the mine-workings. This near coincidence of line of outcrop with axis of plunge explains to some extent the fact of a relatively straight line of outcrop of the limestone in spite of the evidence of drag-folding seen in the mine-workings.

The outcrop below No. 5 level apparently is not mineralized, but almost all other outcrops are in the form of steep cross-fractures, more or less widely spaced. The most heavily cross-fractured zone, between Nos. 4 and 2 levels, constituted the original discovery and the site of earliest mining. Above No. 1 level almost all natural exposures have been investigated by open-cuts and short adits where mineralized cross-fractures occur containing some galena and sphalerite. On the Gringo claim two old crosscut adits, completely caved, were driven on an underlying calcareous unit which evidently contained some galena and sphalerite. On the north-west corner of the Chickadee a drag-fold in the limestone with a steep plunge is exposed in a prominent bluff. The rock there contains mineralized cross-fractures, the highest or farthest south-east known; two adits near the base of the bluff are driven off the limestone in slaty rocks.

In the higher ground, exposures are so few that comparisons can not be made, but a zone of contortion in the banded rocks on the Chickadee ridge probably signifies a local flattening of the structure. This flattening may represent a pinching-out or disappearance of the folding which is exposed in Seaton Creek valley. It was not found possible to prove this point conclusively, but such a pinching-out or modification of folded structure in such a distance is not out of the ordinary in this area.

MINE-WORKINGS.

The mine is opened up by six adits at elevations ranging from 3,554 feet at the portal of No. 9 to 4,660 feet at No. 1. Nos. 2, 3, 4, and 5 levels also are adits, and Nos. 450, 6, 7, 8, and 850 levels are driven from raises. A winze extends below No. 9 level a distance of 219 feet at a slope of 20 degrees. A plan of the workings is shown in Fig. 7.

In early years a tram-line extended from near the portal of No. 3 level to the track below, but this was destroyed by fire in 1910. Later a tram-line led from No. 5 level to bunkers at the track, but was abandoned. At present a tram-line reaches from No. 9 dump to the portal of No. 4 level and is used for servicing Nos. 4 and 5 levels. A road was built to No. 1 level in 1945, and compressed air is to be piped through the mine for the proposed exploration at that level.

No. 9 level is driven as a crosscut for about 1,000 feet to intersect the limestone which is explored on the level for a strike length of 900 feet. A second portal, through which all ore and waste is now trammed, is 400 feet north-east of the first, the extra tunnelling having been done to avoid building a surface track past a slide area. A main raise extends from near the innermost end of the level up to No. 5 level and a second service raise extends up to No. 8 level.

Almost all parts of the workings are accessible. There is little timber in the mine and the limestone, in which most drifting and all stoping has been done, maintains openings exceedingly well. The banded, slaty rocks also maintain openings of drift size with little or no support.

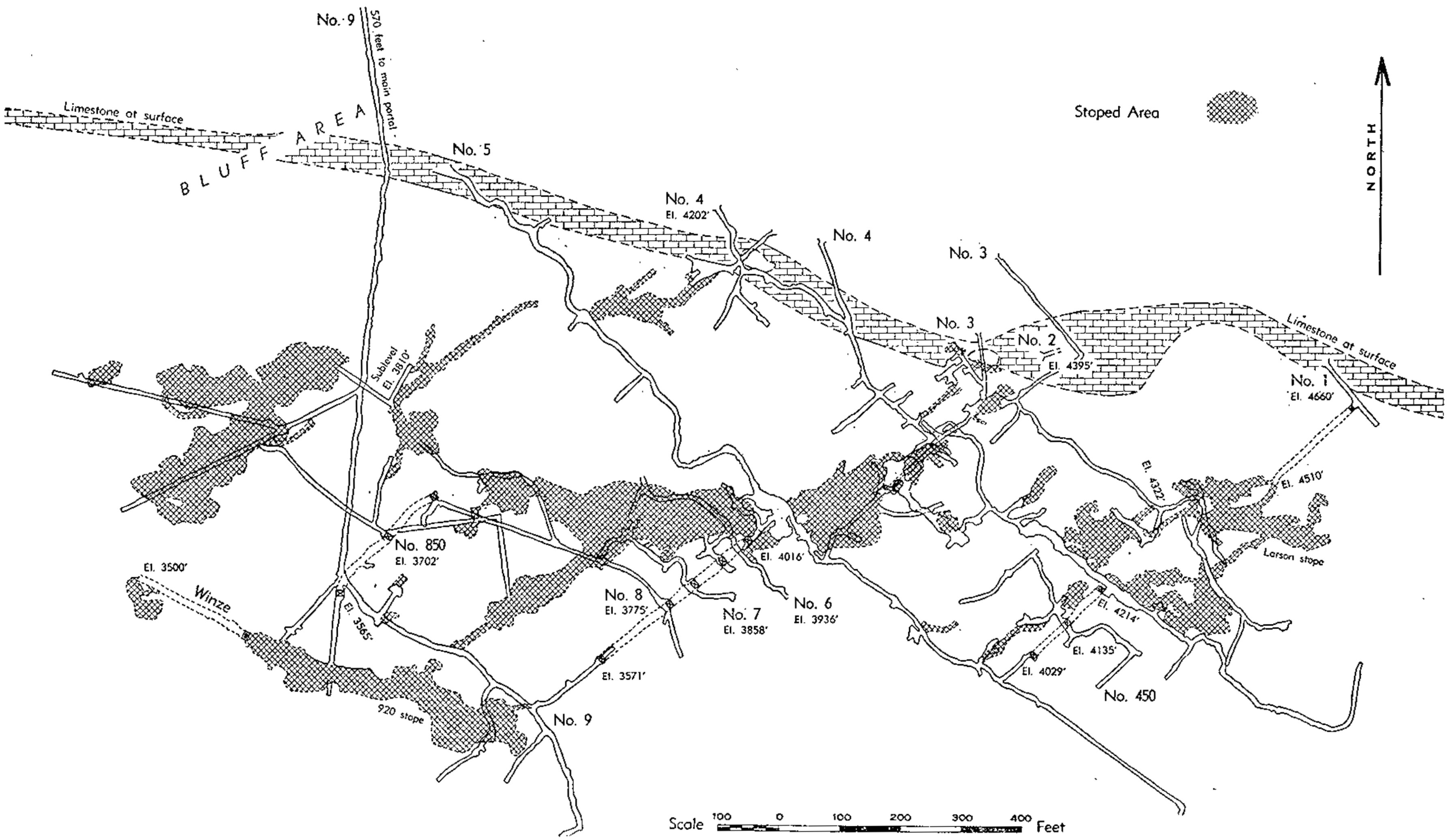


Fig. 7. Plan of Lucky Jim mine-workings.

