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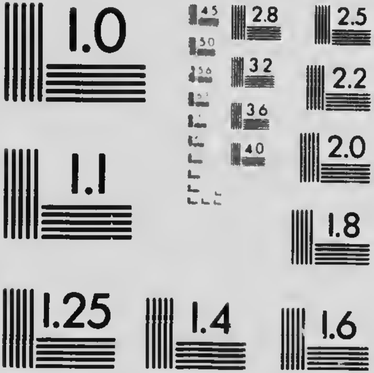

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Subject to revision.] [*A Paper to be discussed at a Meeting of the Institution of Mining and Metallurgy, to be held at the Rooms of the Geological Society, Burlington House, Piccadilly, W., on Thursday, April 18th, 1912, at eight o'clock p.m.*, and at a Meeting of the Canadian Mining Institute at Toronto, on March 6th, 1912.

The Domes of Nova Scotia.

By T. A. Rickard, *Member.*

PART I.

General Geology.

The Province of Nova Scotia is remarkable among regions yielding gold, not for the amount of precious metal produced, but for a beautiful lode-structure, the origin of which has provoked the constructive imagination of geologists for 50 years. As this interval of time coincides with the age of modern geology, the theories offered in explanation of local conditions serve admirably to illustrate the development of a science that has only lately achieved obvious economic importance as an aid to world-wide industry.

The gold mining region in question occupies the seaward half of the peninsula of Nova Scotia and is traversed by a series of sedimentary rocks into which granite has intruded. Mining in the granite has not been profitable, all the productive activities of the past having been confined to the sedimentary series, consisting of highly altered beds of quartzite and slate of great geologic antiquity, that is, at least as old as the Cambrian, although, in the absence of trustworthy fossil remains, it is uncertain whether they may not be even pre-Cambrian, namely, Algonkian. These beds of quartzite and slate have a known thickness of 30,000 ft., divided into an upper division of dark slate, with an estimated thickness of 11,500 ft., and a lower division of slate and quartzite about 18,000 ft. thick. It is in the lower series that the gold-bearing lodes are found, only one noteworthy mine having been worked in the upper slate, and even this exception occurs close to the line drawn between the two divisions.

The gold mining region has a maximum length, from east to west, of 200 miles, and a width, from north to south, varying from 8 to 50 miles, so that the total area comprised is about 3000 square miles (See map). The heart of the region extends from Caribou to Moose River, the horizontal distance being 10 miles and the vertical thickness of strata 18,000 ft., in one broad monoclinal fold with minor undulations. Across this section quartzite predominates, the slate appearing in beds relatively infrequent and thin. The sand-rock from which the quartzite originated must have contained lime, for calcite is abundant. The fine silt, now changed to slate, has been much hardened, but its true character is not obscured. Of later igneous rocks there is scant evidence, save at Tangier, where dikes of diorite have been noted; but they do not appear to have influenced the distribution of the gold. We have to deal, therefore, with metamorphosed sediments of one series and the granite that has intruded into and through them.

The age of the granite is important, for it bears upon the geologic antiquity of the ore deposits. By reference to maps* it can be seen that the granite has displaced more than a third of the superficial area formerly occupied by the slate and quartzite formation; indeed, it has been suggested that the granite represents these rocks in the last phase of their metamorphism; but this is a deep question, in more senses than one, and need not concern us just now. As we see the granite today it is an intrusive rock, and therefore younger than the gold-bearing formation into which it has been thrust. How much younger? The evidence on this point is adequate: fragments of detrital granite are found in northern Nova Scotia within Middle Devonian sediments; on the other hand, in the Bear River basin the granite cuts into the Upper Silurian of the Oriskany horizon. Therefore the granite is older than the middle, and younger than the base of the Devonian; it is of early Devonian age. Between the deposition of the sediments now constituting the slate-quartzite series and the irruption of the granite, there stretches the whole of the Silurian period, and a part, if not all, of the Cambrian.

The slate-quartzite series is probably Algonkian; the granite is early Devonian; what, then, is the age of the gold-bearing quartz? The best answer to that is afforded by the fact that the quartz veins in places (as at Forest Hill) follow tongues or apophyses of granite, and gold has been detected in the granite at such places. Moreover, mineralized quartz penetrates the granite at other places (as at Country Harbour). Therefore the quartz is younger than the granite. Finally, a conglomerate known to be of Lower Carboniferous age and composed of the eroded fragments of the slate-quartzite series has been found at Gay's River, and from this conglomerate gold

* I refer to the excellent maps prepared by E. R. Faribault for the Geological Survey of Canada.

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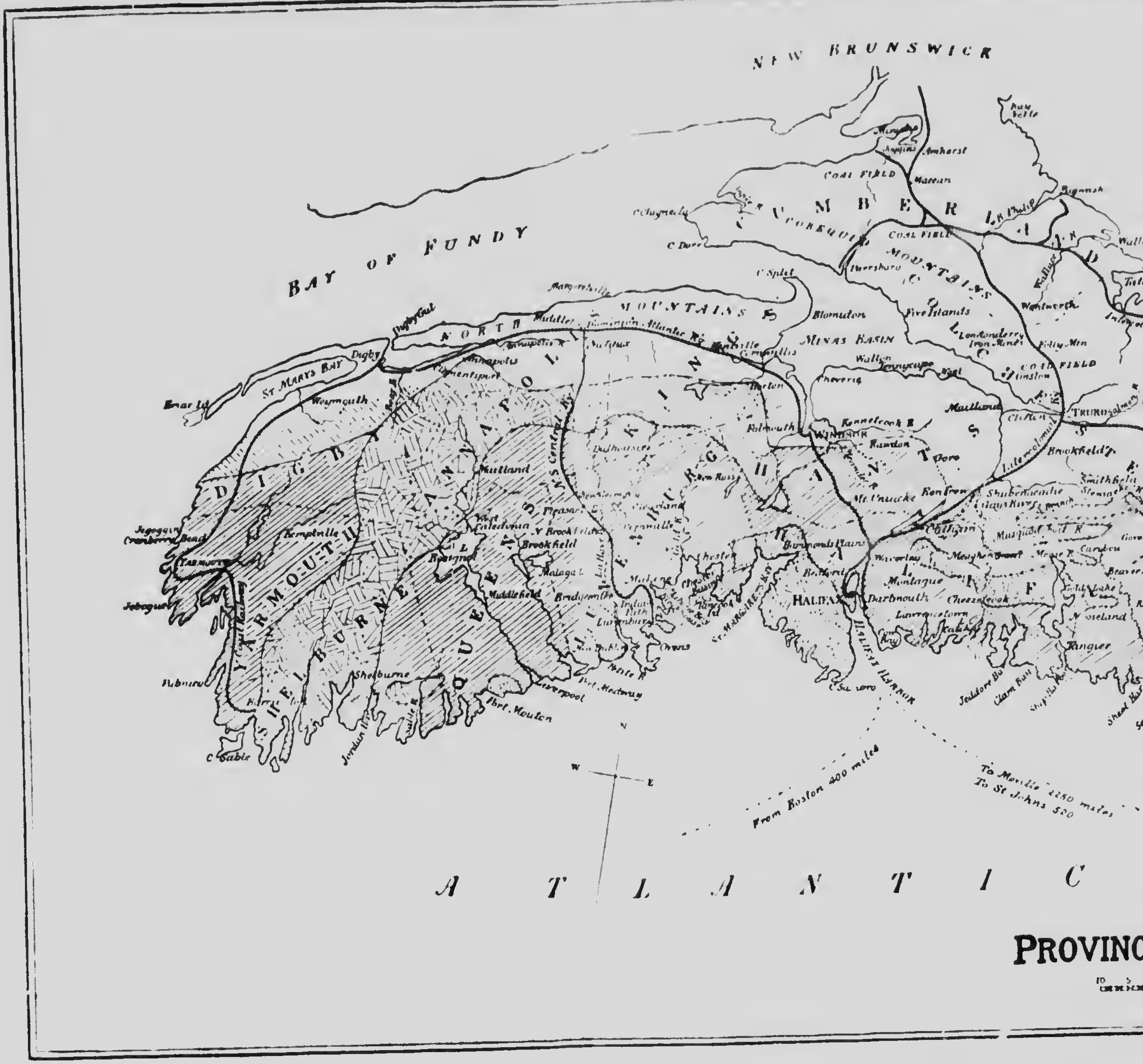
NEW BRUNSWICK
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Weymouth
Annapolis
Amherst
COAL FIELD
CUMBERLAND
MOUNTAINS
NORTH MOUNTAINS
MINAS BASIN
Blomidon
Windsor
Falmouth
Kennetcook R
Rawdon
Maitland
Truro
Wentworth
Londonderry Iron Mines
Five Islands
Brookfield
Shubenacadie
Caledonia
Brookfield
Kemptville
Yarmouth
DIGBY
YARMOUTH
SHELBURNE
QUEENS
ANNAPOLIS
KINGS
LUNENBURG
HANTS
COLCHESTER
HALIFAX
Shelburne
Liverpool
Port Medway
Port Mouton
Lunenburg
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Bridgewater
Middlefield
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Dartmouth
Lawrencetown
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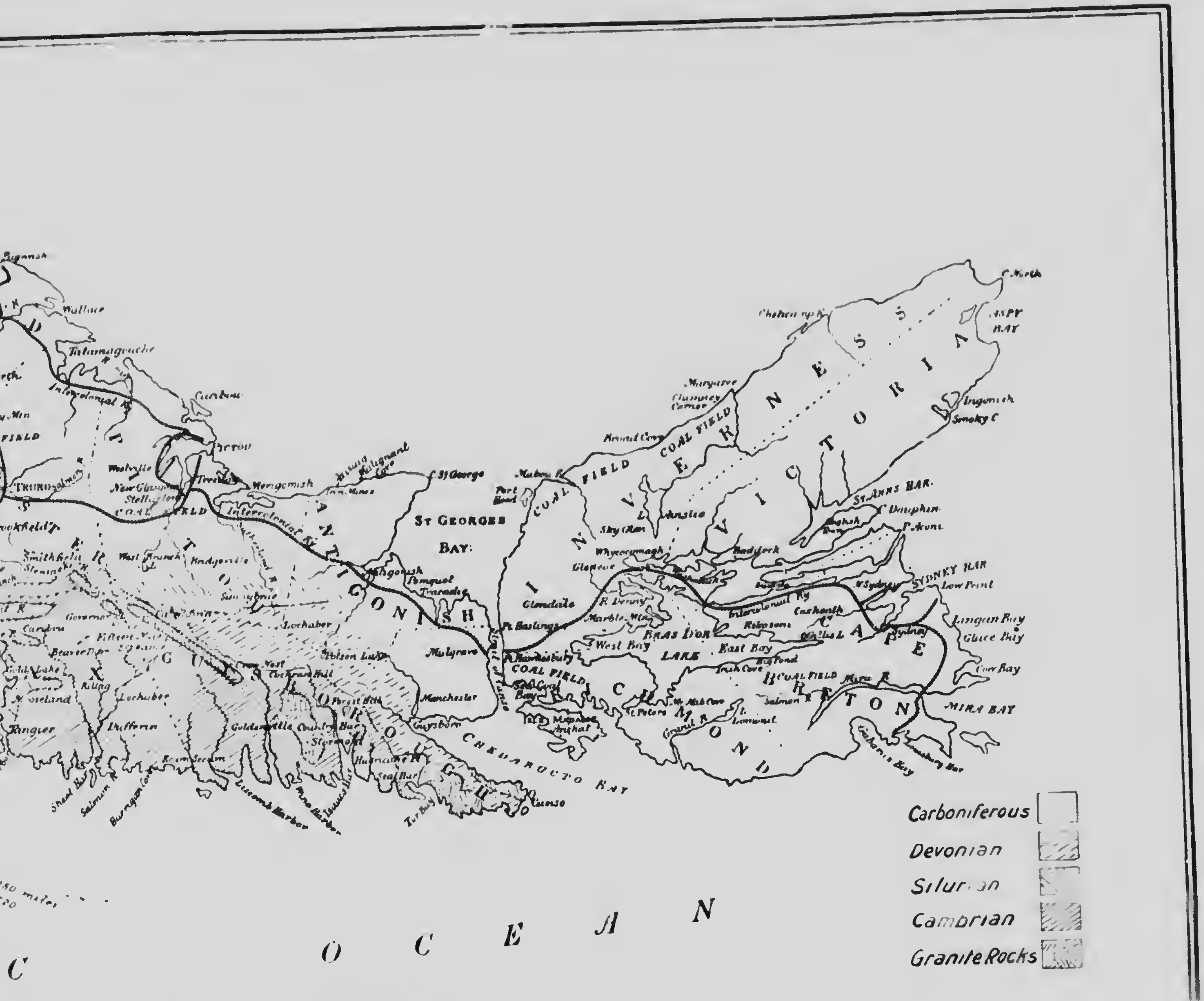

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has been won by mining. The deposition of gold in the slate and quartzite may have commenced before the Carboniferous. Thus the gold and the granite do not differ widely as regards the time of their introduction, although the limits of one of the older geological divisions, such as the Devonian, include a period of time so vast as to beggar the imagination of a chemist in his laboratory. Nor is it to be assumed that the deposition of the gold, much less its distribution and concentration in the quartz, so as to constitute orebodies, was confined to any single period. Once brought within reach of the agencies of solution and precipitation lurking in the waters that circulate near the earth's surface, the gold became forever subject to migration, tending to concentrate or to scatter the metal according to changing chemical and physical conditions.