Not every part of the stopes can be examined, partly because of their size and the local steepness of some of them. Stopes on cross-fractures are vertical slots extending more or less across the local width of limestone. Stopes in the zones of more widespread replacement are as much as 200 feet in strike length and as much as 60 feet vertically between foot- and hanging-walls. Stope surveys other than progress outlines are not available.

There are three main axes of stopes: (1) the strike of the cross-fractures, (2) the strike of the axis of plunge of folding, and (3) approximately the strike of the limestone. These directions of stoping are directions of structural control of ore deposition.

Mineralogy.

The ore consists of sphalerite and pyrite replacing limestone. Concentrates from current production contain less than 1 per cent. lead, about 1 oz. of silver per ton, a small amount of cadmium, and a trace of tin. Galena, common in the cross-fracture zones of the upper levels, has not been a recoverable constituent of the ore below No. 5 level, and is reportedly very rarely seen during the course of current mining. Tin, in minute amounts within the sphalerite, occurs at least partly in the form cassiterite.*

Cavities within the ore sometimes contain coarsely crystalline sphalerite. The crystals are as much as 1 inch across, and many beautiful specimens have come from the mine. The cavities also contain pyrite, calcite (commonly as scalenohedra), and, less commonly, quartz.

The typical ore is sphalerite and pyrite in limestone. There is little or no siderite, which mineral is common in many parts of the Slocan, and only in rare instances is there a noticeable amount of quartz; some silicification accompanies bleaching in the Larson stope above No. 3 level, but is rare elsewhere in the mine. The relative proportion of sphalerite and pyrite varies widely, but the same variations can be seen throughout the range of mine-workings.

The distribution of mineral within an ore-body varies considerably, as is the case in many replacement deposits. In bodies localized by cross-fractures the sphalerite may be relatively massive with distinctly minor amounts of pyrite and, in the upper levels, masses of galena (now all mined out, but referred to frequently as "clean lead"). The margins of such bodies may be clean cut against unmineralized limestone. In the more general replacement ore the sphalerite and pyrite occur in streaks and masses or, less commonly, scattered through the rock. In some stopes the minerals occur in bands or lines which strongly suggest that they follow a fracture pattern, but this is far from being the case in general. The margins of the larger ore-bodies are in many cases poorly defined.

In some instances the ore occurs in bleached limestone but in many instances does not. The bleaching, at least in some places, is accompanied by an increase in the magnesia content of the limestone. It also represents a decrease in free carbon or carbonaceous impurities. The following table shows the results of six analyses of limestone:—

Partial Analyses of Limestone.

	1.	2.	3.	4.	5.	6.
CaO	50.9	32.1	54.9	50.6	55.0	48.7
MgO	0.9	20.0	0.3	2.4	0.4	3.7
Fe_2O_3	0.55	0.36	0.09	2.1	0.13	3.31
S	......	......	......	1.5	......	1.2
Insol.	6.1	2.1	1.2	1.1	0.9	0.8

(1) Black limestone from No. 5 level.
(2) Bleached limestone from Larson stope.
(3) Dark grey limestone, No. 4 level.
(4) Bleached equivalent, containing some pyrite.
(5) Medium grey limestone, No. 4 level.
(6) Bleached equivalent, containing some pyrite.

* H. V. Warren, personal communication.

Nos. 4 and 6 were taken from bleached zones along fractures 1 inch from the unaltered rock of Nos. 3 and 5 respectively. The analyses prove only the introduction of magnesia into rock originally low in that constituent. The magnesia was introduced along channelways and hence presumably by hydrothermal agencies.

STRUCTURE.

The Lucky Jim limestone was originally a dark grey rock about 30 feet thick. It is now much brecciated, bleached in part, and is warped and drag-folded. In spite of the rather extensive workings the amount and distribution of the brecciation is not accurately known, nor are the distribution of bleached zones and the outline and continuity of the drag-folds sufficiently well understood. In fact, many drag-folds may be inferred although their presence is not proved. The chief reason for this lack of knowledge is the fact that the mine-workings do not, except locally, follow the contacts of the limestone and rarely provide a full cross-section.

The horizontal width of limestone encountered in the workings ranges from about 20 feet to more than 300 feet (*see* plan of level, Fig. 8). The reason for this great variation in horizontal width is not everywhere apparent, and throughout much of the mine it might be attributed to squeezing alone were it not for the evidence of sharp drag-folding on the south-western end of No. 9 level and of duplication of limestone on No. 5 level. Elsewhere small drag-folds are seen in a few places where the contact with slates is exposed, and a doming in the hanging-wall slates in others.

The great variation in apparent horizontal width is the result of repetition by drag-folding. Moreover, the folds are not symmetrical and squeezing which has accompanied their formation has both thickened and thinned the limestone. The figure of 30 feet original thickness in the mine-workings is an estimate only; it is greater farther to the south-east, but there is a regional thickening in that direction.

Fig. 8 shows the distribution of limestone on No. 5 level. The presence of a fault cutting a complex structure diagonally makes the precise outline of the folding in plan a matter of some doubt, but it is believed to be an asymmetrical drag-fold. The sections are less certain and represent an attempt to account for the known facts on the basis of folding, only part of which can actually be seen. One thing is certain from regional studies, and that is that complex, discontinuous folding of this sort is to be expected.