The land now represented by Nova Scotia has passed through successive periods of pressure and uplift, the margin of the aboriginal American continent having been roughly parallel to the longer axis of the Province. The Algonkian beds have undergone tremendous folding. The Silurian and Devonian rocks overlying the gold-bearing series also exhibit plication, but the folds are not so conformable as to warrant the belief that one agency was responsible for all the disturbances recorded by these rocks of different geological ages. It is probable that the Algonkian sediments underwent lateral pressure throughout the Cambrian period and later, especially at the time of the granitic intrusion, for it is apparent that the basal strata from which the slate and quartzite were evolved have suffered long-continued deformation. Besides the main folds, with their axes running east and west, there are cross-folds, the net result of which has been to form domes and troughs. These constitute the characteristic geological feature of the region and largely determine the shape of the orebodies from which gold is extracted by mining and milling.

The Domes.

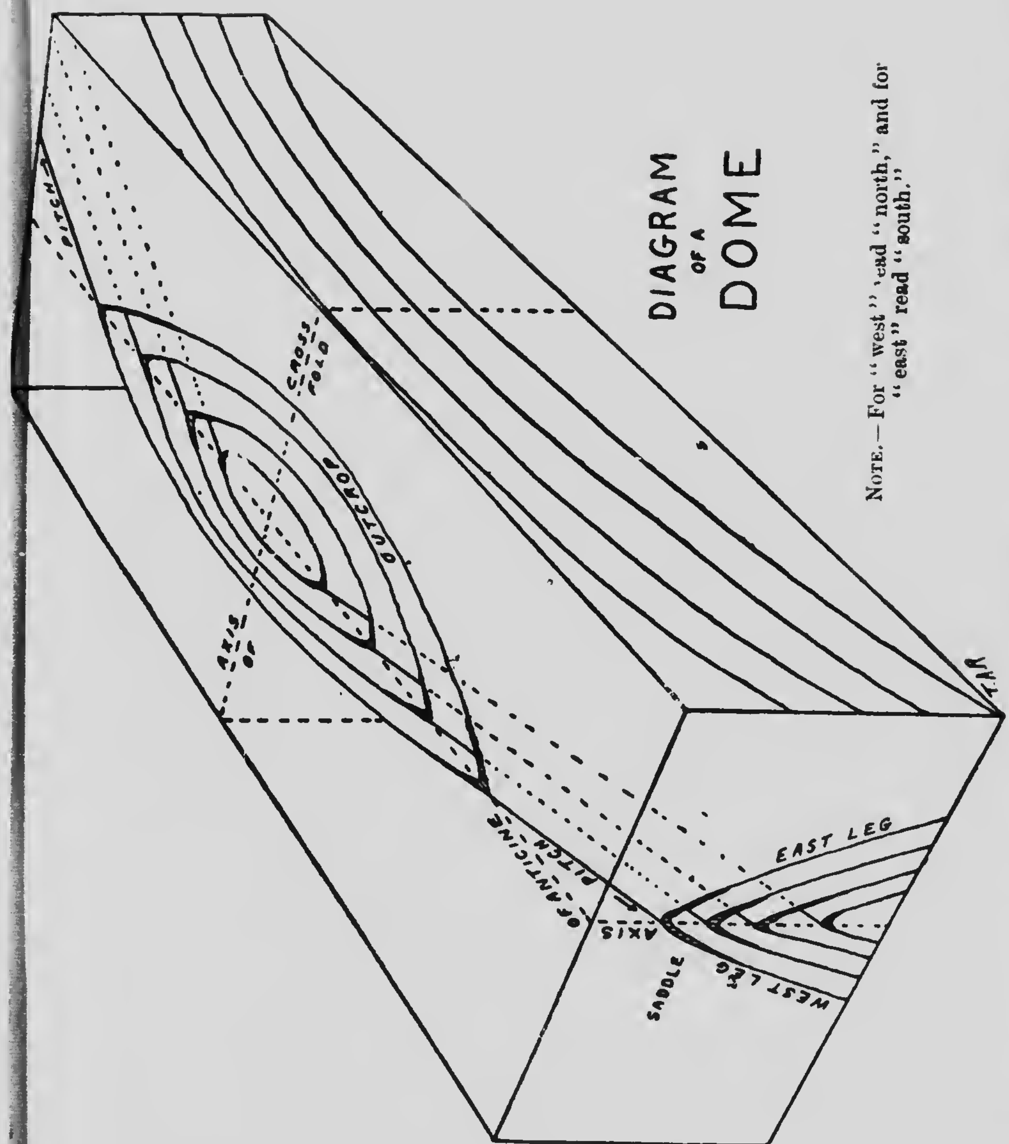
The gold is associated with quartz, which in the main follows the bedding of the country-rock; hence it forms sheeted bodies of ore that are sandwiched between the stratification, especially along the thin seams of slate. Since the quartz follows the structural lines of the country-rock, it forms 'saddles' where the slate and quartzite have been bent into anticlinal folds; but the most pronounced development of ore—for sometimes the quartz contains enough gold to constitute ore—is on the 'domes' formed where folds cross each other.

This domical structure leads to interesting results. Owing to erosion, the crests of the domes have been degraded to the level of the present surface, on the plane of which the bedding now assumes an elliptical form. Any vein of quartz deposited along a bedding-plane will reproduce this structure. If on a flank of the dome, north or south, it will have a nearly straight strike, but in the approach to the ends, east and west, of the dome, it will curve in accord with the fundamental structure. At the 'nose,' or extreme ends of the longer axis of a dome, the quartz will be curved to a bow. All this is on the plane of the surface. If followed underground such a quartz vein will form a saddle, by being curved with the bedding of the anticlinal fold whose axis runs east and west. Again, owing to the synclinal fold, whose axis runs north and south, the saddle will pitch or slope if exposed at the east or west end of the dome, where the strata plunge in accord with the synclinal curvature of the cross-fold. This description will be made clearer by reference to the accompanying diagram, which, in effect, exhibits the appearance of a model if made in glass. The top of the block represents the geological surface; the elliptical outcrops are evident; at the west end of the curving strata are shown the quartz veins. These in cross-section, as exposed at the left side of the block, constitute 'saddles,' the pitch of which is indicated.

As regards actual mining, the workings that follow the pitching saddles usually consist of a sloping shaft with curving levels. This is best exemplified by the Richardson mine, a model of which was prepared by E. P. Brown.* At Bendigo, an Australian locality famous for this type of lode, the 'saddle-reef,' as it is there called, follows sharp arches in slate and sandstone, but the pitch of the anticlines is flat, because cross-folds are not emphasized; that is, the Bendigo saddle is like a steep ridge with slightly undulating crest. The Nova Scotian dome resembles the upturned bottom of a boat, the keel of which stands for the major anticlinal axis.

While referring to Bendigo as a geological analogy, a further reference may be made to the question of anticlinal pitch. In 1890 and 1891, when I was examining the Bendigo mines, the truly anticlinal structure of the 'saddle-reefs' was not recognized; hence the pitch of the anticlines was not considered. As the crests of the folds at Bendigo are not marked by violent changes of slope, especially within the short extent of a single mining property, it is not surprising that this detail of the local geology was neglected. Within recent years, however, it has become generally recognized that the changes of pitch or undulations along the anticlinal axis

* *Canadian Mining Journal*, August, 1908.



NOTE.—For "west" read "north," and for "east" read "south."

(there called 'lines of reef') constitute an important factor in modifying the distribution of gold-bearing quartz. Thus the Bendigo type of ore deposit finds closer resemblance to the Nova Scotian dome.

Only a small portion, however, of the gold contributed by Nova Scotia has been extracted from quartz at the apex of these domes. Most of it has been broken from interbedded veins associated with the legs or stumps of arched structures whose crests have vanished. It will be understood that the present surface, from which all mining starts, represents a nearly horizontal section that has been cut, by erosion, through the folds at a varying distance from their crests. The bedding-planes, and the quartz veins conforming to them, that are least curved, are simply farthest from the anticlinal crests, since all the beds of slate and quartzite are members of the folded series. The greater the distance from the anticlinal axis the less the curvature, so that many veins following the nearly straight strike and nearly vertical dip of the country appear to be unrelated to quartz deposits on the domes, although structurally they are allied. Such veins follow the lower portion of an arch, the crest of which, at a higher horizon, since denuded, overlapped the dome that survives in the centre of the fold. A distinction must be made, however; it is not necessary to assume, as some writers have done, that every quartz vein at one time extended over an arch of rock that has since been removed. That is another question. Whether the quartz was conterminous with the entire fold of the country-rock before it was reduced by erosion to the level of the present surface is a point on which I shall speak later. At present I am dealing with facts only, not theory. It is advisable to follow the scientific method of proceeding from the known to the unknown. It is not necessary to assume, and I do not believe, that the quartz vein distant from a dome, or an anticlinal arch, is a part of a much more extensive body that covered the crest of a dome eroded long ago, nor that the interbedded quartz now found several thousand feet from any anticlinal axis was contemporaneous in its origin with, however dependent in structure upon, the lines of weakness created in the rock formation during the process of folding.

At the Dufferin mine, in the Salmon River district, I saw a dome whose outcrop is barely 2000 ft. long, east to west. In other districts such as Caribou, Mount Uniacke, and Oldham, it is obvious, from the geological surveys of Mr. Faribault, that domes exist having a length of 2500, 2000, and 3000 ft., respectively. Quartz, in the shape of saddle-veins, has been concentrated at the cross-folds, where the nose of the dome plunges underground, but in no case, as

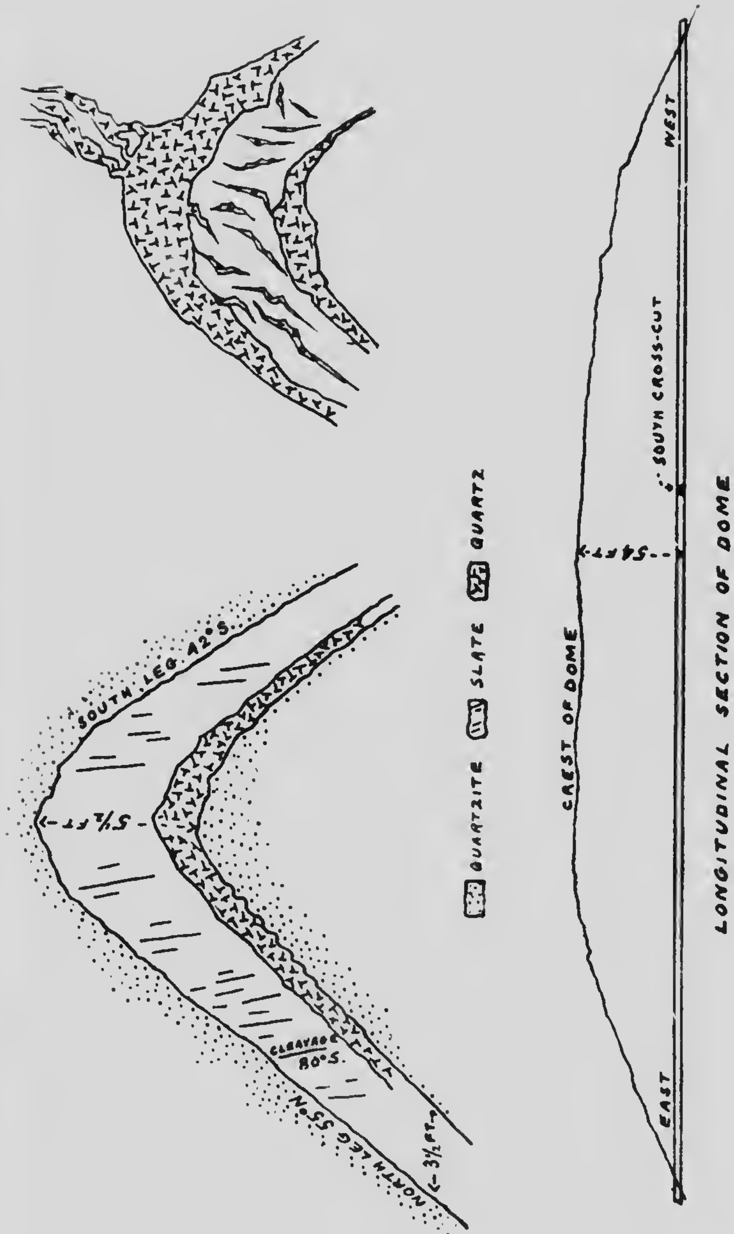

SOUTH LEG 42°S.
5½ FT.
CLEAVAGE 80°S.
NORTH LEG 55°N.
3½ FT.
QUARTZITE
SLATE
QUARTZ
CREST OF DOME
5 FT.
SOUTH CROSS-CUT
WEST
EAST
LONGITUDINAL SECTION OF DOME

Fig. A.

far as I know, has it been exploited profitably at both ends of a dom In the Dufferin the domical structure is exposed on the 300-ft. leve which follows a quartz vein known as the No. 1A. Here, as show in Fig. A, the east and west legs of the dome are 1300 ft. apart, whi the north and south legs have a spread of only 200 ft. at the sam level. Since Mr. Faribault's map was published, it has bee ascertained by him that the anticlinal fold is not a single flexure but divided into two saddles at its crest. Of these, the southern i accompanied by a succession of quartz saddles, which have bee exploited to a vertical depth of 300 ft. and then abandoned a unprofitable. The northern minor flexure has no saddle of quartz but its northern leg is accompanied by a band of quartz stringers tha extend as cross-veins from the apex to the surface and reach in depth to the point where the bedding is turned by the syncline. Stringers of quartz cross the veins that follow the bedding, and it is suggested that the former coincide with fractures due to the cross-fold. In 'centre country,' that is, at the axis of a fold, even the quartzite exhibits cleavage. As regards the saddles, it is apparent (in Fig. A) that the anticlinal axis is not vertical, but dips south; hence the south leg is flatter than the north (See also photo No. 1). The cleavage is at a high angle southward. The north leg has been more profitably mined than the south, because the latter is terminated abruptly by the synclinal flexure. The corrugation shown under the north leg of the larger saddle near its apex nearly conforms to the pitch of the anticline, which is 2° W. at 125 ft. west of the shaft. The saddle shown on the left of Fig. A is a supplementary saddle below the main formation exploited in the Dufferin mine. The quartz is from 8 to 10 inches thick at the apex, and thins going down. The right-hand sketch shows how stringers extend from the saddle across the bedding, but in the line of the anticlinal axis.