The displacement on the fault on No. 5 level is not known. It has apparently been such that the displaced masses of limestone line up along the course of the drift, and the offset which folding would normally produce has been counteracted by it. The fault can be traced downwards to No. 7 level, but not lower with certainty; it is a curving and branching fracture which is not everywhere clearly defined within the limestone and it locally swings into the bedding.

This drag-fold has been recognized only on No. 5 level, but it has probably been missed by other workings. Some doming on Nos. 4 and 3 levels proves that there are local reversals of plunge and that, consequently, the structure may vary in outline from place to place along its extent.

Below No. 5 level even less is known of the structure. There is a marked flattening above No. 9 level on the line of section A-A′, but details are not known. Diamond-drilling on No. 9 level has indicated but not yet fully outlined another plunging drag-fold of importance at the start of the flattening, and the south-easternmost faces on that level are beneath the fold and beneath the top end of No. 920 stope which lies within the fold.

No. 920 stope is at the edge of a general zone of flattening which is probably related to the larger syncline lying south-west of the area. Irregularity of cross-sectional outline and some reversals in dip are to be expected in the course of exploration of this zone. The plunge is about 20 degrees west-north-west.

There is drag-folding of the limestone in the area of the western faces on No. 9 level. A sharp double drag-fold is imperfectly outlined on the level but is seen in the

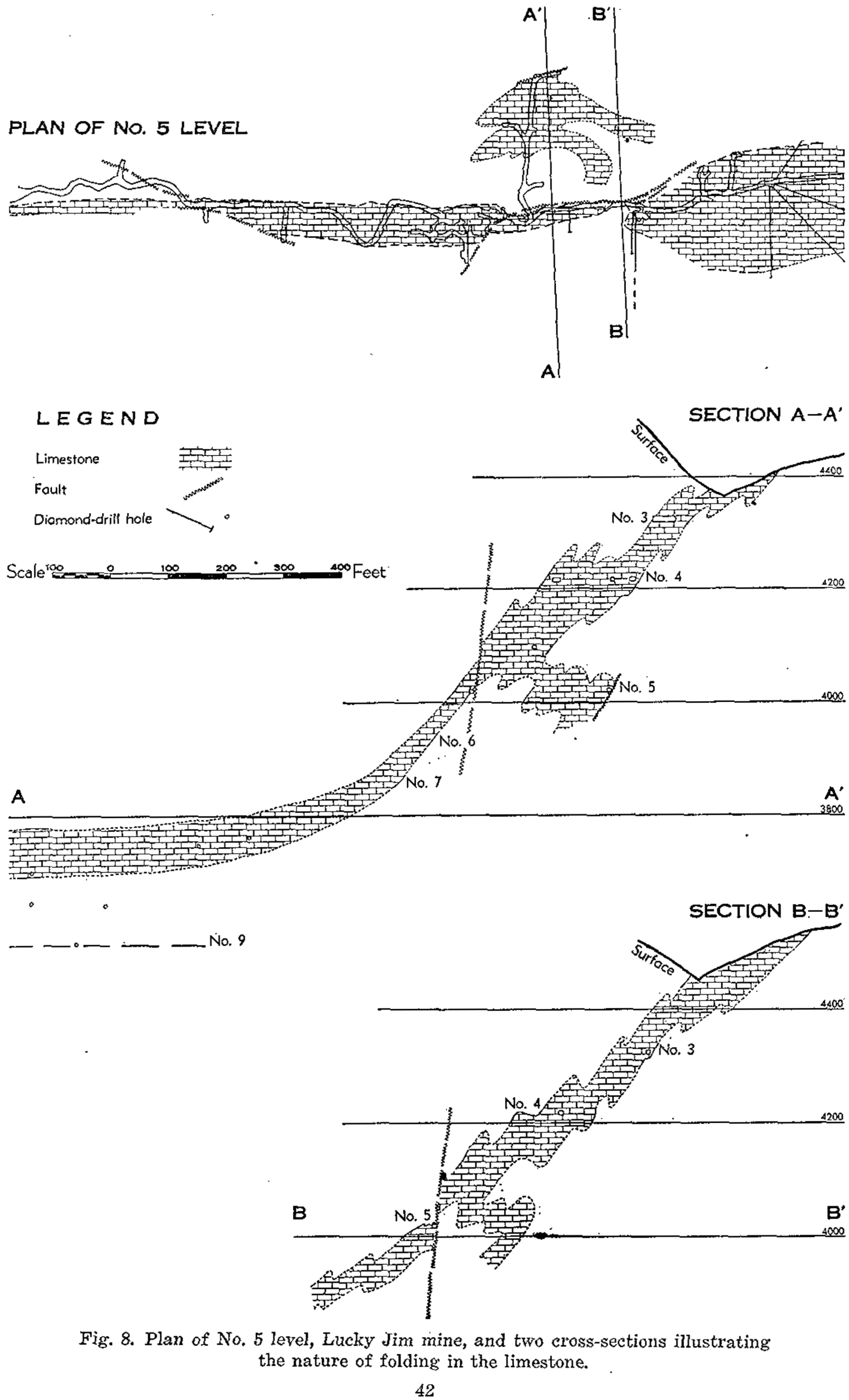


Fig. 8. Plan of No. 5 level, Lucky Jim mine, and two cross-sections illustrating the nature of folding in the limestone.

stopes, where mining has followed ore on both sides of an upward tapering limb of slate. In the crosscut and in a diamond-drill hole ahead of it three widths of limestone are crossed, with two intervening bands of slate.

The ore is not entirely localized within the drag-folds, and since their outlines are not fully known the influence of the drag-folds on ore deposition is at present a matter of doubt. That they have served in some degree to localize the ore is certain.

Localization of Ore.

There is a system of fracturing throughout the mine striking at right angles to the regional strike and dipping vertically. The cross-fractures, as they are called, have as a rule produced no displacement, although a movement of the northern wall westward a distance of 1 foot or so was noted in one instance on No. 3 level. The fractures may be mineralized in the limestone, but although they also penetrate the slates they are not mineralized in that rock. They are sometimes a few feet or even a few inches apart and locally produce a rude sheeting in the limestone, but in other places are widely and irregularly spaced. They are most abundant and best defined on No. 5 level and above, and a large amount of the ore in the upper part of the mine has been localized along them.

In the upper levels, although not all cross-fractures are mineralized many do contain sulphides in the form of seams, tiny lenses, or scattered grains, and single fractures are seen that localize 1 foot or more of almost massive sphalerite. Large ore-bodies have resulted from a merging or coalescence of ore between near-by fractures, producing a width of about 40 feet in extreme cases. The ore formed chimneys on single or multiple fractures and, in zones of more intense fracturing, swelled into large and irregular bodies. In the largest, however, controls of ore deposition other than cross-fractures were of some importance also, and in the Larson stope the cross-fracturing played an apparently minor rôle.

In the lower part of the mine the influence of the cross-fractures is definitely less important. A single cross-fracture is followed in the large, westernmost stope between Nos. 9 and 8 levels, but the influence of the fracture is not so clearly marked as in the upper levels because scattered mineral extends for tens of feet on either side of it and is not strongly localized along the fracture itself. The main raise extending from No. 9 level to No. 5 was driven on a prominent zone of cross-fracturing on individual members of which there is slight evidence of mineralization, but the zone does not make ore except in the vicinity of No. 5 level. This same zone has no marked influence on the formation of ore in No. 920 stope, nor do other irregularly spaced individual fractures on No. 9 level have more than a minor effect on the formation of ore.

The greater development of cross-fractures in the upper part of the mine than in the lower is a matter of some importance. The zones of cross-fracturing have not been productive of as much ore as have the zones of more general replacement, but the ore in them has been higher in grade and has contained important amounts of silver and lead in addition to the zinc. The reasons for the distribution of cross-fractures and for the fact of their varying degree of influence on ore formation have not been established, but the following possible explanation is advanced.

The localization of relatively massive sulphides along fractures proves that they acted as channelways for the mineralizing solutions. It may at least be inferred also that they were tensional fractures. In searching for variations in the more general structure which might serve to account for localization of cross-fracturing, attention was given to the fact that minor drag-folds on Nos. 3, 4, and 5 levels show a plunge opposite to the normal direction, and that there is some evidence of doming of the hanging-wall slates on Nos. 3 and 4 levels. The doming can not be accurately traced, but is suggestively near to the larger ore-zones on these levels. It is quite possible that the rocks at the apex of a dome or cross-warp in folded structure would be in a condition of tension and that fracturing might be localized in the dome. Cross-fractures situated in a zone of tension would serve better as channelways for mineralizing solutions than would fractures at other points on the general structure.

The occurrence of lead in the upper levels but not the lower has long been known, and the Lucky Jim has often been cited as an example among Slocan mines of rapid change in metal content with depth. The zonal theory of ore deposition has been advanced in explanation of the changes in metal content in many mines in the Slocan, and the arguments are well summarized by Cairnes (Mem. 173, pp. 110–118); but the fact that galena is a constituent of cross-fracture ore and not of ore of more general type in the Lucky Jim may mean that factors other than depth governed its distribution. The nature and continuity of the channelways followed by ore-bearing solutions were probably more important in influencing deposition than was the depth at which deposition took place.

If the emphasis is placed upon channelways or "feeders" of mineralizing solutions and not upon relative distance from a source whose position must remain in doubt, the factor of depth appears less important to the occurrence of lead. The zone of cross-fracturing was one in which there were obviously definite channelways whose walls were replaced, whereas the larger ore-zones of the lower mine did not apparently possess such a well-defined system of fracturing.

A number of problems are unsolved, such as why the cross-fractures are most prominently developed at upper levels and why, if longitudinal fractures may also have acted as feeders, should they not also have been sites for deposition of galena. However, before the variation in metal content can be considered a function of depth or of thermal gradient alone geological uniformity throughout the observed range should be proved. The change in the structural conditions of ore deposition in a relatively short vertical range may be sufficient to explain the known facts of metal distribution.

The cross-fracturing makes a pattern of ore formation that is obvious in the stopes on the upper levels and is also represented in the lower levels. The longer axes of the stopes are aligned with the direction of cross-fracturing.

A second axis of ore formation is seen in the large stope between Nos. 8 and 5 levels, in the Larson stope above No. 3 level, and in other stopes. The ore in these stopes is not so clearly defined as those in which the ore is localized apparently through the sole influence of cross-fractures. The direction is, in general, that of the plunge of the drag-folding, and this fact is the chief reason for asserting that the folding served to localize the ore. Whether or not that means only that the fold served as a containing structure in which ore was further localized by fracturing within it is more difficult to prove, and a matter that is of more theoretical than practical importance in mining.

A third direction is that of No. 920 stope, which is roughly parallel to the average strike of the limestone. This may be anomalous in that this stope may follow a fold whose axis diverges from the average, but there are, along the north-east boundary of the stope, longitudinal fractures in the limestone that are in general parallel to the stope. These longitudinal, essentially vertical fractures are seen in relatively few places. They are no more than cracks as a rule, but are as well defined as are the cross-fractures in general appearance. It is considered quite possible that they have in some instances served as feeders or localizing factors in ore formation. On the north side of No. 920 stope on No. 9 level they are related to a bleaching of the limestone.

There are thus three main factors responsible for the formation of ore; that is, three factors with a somewhat systematic development throughout the mine. In any part of the mine one factor may locally dominate or two or more may combine. Still other factors of more random occurrence also affect ore deposition.

The distribution of sphalerite and pyrite in some stopes forms locally a pattern of ribs or stripes through the rock, evidently governed by pre-ore fracturing. In many places the pattern does not fit the foregoing concepts and, furthermore, is differently oriented in different parts of a single stope. It is believed that this minor fracturing was developed as the result of purely local stresses, and that it is important but unpredictable.