From 1881 to 1895 the Dufferin mine yielded 39,130 oz. gold from 93,701 tons, showing an average of 8 dwt. per ton.

Crenulation.

The 'saddles' of Nova Scotia are also remarkable for peculiar corrugations or crumplings of quartz, to which the name of 'barrel formation' has been accorded, because, when such a corrugated deposit is uncovered, it looks to the miner like the back or top of barrels lying in rows. The accompanying reprints (See p. 33) from old woodcuts, appearing in a report by Silliman, will indicate the appearance of such a lode as exposed in a large open-cut on the

s of a dome.
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No. 1.—A saddle lode in the Dufferin mine.

crest of a hill at Waverley.* I went thither in August, 1905, and saw enough to confirm the general accuracy of these sketches. The corrugation, crinkling, or crumpling, as it has been variously termed, was most remarkable. As a technical term descriptive of this structure, I suggest 'crenation,' from *crena*, a furrow or notch, for the larger barrel structure, and 'crenulation,'† from *crenula*, the diminutive of *crena*, for the smaller apparently serpentine threads of quartz.

While adopting the Latin derivative for the barrel structure, I deem it best to use the English word, 'furrow,' for the individual markings that constitute the appearance termed 'crenulation.' For the larger manifestation of the same structure it might, from an academic point of view, be desirable to use 'crenation,' but this is not necessary to a clear description, and may therefore be set aside for the present. 'Furrow' and 'crenulation' apply to the markings in the wall-rock, and not to the quartz filling them. The quartz is found in veins of varying continuity, and in shape reproducing the structure of the encasing rock. Hence it appears crinkled, corrugated, crumpled, or serpentine, according to the degree to which the angles are curved. When enlarged, the bends make the so-called 'barrels'; when infrequent or individual, and especially when persistent, the 'barrel' becomes known as a 'roll.' Though varying in size and multiplicity, these forms of gold-bearing quartz are the product of similar structural relations.

The famous ore deposit of Waverley lies at the crest of a low hill, and at the western end of it, where an anticline is crossed by a syncline, so as to cause the folded strata to pitch steeper than the gentle hillslope. The accompanying map and section (Fig. B and Fig. C) are cut out of the larger map made by E. R. Faribault for the Geological Survey of Canada. They illustrate the excellence of his topographical and geographical surveys. The following description is transcribed from my notes made on August 18, 1905. On the crest of the hill the apex of the pitching saddle is uncovered by shallow diggings; the quartz has been removed, but Silliman's sketch indicates how it looked when stripped. In the old excavations, which followed the north and south legs for a few feet, the crenulation on the hanging-wall quartzite can be seen. The furrows are nearly horizontal, or at right angles to the dip of the wall-rock. On descending the incline-shaft of the mine to the third level, the

* It is sometimes spelled Waverly. I have adopted the spelling used by the Canadian Geological Survey.

† This term has been previously used by J. Edmund Woodman, in his paper on the 'Geology of Moose River Gold District'; Nova Scotian Institute of Science, 1903, vol. xi., part I, pp. 18–88.

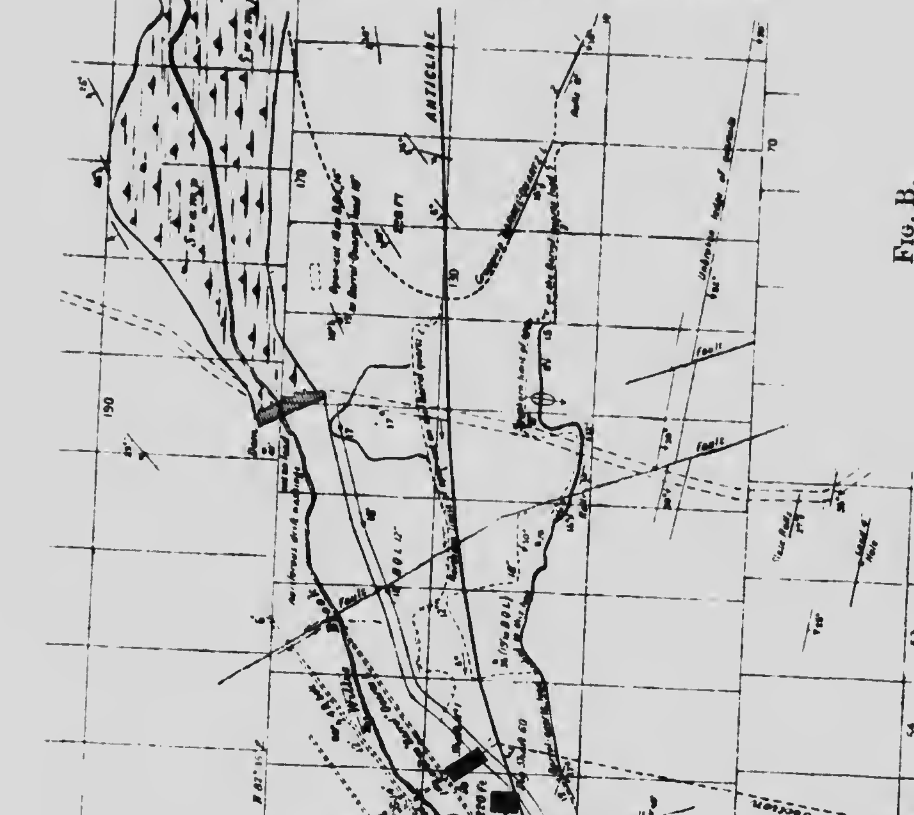

WAVERLEY GOLD MINING CO.
LAIDLAW HILL
ANTICLINE
ANTICLINE
Line of Section
Line of Section
TRAMWAY
Swamp
fault

Fig. B.

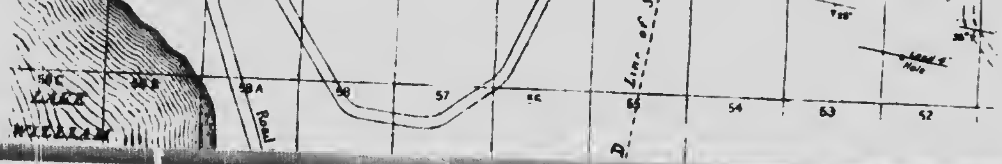
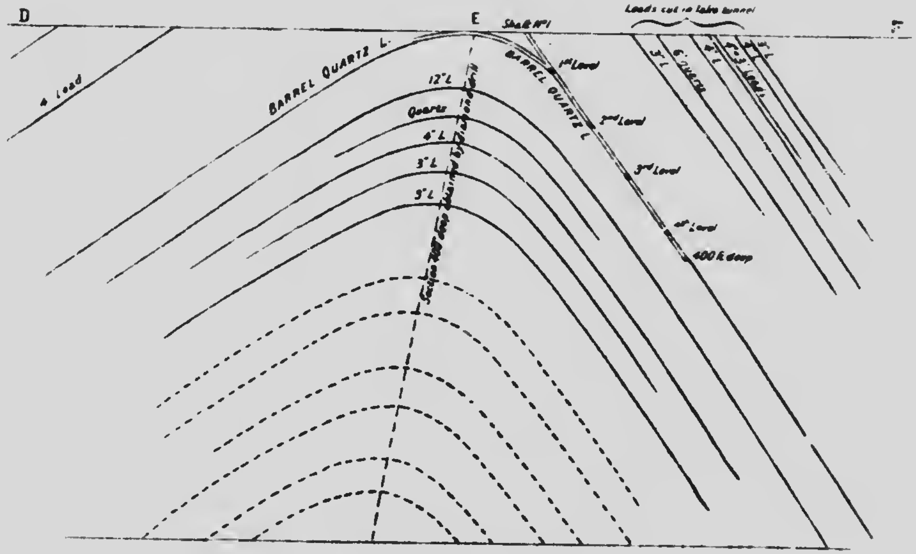


Fig. B.



CROSS-SECTION ON LINE DEF

Index to signs in Fig. B.

- Vertical dip
- Dip and strike of strata
- Interbedded quartz veins Leads
- Dip of veins
- Dip of rolls in veins
- Dip of pay streak
- Thickness of veins in inches
- Depth of shaft in feet measured on the incline
- Glacial striæ
- Roads
- Wood roads
- Faults
- 320 ft. Elevations above sea level

crenulation is found pitching at a strong angle with the dip of
stratification, becoming steeper in the approach to the main a
clinal axis. On this level the slate of the foot-wall shows w
the crenulated quartz formerly lay, leaving casts like those lef
river mud by logs, of irregular length and width, placed alongs
It is not an undulation; it is a furrow (See Fig. D.) The qu
remaining averages 8 in. thick, with a maximum width of 12
15 inches. The vein crosses from the foot to the hanging-wall of
slate bed within a distance of 20 to 25 feet. The slate is not fault
Numerous joints cross the fluting and cause it to resemble bamb
The cleavage and the bedding intersect along the line of
crenulation. On the south side of the anticline the furrows plun
eastward, until on reaching the anticlinal axis (near the Pig sha

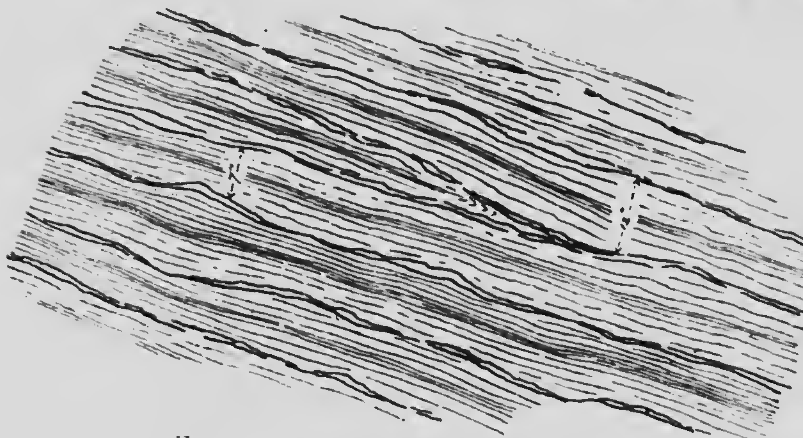


FIG. ' —Furrowed foot-wall at Waverley.

they are parallel to it; here, therefore, they are identified with the dip and at right angles to the strike of the vein and its enclosing wall-rock. As the vein curves at the nose of the dome and is followed around the corner, so to speak, the crenulation begins to exhibit a deviation from the dip until it is again pitching at a decided angle. At a point 125 feet eastward from the Pig shaft the quartz has diminished to a seam only 2 or 3 inches thick; concurrently the slate has dwindled from a bed 7 or 8 feet thick (at the apex) to a few inches, and the crenulation has faded away. When last visible it was nearly horizontal, that is, at right angles to the dip of the wall-rock. On the intermediate level the cleavage is seen to be opposed to the bedding. There is a suggestion of radiated fracturing or fissility. The accompanying sketch (Fig. E) shows the lode on the No. 1 level looking west at the north leg. Thus at Waverley the crenulations or barrels pitch with the anticline at the axis and flatten as distance is gained along the flanks of the dome. At 400 ft. from the axis the furrows lie at an angle of 8° from the horizontal, and shortly before becoming horizontal they disappear.

The total yield of the Waverley district (up to the cessation of work in 1898) is 61,808 oz. gold from 122,846 tons of ore, this being an average of 9½ dwt. per ton.

As a persistent advocate of the precise use of technical terms in descriptive writing, I cannot refrain from remarking on the fact

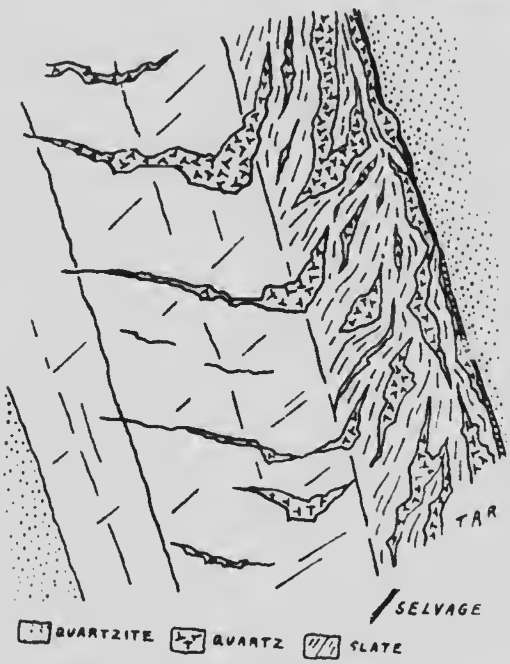


Fig. E.—The Lode at Waverley.

that the maps of the Geological Survey employ the word 'dip' to indicate the angle of the rolls and of the crenulation, when reference is obviously meant to the 'pitch.' The 'dip' of the slate is given, say, as 52° W., and then the 'dip' of the crenulation is given as 15° N., when, of course, the crenulation is on the plane of the slate bed, and therefore dipping the same, but pitching north at a strong angle. 'Dip' is measured at right angles to the strike; 'pitch' is measured along the strike. Again, the use of 'whin,' to signify quartzite, is bewildering to anyone who is not familiar with the local Nova Scotian usage: for 'whin' has heretofore been applied, also locally, in Derbyshire, to an igneous rock. Hardly less objectiona is the local term 'belt' for slate, because this is commonly used another sense in geology. Thus, one author speaks of a 'belt' angulars: one might infer that it was a bed of slate full of cro veins; and when it is written that "the belt follows the stratifi tion," one concludes—at least I concluded for a moment—tha geologic truism was being stated. Another objectionable locali is 'pay-streak' to signify ore-shoot; in mining a 'streak' is thin prolongation of ore, a thread-like or ribbony structure, but Nova Scotia it refers to an orebody having a definite pitch. Wh clumsy and unnecessary when employed locally, such terms undoubtedly confusing when used in writings intended to be re by persons at a distance.