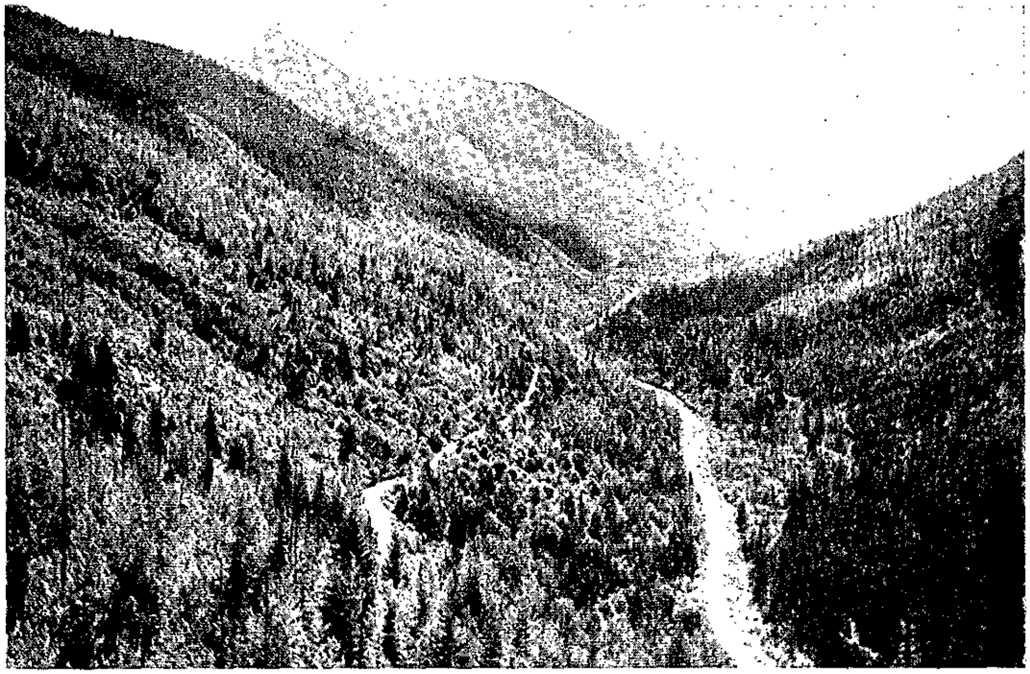
Ore deposition is further localized by the presence of slate ribs within the limestone. Such ribs are of rare occurrence but, when present, may constitute one boundary of a stope. Some may be unbrecciated slate interbeds, but some appear to be thin wedges of slate drag-folded into the limestone and perhaps broken off. Nearness to main contacts of the limestone does not as a rule seem important, although some ore does follow the main slate wall. In general, the stopes that do not extend fully across the limestone appear to favour nearness to, but not necessarily contact with, the foot-wall.

Dykes or sills within the limestone are pre-ore. They are never mineralized, but in rare instances a fracture cutting across a dyke may contain a thin seam of sphalerite. Dykes form a local, but far from general, damming effect and so may constitute the local wall of a stope.

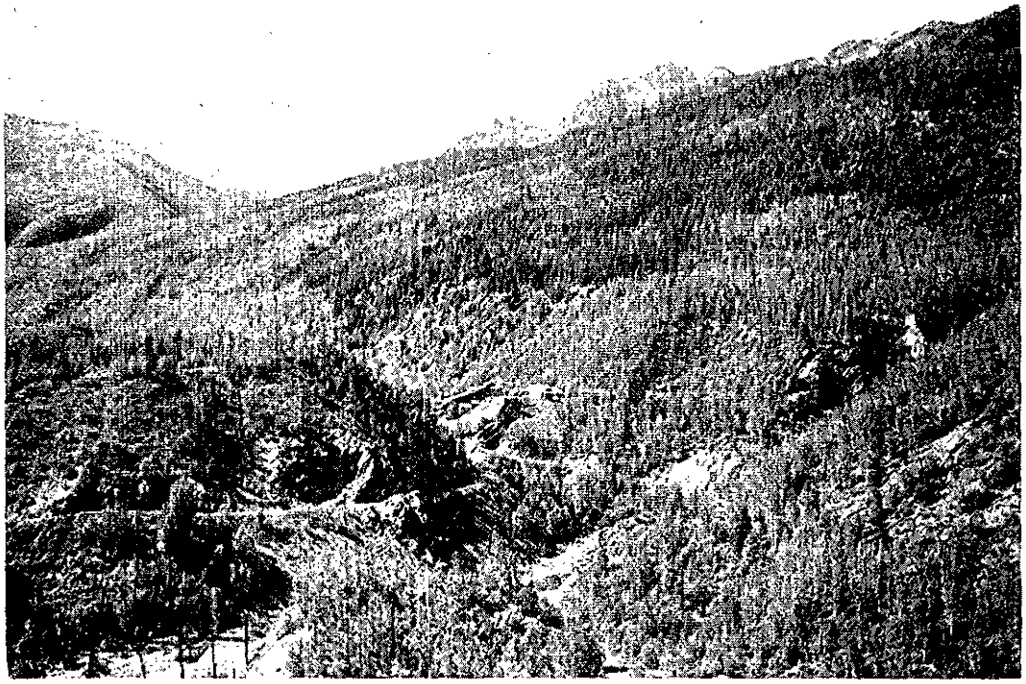
Some of the limestone in the ore-zones is brecciated and some is not. More ore occurs in brecciated limestone than unbrecciated, but not enough is known concerning the distribution of breccia to state that this is any more than a chance relationship. It is a subject worth further study.

Little study has been given to the effect of bleaching on the localization of ore. The Larson stope is almost wholly in bleached limestone, whereas the ore in No. 920 stope favours the unbleached rock. Many cross-fractures are accompanied by bleaching for a distance of a fraction of an inch to 1 foot or more from the fracture, and the bleached rock may be pyritized, but there does not seem to be any obvious general relationship between the presence of ore and bleaching.

PLATE I.