At Oldham more evidence was gathered. Here the mining w at the eastern end of a dome. In an excavation at the side of t road I made the sketch shown in Fig. F. The bedding dips 45° S the cleavage is 62° N. The line of intersection pitches clearly 12° E. The crenulation pitches similarly. In approaching t nose of the dome, or the place where the anticline is crossed by syncline, it is apparent that the furrows and the quartz associat with them pitch eastward at an increasing angle.

Oldham is celebrated for its 'rolls.' These I regard as isolat or infrequent furrows of larger amplitude. Thus a 'roll' in quartz vein, following the bedding-plane, represents a persiste enlargement and enrichment along a bend in the foot-wall. A ro is sometimes found where a cross-vein or 'angular' meets a ve that follows the bedding. This would appear to mark a displac ment at the intersection, just as the normal roll represents a sli where the cleavage crosses the bedding. Angulars are mos plentiful at the place of cross-folding, that is, where intensity o movement has induced maximum fracturing.

Oldham has been able to boast some small rich mines. Most o them have yielded gold from recognized rolls, to which the name of their discoverers still cling. One of the most famous is th Hardman roll, named after that veteran engineer, John E. Hardman This roll is on the Dunbrack vein, which dips 38° S. near th surface and increases (at a depth of 300 ft. vertically) to 46°. Tw rolls, parallel to each other, have been found. The first, or Ned' roll, carried 6 to 8 inches of quartz in an ellipsoidal body 10 t 15 feet long. The second, or Hardman roll, carried 10 to 15 inche of quartz, increasing rarely to 18 in., and for a length of 18 ft. narrowing at one place to 8 ft., but fairly uniform in size. Both rolls are accompanied by minor fluting of the foot-wall. In goin eastward this crenulation, with the rolls, pitches more steeply. Between the rolls the wall-rock exhibits sharp fluting and is accompanied by 4 to 5 inches of quartz. The first roll was struck in the No. 2 shaft at 160 ft. and the second at 800 ft. on the dip. The No. 1 shaft cut the first at 300 ft. and the second at 450 ft. on the dip. It appears, therefore, that they maintained an approximate parallelism. Eastward these rolls are cut off by a well-defined fault; they have not been exploited beyond it, although the geological map indicates the position of the vein east of the fault. It is stated that the top roll marks the junction with an angular. These

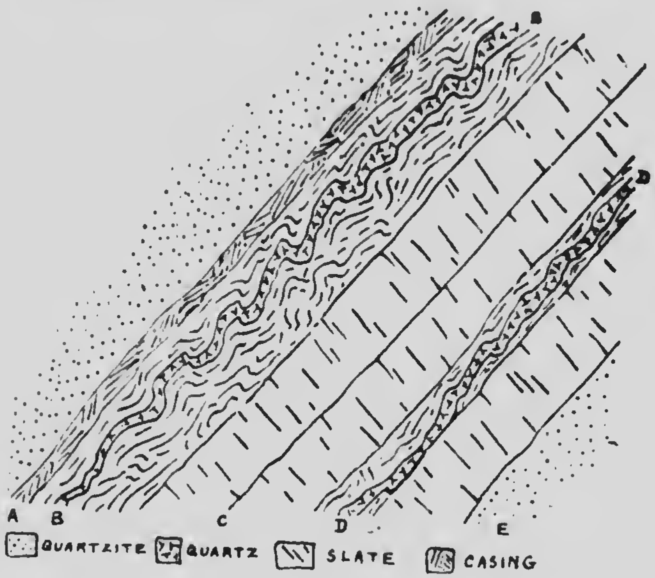
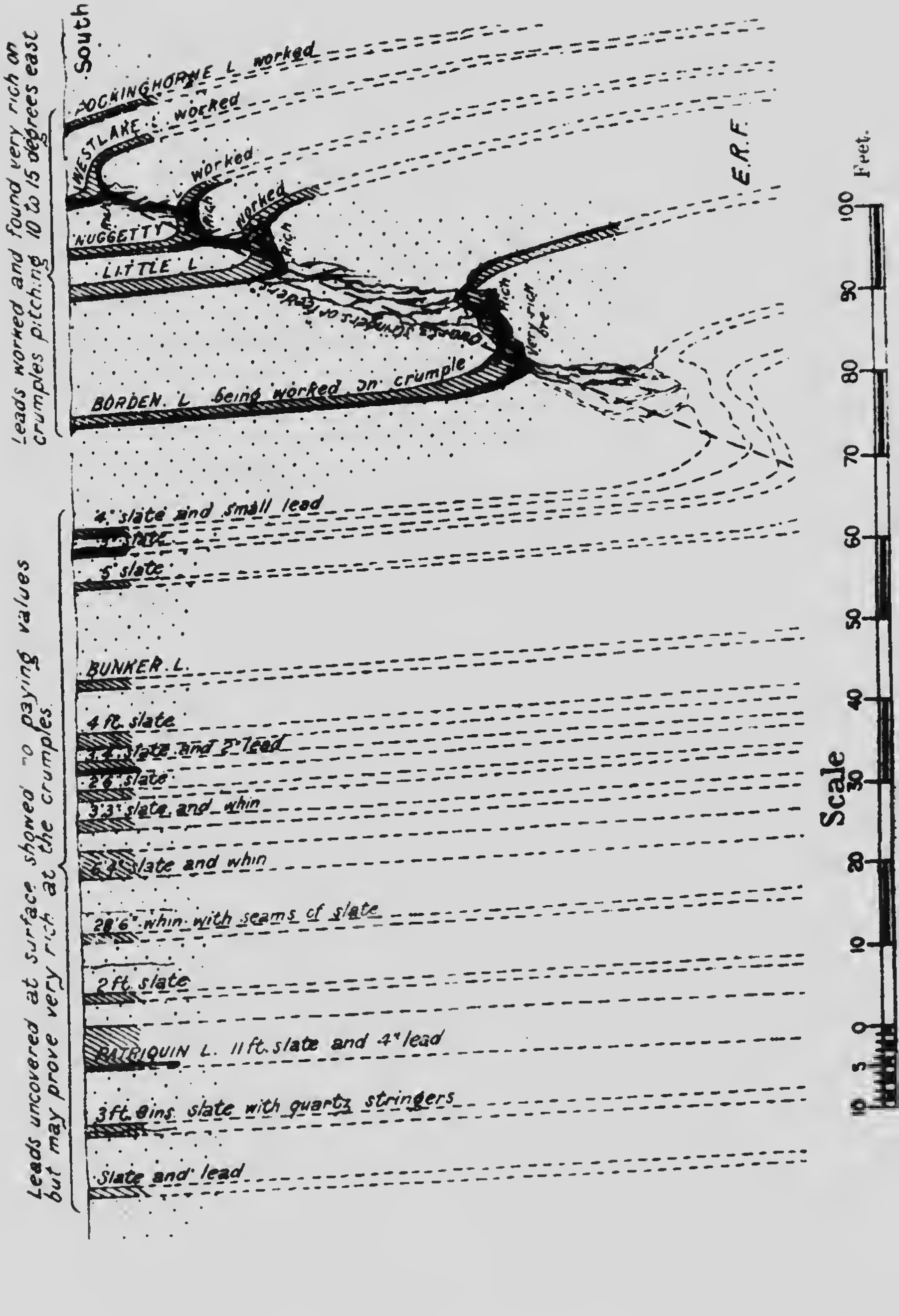


Fig. F.

are notes obtained from Messrs. Faribault and Weatherbe, with data given by resident miners. The workings are no longer accessible.

On writing to Mr. Hardman, in November, 1905, he stated to me that the rolls are "simply enlargements of the quartz vein-filling, horizontal sections of which have the form of elongated ellipses." The quartz of the Dunbrack vein, he added, had a general assay-value of $8 to $15 (or 8 to 15 dwt.) per ton in free gold, whereas the ore of the roll itself never yielded less than $25, and sometimes as high as $1600 per ton "for lots of 8 to 10 tons." The high-grade ore was associated with galena and zinc-blende, the poorer quartz carrying from 1½ % to 2½ % mispickel, iron pyrite, and pyrrhotite, all


South
Leads worked and found very rich on crumples pitching 10 to 15 degrees east
ROCKINGHORNE L. worked
WESTLAKE L. worked
worked
NUGGETTY
worked
LITTLE L.
BORDEN. L. Being worked on crumple
very rich ore
E.R.F.
4" slate and small lead
5' slate
BUNKER L.
4 ft. slate
slate and 2" lead
slate
3'3" slate and whin
slate and whin
whin with seams of slate
2 ft. slate
PATRIQUIN L. 11 ft. slate and 4" lead
3 ft. 8 ins. slate with quartz stringers
Slate and lead
Leads uncovered at surface showed no paying values but may prove very rich at the crumples.
Scale
Feet.
100
90
80
70
60
50
40
30
20
10
0

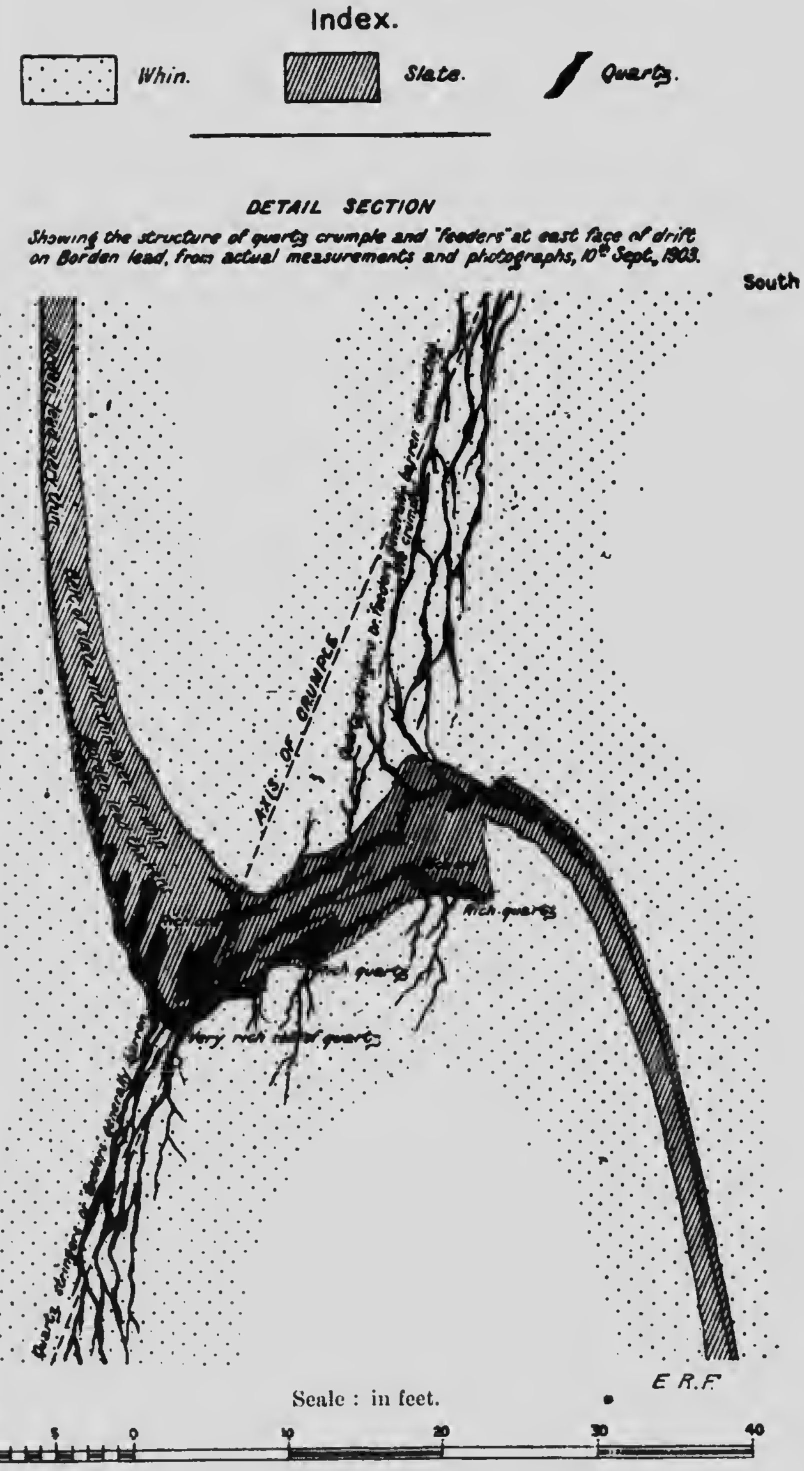

Index.
Whin.
Slate.
Quartz.
DETAIL SECTION
Showing the structure of quartz crumple and "feeders" at east face of drift on Borden lead, from actual measurements and photographs, 10th Sept., 1903.
North
South
AXIS OF CRUMPLE
Rich quartz
Rich quartz
E.R.F.
Scale : in feet.
10
5
0
10
20
30
40

Fig. H.

of these minerals being found also in the rich ore, but subordinate to the galena and blende. Mr. Hardman says:

"The thickness of the Dunbrack vein as a whole (throughout its worked extent of over 2000 ft.) would range from 4 to 5 in.; in places it narrows down to an inch or less, in other places it widens out to about 9 in., but the average width, apart from the rolls, I should put at about 5 in. In the rolls this width is much increased, the average width of the quartz in a roll being about 17 to 18 inches. The extremes within the roll would run from 8 to 22 inches. Occasionally there came into the vein what are called 'angulars,' which you will recognize under the more general name of 'feeders.' These are small quartz-veins, of very limited length, and comparatively limited width (ranging from ½ in. to 1½ in.); often they are pure quartz, but also often they contain quite an amount of carbonate of iron or siderite. These angulars, when coming into the vein from the quartzite hanging wall had little or no effect on the richness of the ore, but when they came in from the foot-wall side, also through the quartzite, they were decided feeders or enlargers of the quartz above them."