A. The valley of Kaslo Creek, looking west, with Retallack in mid-distance.

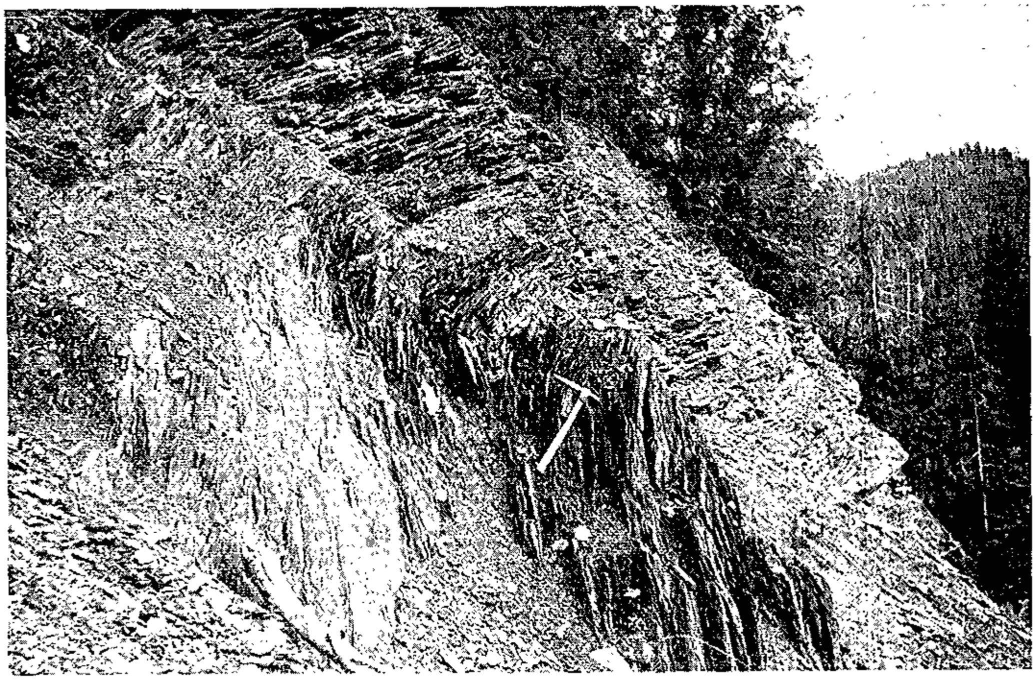


B. Whitewater concentrator at the portal of No. 14 adit-level. Whitewater Creek canyon on right, valley of Goat Creek in left distance.

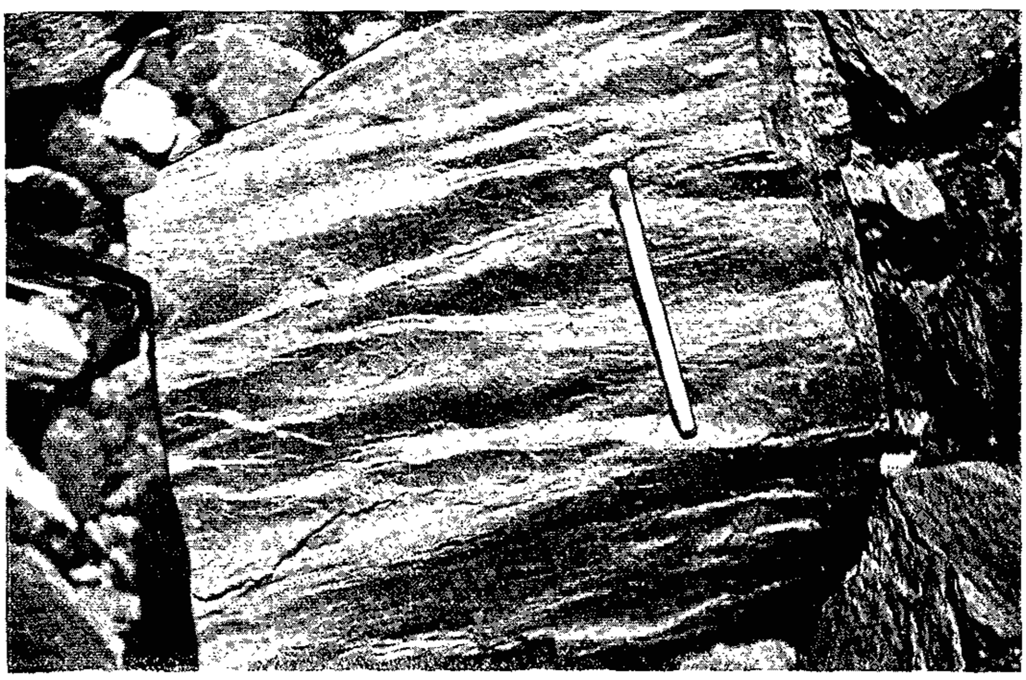
A. Reco Mountain, as seen from the uppermost workings of the Wellington mine. Jackson Creek is in left foreground and Idaho Peak in right distance.

B. Fish and Bear Lakes, at the head of Kaslo Creek. Note the low pass to Seaton Creek beyond Bear Lake. The slopes on the left rise to Reco Mountain.

PLATE III.



A. Outcrop of Slocan slates, showing rotation of cleavage-planes at surface caused by slumping. Railway-cut west of Retallack.



B. Cleavage-block of finely plicated phyllite. The match-stick gives the scale.

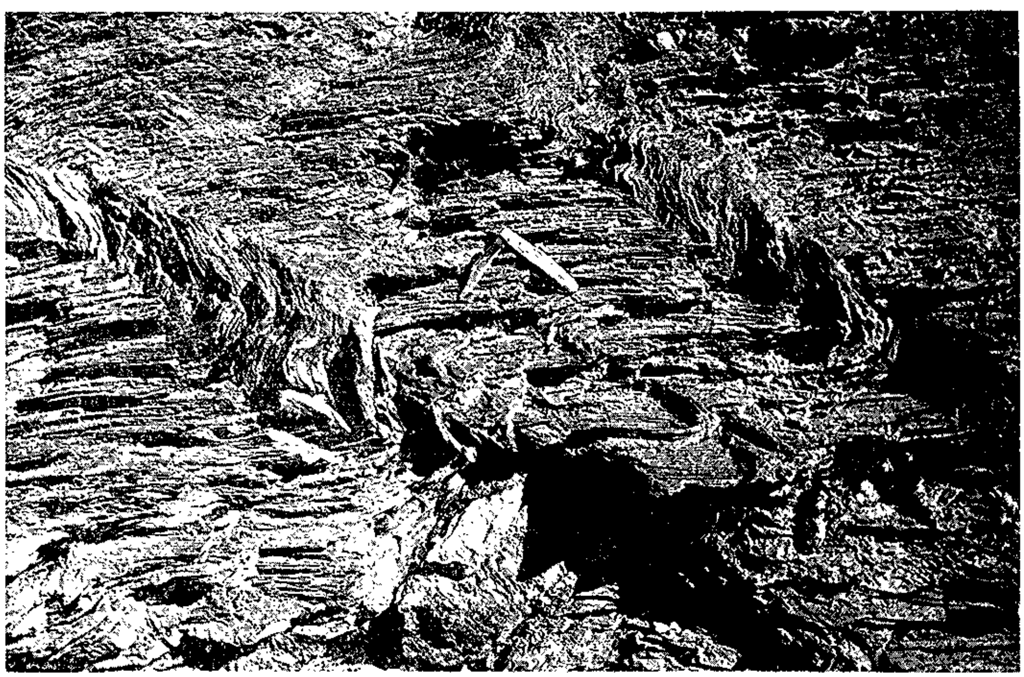
PLATE IV.

A. Part of a small anticline on Highland Surprise Road in which cleavage transects the bedding. The nearly vertical ribbing in the left half of the photograph is plainly conditioned by the cleavage but closely simulates bedding.

B. Detail of a folded area, showing a quartzitic bed between softer argillaceous beds. Cleavage has sliced the harder beds, and the softer material has locally been squeezed between the irregular sheets.

PLATE V.

A. Detail of close folding in thin-bedded rocks which has been completely ruptured, with production of a breccia.



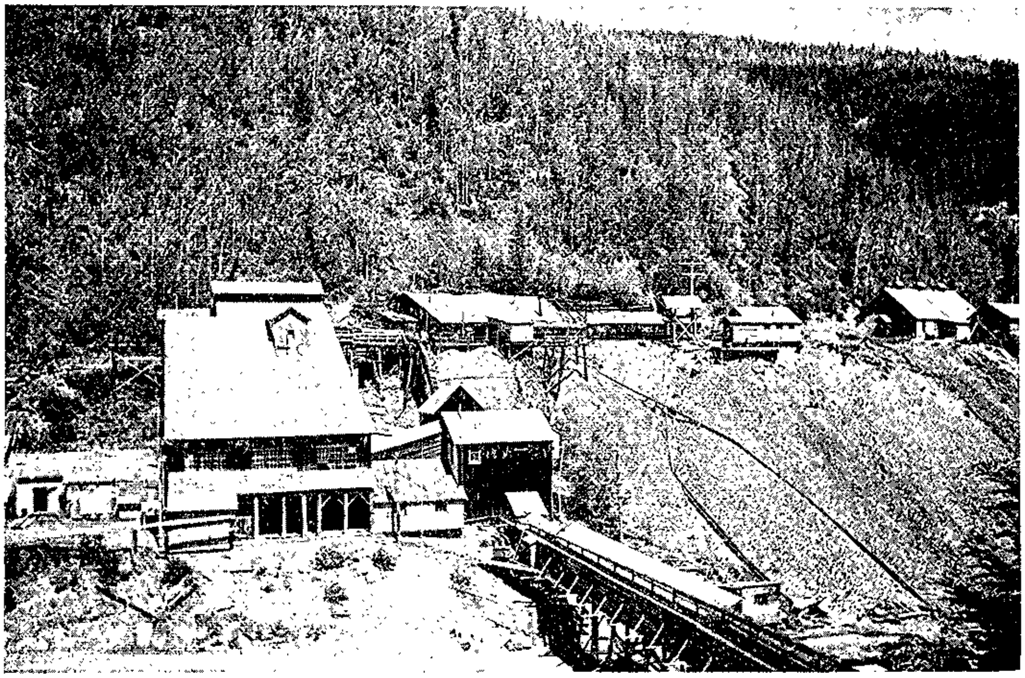
B. Flat-lying slates east of Goat Creek with planes of crumpling which represent incipient thrusts.

PLATE VI.

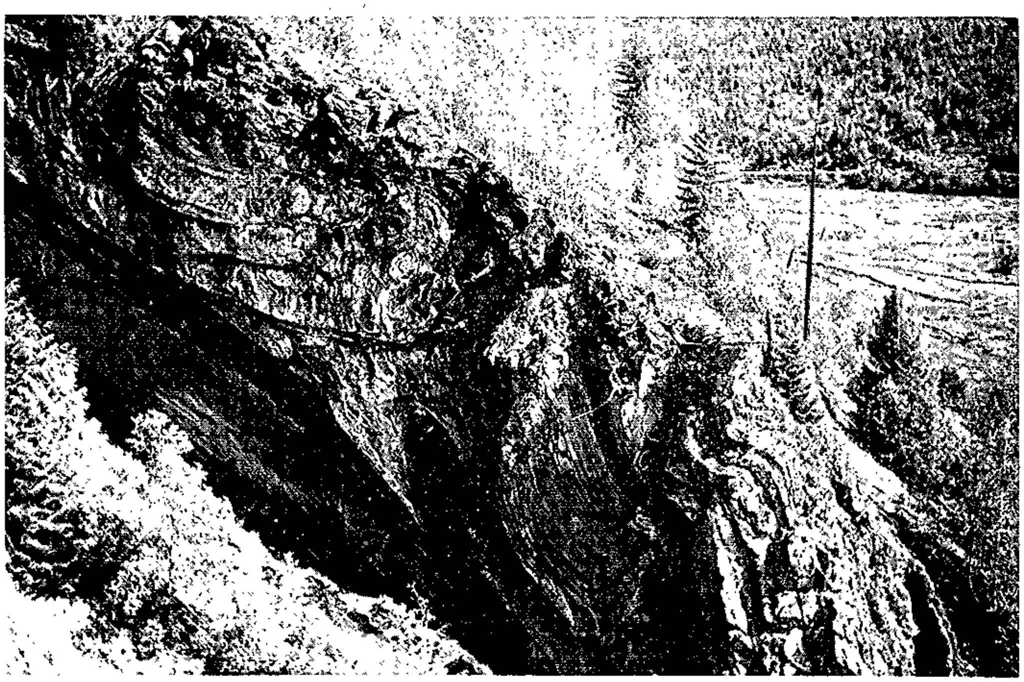
A. Small plunging fold in banded argillites at portal of No. 4 adit, Lucky Jim mine. The fold is not distinguishable except at this point.