I append a photograph (No. 2) given to me by Mr. Hardman, but taken by Mr. Faribault. I also add a photograph (No. 3) of the furrowed foot-wall of the Sterling vein, at Oldham, as seen near the bottom of a 35° incline on the eastern nose of a dome. The incline had followed the quartz, here removed, for 725 ft. on the incline or pitch of the anticlinal fold.

At Mount Uniacke, on August 21, 1905, I saw a 'crumple' or subordinate fold in the Borden vein. This was described by Mr. Faribault in the summary report of the Canadian Geological Survey for 1903, and is there accompanied by a beautiful explanatory drawing. The evidence obtained in the course of mining indicates that the subordinate fold is echoed by a series of strata, and that the quartz veins following the fold are connected by stringers along the anticlinal axis. The workings visited by me showed that the fold had an amplitude or cross-sectional measurement of 40 ft., and a height or vertical measurement of 15 ft. It had been followed for 340 ft. on the pitch, which sloped eastward at 15°. This small fold showed a double crumple in the roof or hanging wall and a single bend in the foot-wall, the divergence into the two crumples being accentuated eastward. Here we have, on a small scale, a maximum of contortion in the bedding, creating highly favourable conditions for the passage of mineral solutions. This locality is 650 ft. south of the main anticlinal axis, and at the westward end of a dome.

The accompanying sketches and photographs will illustrate the structure. First come Mr. Faribault's drawings. Fig. G is a general cross-section, showing the relation of a series of parallel

No. 2. The Dunbrack vein at Oldham.

No. 3.—Crenulated foot-wall of the Sterling vein at Oldham, as seen after the quartz has been removed.

veins, and the subordinate fold as exposed in four successive 'leads' or veins. Fig. H is a detailed section on the Borden vein. It will be noted that he marks the cleavage in the slate as being at a high angle northward. Fig. I is a sketch made by me in an old stope. A quartz stringer along the anticlinal axis indicates the system of feeders connecting the successive crumples. The crenulation accompanying the quartz, previously removed by mining, is seen in an adjoining shaft, where it slopes west slightly; in an open-cut farther west the 'fluting' or crenulation pitches 4° to 5° eastward owing to a local bend in the strike of the stratification.

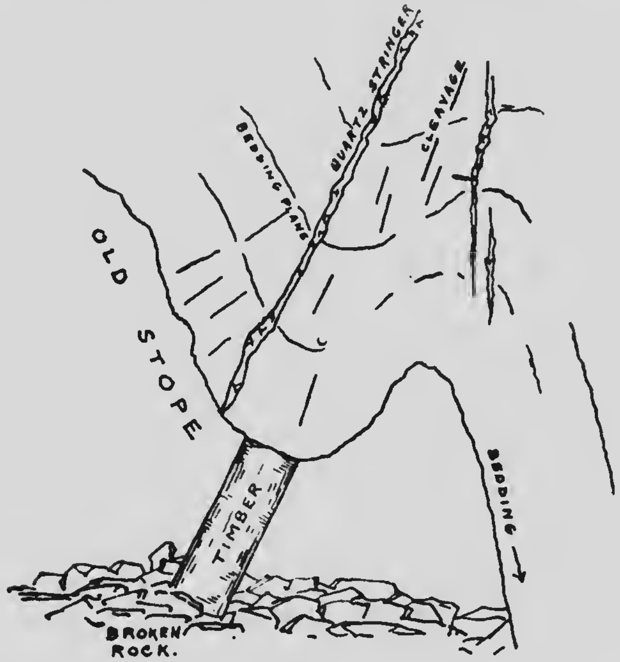


Fig. I.

The crumpling or subordinate fold, of course, will not be confused with the crenulation; one is a local plication of the bedding-planes, while the other is a fluting along the surface of the beds. On the bottom level of the mine the cleavage is distinguishable in the quartzitic rock of the foot-wall, and it is seen that the line of intersection with the bedding pitches 15° to 20° west, while the incipient crumpling on the same wall-rock pitches 10° to 15° east. Fig. J is a sketch taken in a stope on the south leg of the crumple and 150 ft. east of the shaft. The crenulated quartz vein is nearly in the centre of a bed of slate (2 ft. thick), but it does not follow the bedding. The cleavage is almost at right angles to the walls of the slate bed, the foot-wall of which is followed by a vein of 'bull' quartz, namely, barren white quartz as distinguished from the bluish-grey mineralized quartz of the crenulated vein. The latter shows occasional banding, due to included slate. This is a good example of the 'barrel' quartz of Nova Scotia.

The accompanying photographs (Nos. 4, 5, 6, 7 and 8) will illustrate the extraordinary character of the crenulation. The photographs were taken by D'Arcy Weatherbe and E. R. Faribault, who were deputed to be my assistants when making the geological investigation for the Government. No. 4 and No. 5 show the crenulation impinging on the 'roll' formed by the crumple or minor fold. No. 6 exhibits a small fault. The crenulated quartz

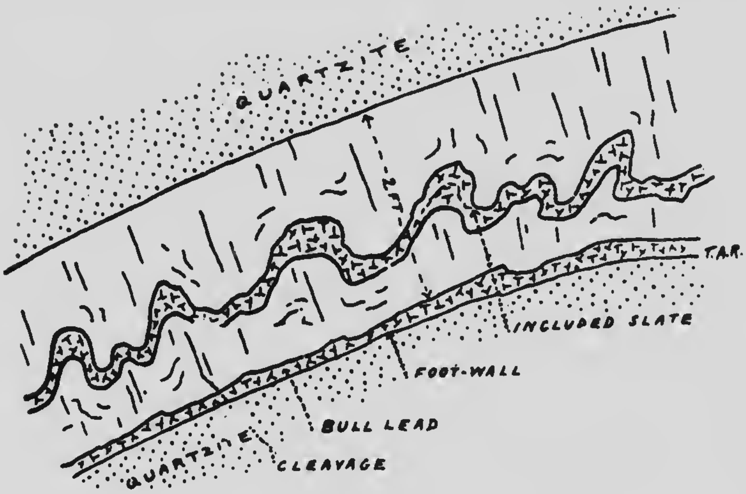


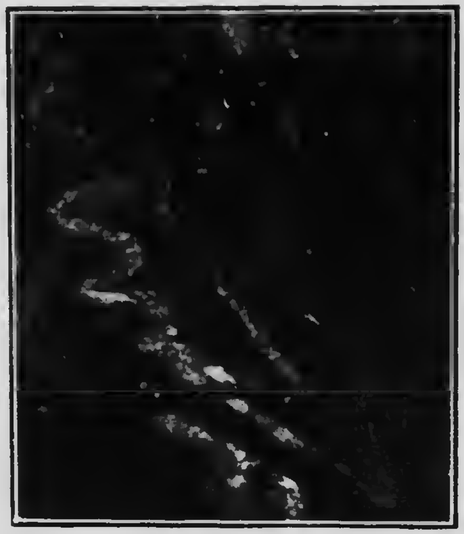
FIG. J.

vein overlies a 'bull lead,' that is, a barren quartz vein, which follows the bedding-plane. The crenulated or 'barrel' vein is in a bed of slate. No. 7 is another of the same vein, the Borden 'lead,' at Mount Uniacke. No. 8 again exhibits this remarkable ore deposit; for the quartz is gold-bearing and was being stoped profitably. No. 9 exhibits the structure even better. The crenulated vein is accompanied by a simple quartz seam, marking the bedding-plane between the slate, in which the crenulated vein lies, and the quartzite of the foot-wall. No. 10 shows the crenulated foot-wall of the Murray vein at Mount Uniacke. The crenulation pitches 75° E. No. 11 illustrates the same structure on a larger scale. It is similar to that shown in Fig. 10. Additional examples

No. 5.

No. 7.

No. 4.



No. 6.

No. 18.—A crenulated vein traversing the bedding.

appear in Nos. 12, 13, 14, 15 and 16. The first of these (No. 12) is a fine photograph, by Mr. Faribault, of the Serpent vein in the Moose River district. The scale is about 1 ft. to the inch. No. 13 represents a "small curly lead" in the Mexican mine at Goldenville. The bedding—diagonally across the crenulated vein—is clearly indicated by another quartz vein. No. 14 shows the Touquoy vein, in the Moose River district. The cleavage of the slate is indicated above the quartz vein. No. 15 illustrates a quartz vein zigzagging across the bedding-planes at Forest Hill. No. 16 is a photograph of two crenulated veins at Moose River. The scale is indicated by the hammer and the Canadian $5 bill. This photograph shows two nearly symmetrical veins, but they are not conformable. In Photograph No. 18 the Great North vein at Moose River is shown. Here the relation of the crenulated vein to the cleavage and the bedding is evident. No. 19 shows the workings on the Taylor vein, also in the Moose River district, on the south anticline, with a minor synclinal fold. The cleavage of the slate is evident. No. 20 shows a subordinate syncline in the Montreal Co.'s quarry at Moose River. The cleavage is evident. Several of these photographs appear in Mr. Woodman's paper on the district, and to him I am indebted for many of my prints. No. 21 shows a thick bed of quartzitic rock overlying the Cameron vein at Ecum Secum. The cleavage and jointing are evident. No. 22 is a photograph of the Richardson vein, where it is evidently crossed by quartz stringers of later origin. No. 23 is a series of veins in the Beaver Hat mine, at Isaac's Harbour. These veins are at a crumple or subsidiary fold in quartzite at a depth of 40 ft. from surface.

Origin of the Crenulation.

The origin of this beautiful structure is difficult to explain. The first idea, adopted by some of the early observers, is that the quartz constitutes an integral member of the sedimentary series, that is, the silica that became quartz was deposited contemporaneously with the silt and sand that became slate and quartzite. According to this theory, the quartz underwent folding and corrugation with the encasing rock, and was particularly plicated at the places where anticlinal movements crossed. This simple explanation is killed by the single fact that the crenulated veins cut across the bedding-planes between the slate and quartzite (See photographs Nos. 9, 13, 15 and 18).

The next theory that may be proffered is that the quartz has replaced another mineral, segregated from the original sediment and distributed along bedding-planes or other lines affording passage to underground solutions. Calcite is prevalent throughout the region, and in association with the quartz; therefore it may have occupied the fractures in which quartz is now found. Such calcite would have been crushed by the earth-movements, and thus it would be all the more easily soluble in silicious acid waters. This theory also lacks the support of evidence. It is true that although we cannot conceive a layer of quartz undergoing violent bending without becoming crushed, a condition in which quartz is not uncommonly found in lodes,* we can imagine more readily that calcite could better withstand the strain, and even if crushed it might, at a later period, be replaced by quartz. In this connection we may remind ourselves, on the testimony of natural sections, that rock deformation ensues in the deeper portion of the earth's crust. C. R. Van Hise has estimated that at 12,000 metres "the weight of the superincumbent mass is greater than the ultimate strength of the rocks,† which then undergo 'flowage' or deformation without fracture." These considerations might well apply to the case in point, for, as we have seen, the rocks encasing the gold-bearing quartz now being mined in Nova Scotia were at one time covered by eight miles, or 42,000 ft., of superincumbent strata. Moreover, the practical researches of Frank D. Adams, in the laboratory of McGill University, prove that many rocks and minerals are capable of deformation without rupture when under great pressure.‡ Thus we have evidence on this point; but it is not applicable to our problem. If it be supposed that the quartz replaced another mineral which was deposited along the bedding planes, either by original sedimentation or by subsequent segregation, we are again faced by the fact that the crenulated veins traverse the bedding. Hence they could not so originate. If we recognize that the quartz does not lie wholly along the planes of bedding, then the problem of explaining the crenulated structure is not facilitated by imagining quartz to have replaced calcite, for any explanation that would suffice for one would be adequate for the other. Therefore this second theory does not carry us any further forward. We dismiss it, with regret.

The next theory is not so easily stated, but it is based on the observation that quartz veins exhibit a step-like or zigzag course

* Such as the Comstock.

† *Trans. Amer. Inst. Min. Eng.*, vol. xxx., p. 32.

‡ *The Journal of Geology*, vol. xviii, No. 6. 'An Experimental Investigation into the action of differential pressure on certain minerals and rocks.' By Frank D. Adams.

in traversing beds of diverse texture and in crossing the cleavage, joints, or other structural inequalities of a homogeneous rock. Thus, at Bendigo, I noticed that the 'spurs' or cross-veins, which are mined profitably on a large scale, have a marked characteristic: they cross the sandstone almost at right angles to the bedding, but they tend to follow the cleavage of the slate. See Fig. 5, 9, 10, 11, 13, 14, 30, 31, 33 and 34 of my paper entitled 'The Bendigo Goldfield' (second paper). *Trans. A.I.M.E.*, vol. xxi, pp. 686-713. Fig. K reproduces Fig. 31 of my Bendigo paper. On turning to the description, written in 1893, I find that I referred (on p. 688) to this characteristic in the following words: "A quartz seam upon leaving a bed of sandstone and entering one of slate, invariably

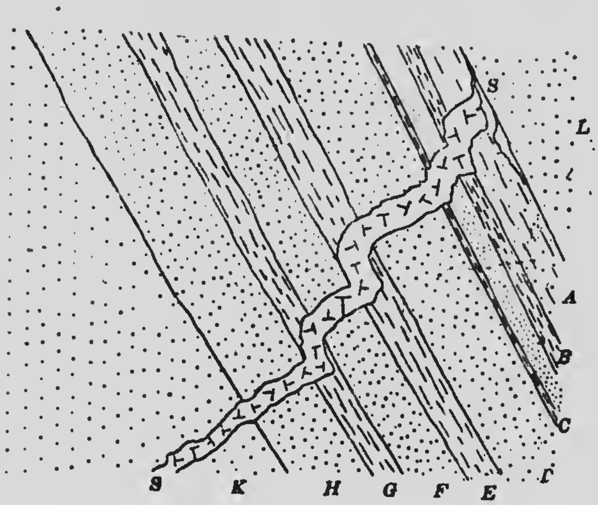


FIG. K.

turns its dip in sympathy with the cleavage of the slate." To put it in another way: a fracture crossing a series of slate and sandstone (or quartzite) beds will cut right across the sandstone because it is of fairly uniform texture, so that it is as easily broken one way as another. The same fracture, when encountering a fissile rock, like slate, will find the path of least resistance along the cleavage rather than across it. Hence the fracture, in crossing an alternation of such rocks, will take a step-like or zigzag course. (See Fig. L).