B. Illustrating the formation of breccia which simulates conglomerate. Highly cleaved soft rock (cleavage dipping downward to the left) is crossed by a harder bed which is ruptured into fragments which are aligned with the cleavage. The harder bed is not recognizable at the right of the photograph.

PLATE VII.

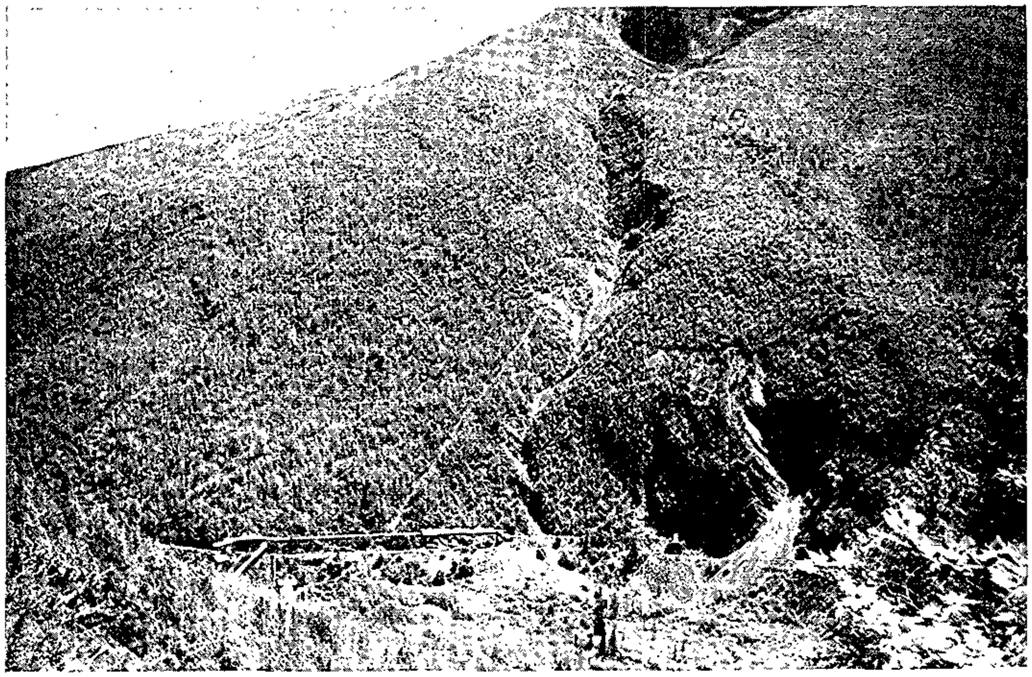


A. Whitewater concentrator and surface plant. The portal of No. 14 adit is at the left of the low building against the hillside. The trestle in the foreground carries concentrates across Kaslo Creek to the railroad.

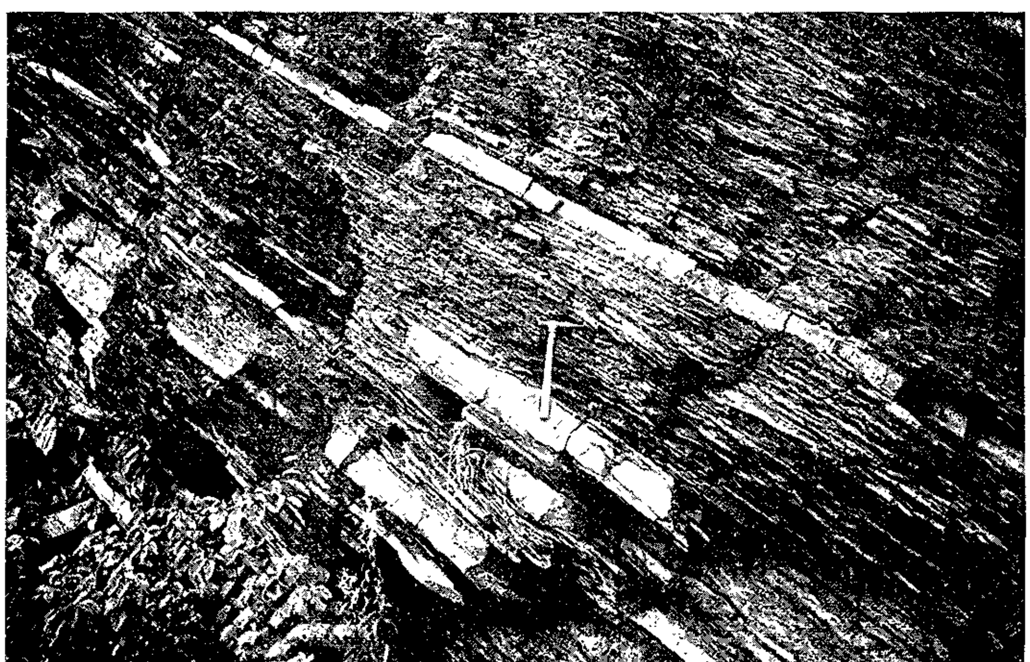


B. Contortion in limestone on the Doherty claim on the side of Lyle Creek canyon.

PLATE VIII.



A. The Lucky Jim mine. The snow-shed leads from the portal of No. 9 adit to the mill, and the concentrate elevator from mill to railroad can also be seen. No. 5 adit is at the top of the bluff on the right, and the straight scar on the hillside is an old tramway which led up to Nos. 4 and 3 levels. The *Chickadee ridge is on the* sky-line, left of centre.



B. Typical weathered exposure of banded argillites of the Zincton member.