If, now, the beds be thin we find this structure emphasized. (See Fig. M).

If, next, we suppose the alternation to be repeated with greater frequency—if, in other words, we take a shaley sandstone marked by well-developed cleavage—we obtain conditions favourable to a crinkly line of fracture. (See Fig. N).

This affords a clue, which appears to be confirmed by the significant fact that the crenulation, as seen in the Nova Scotian mines, has a pitch conforming to the line of intersection between the bedding and the cleavage. It appears to be dependent on a relation to the cleavage.

Crenulation is not unknown at Bendigo, although there it is not a dominant characteristic. On turning to my first paper on the Bendigo goldfield (*Trans. A.I.M.E.*, vol. xx) I find two sketches, Figs. 65 and 66, illustrating this structure. Fig. O reproduces the Fig. 65 just mentioned; it is particularly interesting because it shows that the deposition of quartz has followed not only the lines sympathetic to the bedding but also a nearly vertical fracture along the anticlinal axis, as well as another that shows some kinship to cleavage. We must remember that the shape of the quartz is determined by the nature of the receptacle that it occupies; even if we suppose it to have found space by replacement of portions of the country-rock, we have to ascertain the nature and shape of the fractures along which it found a way when in solution. Veins of quartz vary in dimension and direction in accordance with the diverse texture and hardness of the rocks traversed by fractures precedent to ore deposition.

These fractures are various. The lines of weakness along the bedding-planes, especially such as separate a relatively soft from a relatively hard rock, a slate from a quartzite, for example, furnish obvious facility for rupture. Along these is deposited the quartz of the ordinary saddle-vein. Other things being equal, the crest of an anticline furnishes an opening or a tendency to open; the syncline does this also, but, while the principle of the arch tends to keep the anticlinal fracture open, the dead weight of a trough-like depression or syncline tends to close it. Between the two bends, on the flanks of the anticline—which are also the reversed flanks of the syncline—the strata are compressed, the bedding-planes are tight, and the least possible facility is afforded for the circulation of underground waters. Connection between the crests of the anticlines is obtained by fractures that follow the anticlinal axis, as in Nova Scotia, or by dikes that have been injected in the wake of regional dislocation, as at Bendigo.

In a region marked by folding the greatest intensity of fracturing is exhibited at the place of maximum plication. At Bendigo this is found at the apex of an anticline. In Nova Scotia it is found where the folds intersect, that is, where an anticline plunges in

No. 9.—The Borden vein in the West Lake mine at Mount Uniacke.

No. 10.—Crenulated foot-wall in open-cut at Mount Uniacke.

No. 11.—Crenulated foot-wall at Mount Uniacke.

No. 12.—The Serpent vein at Moose River. Scale: 1 inch = 1 foot.

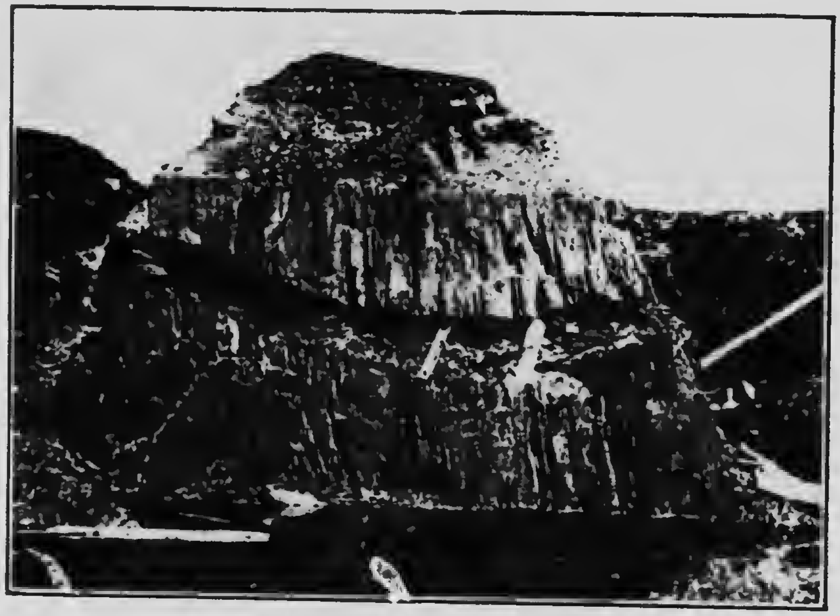
No. 13.—In the Mexican mine at Goldenville.

No. 14.—The Touquoy vein at Moose River.

No. 15.—Quartz stringer cutting across the bedding-planes.

No. 16.—A couple of crenulated veins at Moose River.

No. 18.—The Great North vein at Moose River.
This crenulated vein is shown as a serpentine thread in the midst of a bed of slate.



No. 20.—Montreal Co.'s quarry at Moose River.

No. 19.—Old workings on the Taylor vein at Moose River.

No. 21.—Cleavage above the Cameron vein at Ecum Secum.

No. 8.—Synclinal portion of the Borden vein at Mount Uniacke.

No. 22.—The Richardson vein, with cross-stringers.

No. 23. The main lode in the Beaver Hat mine, at Isaac's Harbour.

Waverley.

Isaac's Harbour.

A series of small mines at Montague.

Old workings at South Uniacke.

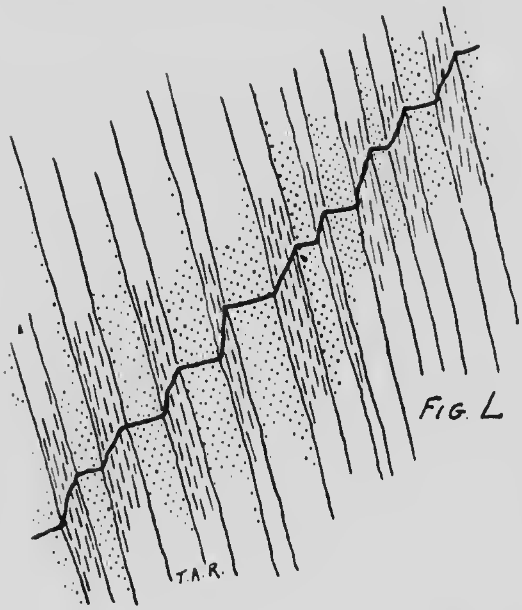


FIG. L

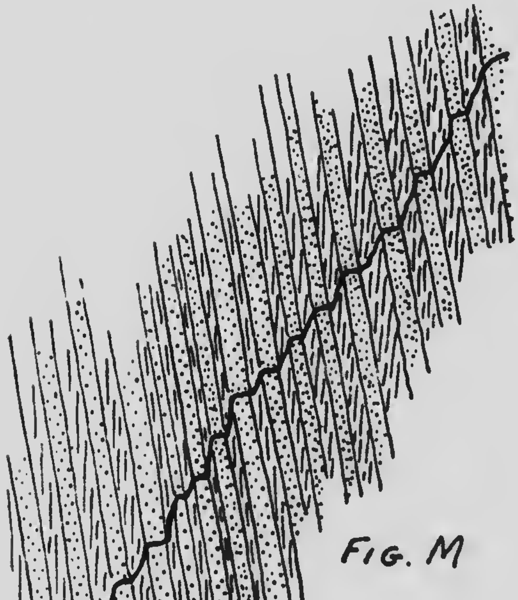


FIG. M

obedience to a transverse syncline: at the nose of a dome. It is there that the crenulation is most marked. Folding is accompanied by cleavage in fissile rocks and by jointing in those of granular texture. The main anticlinal axes are characterized by a dominant cleavage, usually at a high and persistent angle. At the approach to the apex of the fold, and more especially at the place where the rock is twisted by cross-folds, the regional cleavage is dominated by a local radial fissility, exemplified in several of the annexed photographs. It is there that the crenulation is most marked and most continuous.

At the place of maximum flexure, where the cleavage dominates the bedding, any fracture due to regional movement will find a devious way. In part it follows the bedding or, at least, it confines its divagation to one soft bed—of slate; in part it responds to the invitation of the cleavage-lines; in default of such assistance it traverses both bedding and cleavage, but not for long. A vein-fracture in one mine plays many parts. That was the lesson at Bendigo; that is the teaching of Nova Scotia.

When the solutions containing both quartz and gold began to course along the fractures thus prepared, they were deposited wherever conditions were favourable, and after deposition they tended to reproduce the character of their abiding place. Thus I argue that they were precipitated along the bedding-planes, to form the simply tabular deposits that delight the writers of textbooks; they likewise were laid down along the arches that gave us the symmetrical saddle-lode; they rested in cross-fractures that became the 'spurs' of Bendigo and the 'angulars' of Nova Scotia; and, finally, they found a way into the intricate and rhythmically-crinkled passages prepared for them, where cleavage and bedding disputed for structural mastery.

As far as I know, only one writer has made a detailed study of the crenulation. I refer to Mr. J. Edmund Woodman, formerly Professor of Geology in the Dalhousie University, at Halifax. His paper on the Moose River district, to which reference has previously been made, is a good example of careful investigation. The accompanying drawings are excellent. They afford evidence that the crenulation is usually confined to one side of a fold, that it is found on cross-veins as well as on the stratified veins, that the laminæ of the enclosing slate tend to curve with the quartz, that the crenulation is most common in slate beds bounded on both sides by quartzite, that the sympathetic curves in the rock rarely reach more than 2 ft. from the crenulated vein, and that the furrows are larger where not parallel to the bedding. He recognizes strain-slip cleavage, and says that "if it caused the corrugations, we should

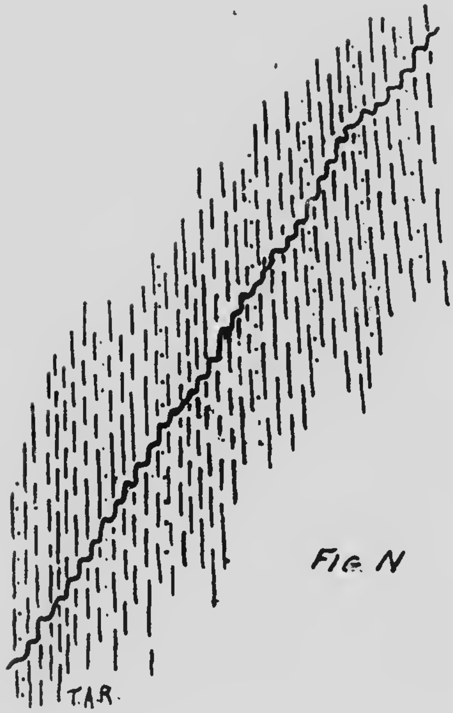


Fig. 65.

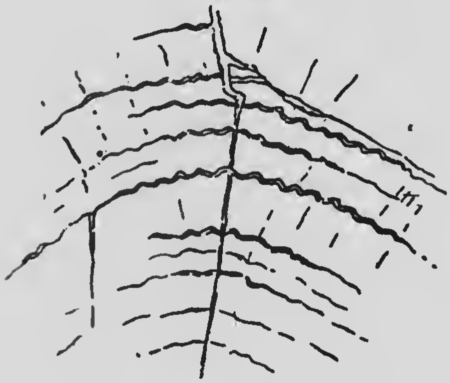


FIG. O.

find some sign of it also in the sediments, either cleavage or acute small-scale folding; but do not." He adds that "there is not the slightest deviation in the dip of the laminæ in proximity to the veins," but I cannot reconcile this with the statement that "the lamination of the slates follows the crenulations of the lead, exactly when near it, less faithfully when farther away." If the "deviation" of the laminæ is not from the normal dip, from what line is the deviation? Dismissing strain-slip cleavage, Mr. Woodman says: "The only explanation remaining, therefore, is that the cross-veins lie in fissures which had their present sinuous course at the beginning of occupancy by the vein material. It is noticeable that this crenulation is not found in quartzite unmixed with slate; but is confined to slate and alternations of the two. It is best developed where no quartzite is present. It appears, then, that in the thinly laminated pelites,* at the time of intrusion of the cross-veins, the rock broke under the strain most easily across the strata squarely or diagonally in places, with the bedding in others, and in some backward or downward rather than upward." Thus I infer that Mr. Woodman and I reach the same conclusion by diverse ways. I had not read the foregoing paragraph until after arriving at my own conclusion. And I reached it by two suggestions: first, the coincidence between the pitch of the crenulation and the line of intersection between the planes of cleavage and bedding, as noted by me in 1905, and, secondly, the analogy of the cross-veins as sketched by me at Bendigo in 1890, showing the zigzag structure when the quartz-filled fracture crosses alternate beds of slate and sandstone. Then came the evidence of such photographs as Nos. 18, 19 and 20, where radial cleavage is seen to be traversed by veins of crenulated quartz. On turning to Mr. Woodman's paper I noted his sketches of cross-veins accompanied by crenulation, but it was not until writing the foregoing paragraphs that I ascertained how closely his conclusion tallied with my own. We express it differently, but the fundamental idea is nearly identical. He wrote in 1903.

Thus the crenulation may finally be regarded as the beautiful product of complex fracture due to cross-folds in rocks of uneven texture. The fissility induced by extreme plication has afforded a sinuous line of passage to rupture and to the quartz that subsequently healed the rupture. As originally formed the veins were crooked, that is, they zigzagged in a sharply angular line. In the course of mineral impregnation they became rounded. Nature hates an angle as she abhors a vacuum. Time softens hard lines is

* A pelite is a rock composed of fine mud.

a poetic way of saying that chemical corrosion is most rapid where the largest surface is exposed to solvent action. The angles of the zigzag vein-fracture were filled with quartz, which, in the course of accretion from further passing solutions, replaced the crushed slate adjacent to it and slowly gained a rounded outline. On the 700-ft. level in the Gagnon mine, at Butte, I have seen boulders 5 or 6 feet in diameter, formed by the solvent action of water that has seeped along joint-planes in the granite. These were similar in origin to the boulders formed by erosion at surface, and were due to the sculpturing hand of chemical waters. Once rounded, the hard quartz bent the neighbouring soft slate to its unyielding shape. Neither movement nor solution cease underground at a given moment. Since the veins were formed, the continual shifting of loads of sediment, by transfer from mountain to river, from land to sea, has caused the disturbance of equilibrium that incites geologic unrest. This has been the cause of new fractures along which later solutions have found a patient way. Photograph No. 22 shows clearly the occurrence of quartz veins differing in character and origin. We who see a vein in a mine to-day are apt to regard it as a finished product, brought to our attention at the close of a completed cycle of chemical and physical operations. We regard ourselves as full-stops in time. On the contrary, the whole of the period during which man has tenanted the earth barely punctuates the geologic record; ours is a brief phase synchronizing with a minute portion of the vast stretch of time during which the vein of ore has undergone successive change. Had we left it in the ground it would have undergone, in later eons, a further alteration. When we remove it with the pick and hammer we break the normal sequence of its development; we are for a brief moment the masters of forces that have operated since the dawn of creation.

PART II.

Introduction.

In 1905 I was engaged by the Government of Nova Scotia to examine and report upon the goldfields of that Province with a view to giving advice concerning the best method of stimulating a declining industry. After I had completed my investigation of the gold-bearing lodes of the country I turned, as was proper, to the descriptions and explanations published by earlier investigators, and in ransacking the literature of the subject * I found delightful evidence of the growth of geological thought from 1860 to the present day. This evidence can be summarized in the form of a series of quotations, accompanied by my own comment, and it is here proffered as a contribution to the study of economic geology.

Before citing a succession of observers, I shall ask you to remember that the longer axes of the saddles and domes, on which the ore is found, have a strike from east to west, that is, parallel to the backbone of the peninsula of Nova Scotia, with cross-folds extending roughly from north to south. Next it is necessary to explain some of the terms used by earlier writers and sanctioned by local usage: 'Lead' is used as a synonym for 'lode.' The slate is variously called 'shale,' 'clay slate,' 'argillite,' and 'belt.' The last of these is also a synonym for 'bed.' The quartz is said to lie in the 'belts' of slate. The quartzite is called 'sandstone,' which is not far wrong, although the rock in question is undoubtedly crystallized by metamorphism. Another local synonym for quartzite is 'whin.' This, of course, is an old British term applied to the trap-rock forming the base of that horizon in the Carboniferous in which are found the lead deposits of the north of England, notably at Alston Moor. Used thus it is the equivalent of the Cornish 'elvan.' As applied to the Nova Scotian quartzite it is entirely wrong, and serves merely to perpetuate an early error. Both 'belt' and 'whin' are localisms of a pernicious character, because any special significance that they may possess is misleading.

Gold was discovered at Waverley † in August, 1861. Earlier discoveries had been made at Tangier, in 1860, but they proved unimportant.

* In which I was greatly aided by a bibliography placed at my service by Mr. J. Edmund Woodman, then professor of geology in Dalhousie University.

† Originally it was Waverly, probably from an error in spelling.

John Campbell.

In 1863 John Campbell made a report to the Provincial legislature. He spoke of the 'whin' as the fundamental or basement rock of the region and drew a section showing that "it comes to the surface six times between the Atlantic coast and the northern boundary of the gold district, say 30 or 40 miles. As in each case the associated rocks accompany it, and with them the auriferous quartz, it is plain that this structure is clearly established, and there must be not less than twelve parallel zones at an average distance of not more than three miles from each other, in which the explorer may reasonably look for the occurrences of gold-bearing quartz."

Evidently he looked for the gold on the sides of the fold, not along the apex. He also assumed that the stratified rocks were continuous sheets, not flat discs. As the quartz also is supposed to be inter-blanketed without a break, we may infer that he imputed the absence of it along the anticlinal crest to the effects of erosion.

John Arthur Phillips.

Campbell quotes John Arthur Phillips, who apparently visited the Waverley district at this time (1862–'63). Phillips says: "The principal workings are here situated near the summit of a hill composed of hard metamorphic shales, where openings have been made to the depth of 4 or 5 feet, upon a nearly horizontal bed of corrugated quartz of from 8 to 10 inches in thickness.

He does not appreciate the anticlinal structure, and this failure to notice a dominant feature may have been due to the small extent of lode then exposed. Apparently the ore had only just been uncovered on the crest of a flat dome, so that it looked like a horizontal layer. Proceeding, he says:

"This auriferous deposit is entirely different from anything I had seen before, and when laid open presents the appearance of trees or logs of wood laid together side by side, after the manner of an American corduroy road. From this circumstance the miners have applied the name of 'barrel quartz' to the formation, which, in many cases, presents an appearance not unlike a series of casks laid together side by side and end to end. The rock covering this remarkable horizontal vein is exceedingly hard, but beneath it, for some distance, it is softer and more fissile. The quartz is itself foliated parallel to the lines of curvature, and exhibits a tendency to break in accordance with these striæ."

Benjamin Silliman, Jr.

In the following year a famous American geologist, Benjamin Silliman, Jr., offered a description of the Nova Scotian goldfield in a paper published at Newhaven, in February, 1864. He made reference to the strong marks of glaciation and the proofs of extreme denudation. Mention is made of "the universal evidence of a high degree of glacial action, which has so worn down and polished the rocks that their edges everywhere resemble the leaves of a book which has been cut with a dull knife in the binder's press; in a direction at right angles to that of the leaves."

Early observers, seeing a few patches of glacial drift, had imagined the existence of large gold-bearing alluvial deposits, hidden in lakes and marshes. Silliman, however, pointed to the marks of denudation and stated that "they account, in fact, for the general absence of alluvial gold." "The great mass of loose materials which come from the scouring of the country by glacial action has gone into the Atlantic ocean, where the gold is safely deposited."

He gives a section and a perspective view of the Waverley deposit (see opposite page), and says:

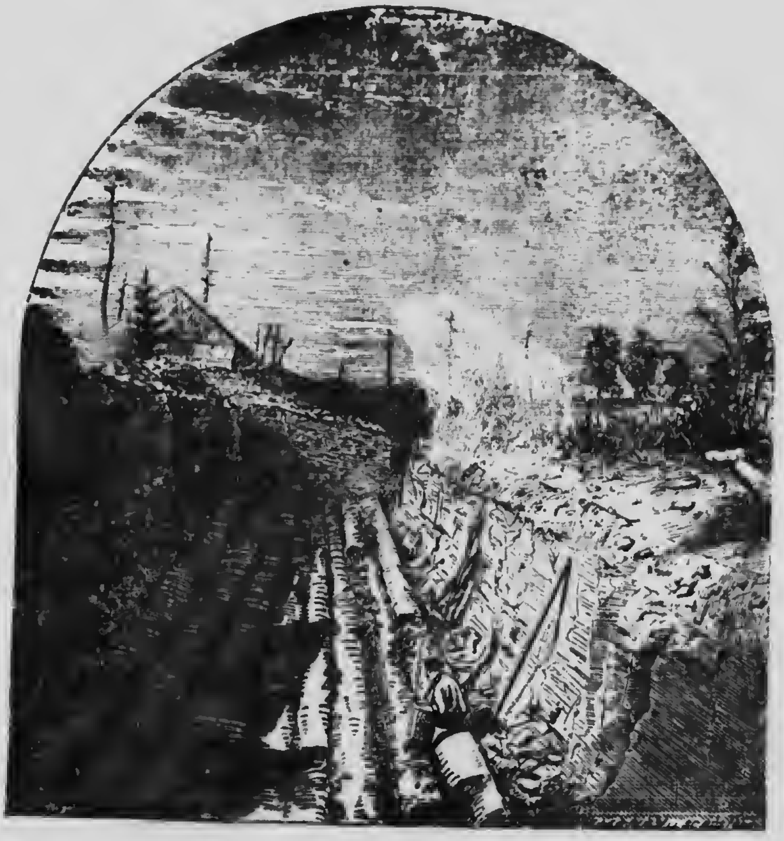
"Only the corrugations in the open part of the cut are visible; the extension of the vein to the right and left is ideal, the superincumbent mass covering it. I measured, however, the quartzite above, dipping to the right and left at a small angle, and I think no geologist would doubt that the crest of an anticlinal axis here comes to the surface and has escaped the denudation which has removed the top of the crest in most places. The corrugations, or folds, appear to be accounted for on the supposition of a lateral thrust producing the undulations. The annexed perspective view of this interesting locality is taken from a stereoscopic photograph, showing the appearance of the barrel quartz after the surface rock (quartzite) has been removed, and before the miners have broken up the quartz layer for removal."

It is obvious that Silliman made an acute diagnosis of the structure and we shall see that many years passed before any later scientist was able to throw fresh light on the subject.

T. Sterry Hunt.

Four years later, in 1868, a celebrated chemist and geologist, T. Sterry Hunt, made a report for the Geological Survey of Canada. He quotes Campbell as having drawn attention to "the grain or reed-like marking often impressed on the surface of the beds in a direction parallel to the east and west axes of folding, and he points out that the angle of dip, eastward or westward, of these markings on the crown of the great anticlinals enables us to detect the transverse, or north and south, lines of undulation, which have at a subsequent period disturbed the horizontality of the east and west anticlinal folds." It is obvious that for the "angle of dip" we should read 'pitch.'

Cross-section of the Waverley deposit according to Benjamin Silliman, Jr.



General view of the Waverley deposit as sketched by Benjamin Silliman, Jr.

Hunt himself proceeds to say:

"The markings in question often appear as rib-like ridges or flutings, which are most conspicuous on the surface of the auriferous quartz layers and the enclosing beds. On the summits of the anticlinal folds they are sometimes so large and so well defined as to give the layers a wrinkled or corrugated form, producing what is designated in the region as 'barrel' quartz, and has by some observers been compared to the ripples on water, and by others, to that parallel arrangement of logs which is seen on what is called a corduroy road."

In explaining the origin of the deposits of gold-bearing quartz, Sterry Hunt says:

"So far as my present observation goes, I think that to describe them otherwise than as interstratified beds would be to give a false notion of their geognostic relations. The laminated structure of many of the lodes, and the intercalation between their layers of thin continuous films or layers of argillite, can hardly be explained in any other way than by supposing these lodes to have been formed by successive deposition at what was, at the time, the surface of the earth. There is, moreover, evidence that these laminæ were formed before the lodes were folded and contorted; this is furnished by some remarkable specimens of the so-called barrel quartz which I took from a lode at Upper Stewiacke. . . . It seems not improbable that the corrugated structure of the lodes, which gives rise to the barrel quartz, is due to the difference in texture, and to the greater resistance to lateral pressure offered by the quartz layers than by the enclosing beds of clay and sandstone, which by their consolidation have given rise to the argillites and quartzites."

Thus he supposes the quartz to be an original member of the sedimentary deposit in which it now lies embedded and he imputes the crenulation to subsequent folding. The corrugation of quartz and the corresponding fluting of the rock encasing them are essentially different from ripple-marks, such as, for example, I saw on the foot-wall of the Johnson's Reef mine at Bendigo.* The efficacy of lateral pressure alone is negatived by the fact that the 'barreling' or crenulation is exhibited by veins that cross the stratification.

Henry Y. Hind.

The next observer to write on the subject was Henry Youle Hind, who published a report in 1869. He had an active imagination, for he says: "A very feeble conception can now be formed by superficial observation of the original enormous magnitude of these huge waves of rock which ridged the surface of the Province. Whether denudation took place as fast as the uplift, or whether the undulations attained their maximum altitude, partially or wholly undenuded, it is certain that not less than 9000 ft., in vertical

* *Trans. A.I.M.E., Vol.* xx, p. 519.

thickness, belonging to one rock series, have been removed from the present surface of the Waverley gold district."

He speaks of "whin, quartzite, and slate," and assumes the 'whin' to be of igneous origin. Having imputed a volcanic character to a sedimentary rock, he next credits the quartz lodes with a sedimentary derivation. He says: "The so-called veins, leads, or lodes in which the gold is chiefly found, are true beds of aqueous origin, and formed by deposition in the same manner as the associated quartzites and slates with which they are interstratified, and indefinitely prolonged in all directions."

In order that we may not be mistaken as to his idea of the true character of the 'whin,' he explains that "under the general name 'whin' are included a variety of rocks which are correctly known as diorite, diabase, dolerite, etc.: but for the sake of simplicity these will all be comprehended in the general description under the term 'whin.'"

Hind's idea of simplicity is to ignore facts. However, in his description of the details of lode-structure he exhibits powers of observation better disciplined. He says:

"At Waverley, movement has occurred between the quartz and the whin, or between the quartz and hard slate, or in the bands of slate, and in all cases slickensides, reed-like markings, ripples, and small undulations have been produced. In the barrel quartz no sliding motion is distinguishable, for the corrugations extend far into the overlying whin rock until they assume the form of a series of connected arches 5, 6, and even 7 ft. in width. The corrugations are by no means confined to the quartz lead, but spread out, fan-like, into the overlying rock."

He distinguishes between "true" veins, namely, the feeders that cross the stratification, and the "bedded" veins of the domes, thus: "While the gold which the bedded leads contain, in common with other metals, was most probably derived from the oceanic waters from which the quartz was deposited, the gold in the short segregated veins of subsequent origin was transferred from the bedded leads or auriferous interstratified slates." He makes note of the fact that at Montague, Sherbrooke, and Laurencetown, the rich quartz or 'gold streak' dips [he means 'pitches'] at the same angle as the corrugations. He attributes the occurrence of these richer portions to precipitation by organic matter, saying: "It would be a simple matter to explain the structure of the gold streak on the supposition that organic matter determined the deposition of the metal in belts or zones, for it is easy to conceive accumulations of stranded organisms on subaqueous beaches in a shallow sea in the form of long bands."

This coincidence between the pitch of the rich ore and a large corrugation or 'roll' is an important fact, as has been proved by many small but successful mining operations in Nova Scotia. The "stranded organisms" are not confirmed by the evidence of vegetal remains, but it is true that slate is more plentiful at the anticlinal crests.

In a later essay, read before the Geological Society of London, in April, 1870, he discusses the 'gneisses' of Nova Scotia. These he supposed to overlie the granite, for he says: "The granite is a sedimentary deposit, and consists of two deposits resting unconformably upon one another." He mistook the effects of contact metamorphism and the schistose character given in places to the quartzite-slate series. As apophyses (dikes or tongues) of granite penetrate the overlying altered sedimentary rocks, he allows that "the granite, or rather gneisses, break through the gold bearing series in many places, but they are brought up by faults. In other places the gneisses appear to have been in a plastic state when the uplift took place,[*] for veins are found squeezed into the cracks and interstices of the thin bedded gold-bearing rocks, and it is this aspect which leads at the first blush to the impression that the granite is an intrusive rock, and not a lower series brought up by a fault." This explanation is itself not wholly unreasonable, but it is negatived by abundant facts, ascertained since Hind wrote.

In describing the mines at Sherbrooke he distinguishes between lodes that are "intercalated, and consequently of later age than the contemporaneous bed." The last two words refer to the interbedded seams of quartz, which he thus distinguishes from the quartz that appeared to him to be unstratified. He goes on to say:

"In broad bands of slate, lodes thicken to the breadth of 10 to 12 inches and thin out to a film of quartz or disappear altogether in the space of a few hundred feet. But before they thin out altogether another lode begins to appear, separated from the first by a few inches, more or less, of slate and quartzite. This cannot be strictly regarded as a continuation of the lode which has thinned out, although it may thin out and be in part overlapped by another lode in the strike of the first one which has disappeared. Some lodes of this description appear to belong to the class of intercalated lodes, that is, they are sheets of quartz that have been formed at a later date than the enclosing rock, and were produced by the replacement, particle by particle, of pre-existing beds of some other soluble material. In lodes of this class, which generally occur in slate, the slate itself is found to be auriferous, and the whole mass is frequently worth crushing. The strong persistent lodes generally occur in quartzites, or with quartzites

[*] The text says: "In a plastic date [illegible] the uplift took place." Obviously typographical errors.

on one side and slate on the other. The intercalated lodes occur in slate, with sometimes thin beds of quartzite, which are also intermittent, that is, 'thin out' and 'take up' again."

Here he recognizes that the quartz assumes the shape of flat discs or lenses, following each other *en echelon*, and he is on the track of the truth in imputing their form to the replacement of soluble sedimentary material. It is strange that he did not take the next mental step, and inquire whether the regular layer-like forms of quartz were not also a replica—in part at least—of rock replaced by silica.

The recognition of quartz in fissures crossing the stratification, and therefore later than the enclosing rock, is shown in another paper read before the Society of Arts, in May, 1870. On that occasion he said: "I consider that all the evidence hitherto accumulated in Nova Scotia tends to show that the gold was originally deposited from oceanic waters, and diffused throughout their sediments, especially in beds of quartz. Much of it was no doubt subsequently concentrated in intercalated beds of quartz, and in some instances in fissure veins." Thus he falls back on Werner's theory of the precipitation of the metals from oceanic waters, and he assumes that the quartz is of sedimentary origin also. If the gold and the quartz were both of sedimentary origin, we should find the gold, by reason of its gravity, concentrated at the bottom of the quartz sediment, that is, on the foot-wall. Hind discards the idea of thermal action due to igneous irruption; he wrote long before hydrothermal activity in forming metallic ores was a recognized theory and at a time when plutonic action was only vaguely surmised. Even this agency he rejects, for he says: "There is no evidence to show that intrusive rocks, or veins, or dikes had any share in the introduction of the gold; indeed, I have not yet seen any rocks in Nova Scotia near the gold districts, which, upon close examination and study, can be regarded as intrusive rocks. Gold is found and worked in beds of quartz of contemporaneous age with the interstratified slates and quartzites, throughout a vertical thickness of 6000 ft. These beds are worked in one district or another throughout that thickness of strata, on anticlinal or synclinal folds." He is not aware of the diorite at Tangier, and he has failed to note that the granite exhibits its intrusive character in many localities.

In his description of Waverley, he is off the dangerous domain of theory, and does himself more credit. He says: "The so-called barrel quartz at Waverley is a fair representation of a corrugated lode, occurring on the crown of an anticline. In nearly all the gold districts the same form of quartz beds may be seen, and in similar relative positions. The corrugated structure is not confined to the quartz, but spreads fan-like into the overlying rocks, and appears to be, in part, the result of unequal pressure during the folding of the strata."

WARINGTON W. SMYTH.

At the meeting of the Society of Arts, in London, before which this paper was read, the chairman was Sir Warington W. Smyth. He was the only person present who cared to criticize Hind's theory, and he did it, as we should expect, in an effective manner. Smyth asked:

"If the gold has been deposited contemporaneously with the quartz by the sea-water, why was not all the gold deposited at the bottom of the sediment, by reason of its greater specific gravity? But by another part of the paper it appeared that the gold ran only in streaks, and that it seemed to be accumulated near certain crossings of these beds by other lines of quartz, which looked more like true veins. At present, therefore, he could not help saying he thought there was a good deal more to be made out. He had on former occasions visited certain localities, though not in Nova Scotia, where it was said that minerals occurred throughout a stratified mass, but he had usually found such a statement to be the result of a deficient observation. In a certain part of the stratified-looking mass there had been a dissemination of mineral matter, but very frequently this apparently stratified mass was nothing else but a mass of stratified material, ground and rubbed together, and existing between two walls resembling those of a regular vein; or, again, the mineral matter had been most decidedly intercalated at a period long subsequent to the original formation of the beds. He could not help thinking that this would prove to be the real explanation of the occurrence of the gold in a good part of these Nova Scotia deposits.

Thus Smyth placed his wide general experience against Hind's local knowledge. The reference to "streaks" requires explanation, that being the word used in Nova Scotia for the richer portions of the quartz, that is, ore-shoots. It is a misleading term, for the "streak" is not a line or thread of rich ore but a band that may be many feet wide, pitching at a strong angle, as determined by the "rolls" to which reference has been made, and by feeders or cross-veins that do not conform to the bedding of the country rock and therefore penetrate the walls of the normal anticlinal sheets of quartz. Undoubtedly Smyth was right in placing his finger on this significant fact, a fact that suggested so obviously that the deposition of the gold could not be due to sedimentation.

ALFRED R. C. SELWYN.

In the following year, 1871, Alfred R. C. Selwyn, famous as an Australian geologist, published his 'Notes and Observations on the Gold Fields of Quebec and Nova Scotia.' He expressed disagreement with Hunt and Hind, and quoted with approval the generalizations of Lieber (Geological Survey of South Carolina, 1856). Selwyn repudiates the idea of contemporaneity as between the quartz and the sedimentary rocks. He says:

"All veins are younger than the country: and hence it is without any reason that many writers regard those only as veins which dip or strike unconformably with the country-rocks, for it is evidently quite immaterial what peculiar relative position is occupied by the two as concerns the origin or the general characters of the veins. Crevices may be formed in any direction, and it is but reasonable to suppose that the planes of stratification, being possessed of less cohesion, will at least as readily present themselves for the formation of cracks or fractures as those planes which traverse the more compact and less fragile portions of the rock."

In other words, the origin of an ore deposit cannot be inferred from its shape, because the shape is dependent upon structural conditions in the country-rock. The ore in veins occupies fractures that follow lines of least resistance, and those lines may be identical with the stratification. Selwyn continues: "In order to substantiate their origin by contemporaneous deposition at the surface, it would likewise require to be explained in a more satisfactory manner than has yet been done, why they are always found in close connection with anticlinal axes, and never at the outcrops of the main synclinal folds, or associated with strata which have not been subjected either to metamorphic agencies, or to folding or faulting." To which I may add that if the quartz had been deposited in a sheet-like layer, sandwiched between silt and sand, at the bottom of the ocean, or even in the flat discs characteristic of sedimentation, it would now be found wherever the quartzite and slate outcrop. Nor would we expect to find it particularly at the crest of the folds, for the pressure incidental to folding would have bent the beds in places where the least quartz offered the least opposition to plication, and not the places where the hard layer of quartz was thickest. But you would rather hear what else Selwyn has to say; he continues thus:

"The bed-like character of the quartz, the comparatively limited distances through which the layers have been traced, their more or less lenticular form, the evidences of motion in the enclosing rocks, the constant connection with anticlinal axes, and the absence of corresponding quartz layers through great thicknesses of strata which do not present evidences of such disturbance and corrugation, are circumstances, all of which are strongly opposed to the theory of contemporaneous deposits and as strongly in favour of the opposite conclusion."

As regards the granite of the Nova Scotian gold-mining region, Selwyn observes:

"It is strictly of an indigenous character, and neither an old granitoid gneissic series of Laurentian age, nor an intrusive mass. Dr. Dawson has shown ('Acadian Geology,' 1868) that in different parts of its course it comes successively into contact with Lower Silurian, Upper Silurian, and Devonian rocks, and the manner in which these sedimentary strata are affected at the lines of contact scarcely leaves room to doubt the posterior origin of the granite. . . . The relations of the granite and gneissic rocks in Nova Scotia to the surrounding auriferous strata, are perfectly analogous to what is observed in this respect in the Australian gold districts, most of which are in close proximity to similar granitic centres. In one instance an auriferous quartz vein, which had been worked close up to the boundary of a large granitic area, was found to pass gradually, by the addition of feldspar and mica, into granite, losing its auriferous character and becoming a vein of ordinary grey granite exactly resembling the rock of the neighbouring granite mass, into which it eventually merged. It will be interesting to trace out the manner in which the quartz beds in Nova Scotia terminate in their strike toward the granite masses."

The comparison with Bendigo and Ballarat is just, as I can testify. The argument can be made stronger by reasoning that the branch or apophysis of granite that penetrated the quartzite and slate lost its mica and felspar, gaining in quartz, until it became like an ordinary quartz vein, acquiring an "auriferous character," and becoming a vein of quartz "exactly resembling" the neighbouring anticlinal formations "into which it eventually merged." The differentiation from a dike of granite containing quartz, mica, and felspar to a simple quartz vein, recalls the modern theory advanced by J. E. Spurr that some veins of silica or 'alaskite' represent the last phase of magmatic segregation. Selwyn's question as regards the behaviour of the quartz veins when reaching the granite in their strike has been answered by mining operations that have followed such veins from the slate and quartzite into the granite. The quartz penetrates the granite and has been found gold-bearing, although not rich. The veins maintain their identity, but not for long, after entering the granite; and there is evidence to suggest that the quartz is an extreme phase of the silicification to which, in places, the granite itself has been subject.

Coming to the barrel structure, Selwyn says:

"The facts which I have observed lead to the conclusion that the corrugation of the quartz is intimately connected with, and dependent on, the operations of the forces which have produced the slaty cleavage; the same forces have likewise, in all probability, caused the opening between the beds in which the quartz has been deposited; and also the great parallel east and west synclinal and anticlinal foldings of the strata. In every corrugated vein which I have examined, the axes of the corrugations or barrels always coincide with the strike of the cleavage. If the walls are of sandstone (whin), they are rarely corrugated, and seldom show any cleavage planes; though their surfaces, especially if in immediate contact with the quartz, frequently show ridges or parallel undulations, which strike with the cleavage and seem to have impressed corresponding swells or undulations on the quartz. Where cleavage and bedding coincide in strike and dip, no corrugations occur, nor are they observed in layers which are enclosed between walls of hard whin. All those veins, which are sharply corrugated and contorted, lie within the limits of beds of highly cleaved soft slates of from three to five feet wide, between beds either of whin and a hard compact slaty rock, which constitute the walls of the veins, but in no instance exhibit corrugations corresponding with those of the vein, and are commonly perfectly smooth and even throughout."

Here Selwyn is on the edge of a discovery that would have gone far to explain the origin of the 'barrel' structure. Whether he expressed himself badly or whether he really appreciated that the 'corrugations' follow the line of *intersection* between the planes of cleavage and the planes of the vein-walls is not clear. He certainly afforded a hint to succeeding observers, but no sign is given that they appreciated it.

Henry S. Poole.

In 1878, H. S. Poole reported that:

"The distinctive features of the gold leads of Nova Scotia are their general conformability with the slate and quartzite beds and their regularity, suggesting that they are beds rather than veins. But there are characters that point to their being true veins in spite of these features, and they are the following: the roughness of the planes of contact between quartz, slate and quartzite; the irregularity of their mineral contents; the termination of the leads; the effects of contemporary dislocations; and the influence of stringers and off-shoots on the richness of the leads, characters that simply or collectively it would be difficult to account for, associated with a stratified deposit."

Mr. Poole is, I believe, still happily living. I hope he may long be spared, for he injected a notable amount of good sense and keen observation into his writings on the subject. Obviously his distinction between 'beds' and 'veins' is well put and conclusive.

In the following year (on March 12, 1879) the same observer read a paper before the Geological Society of London, and again combated the old ideas of Hunt and Hind; for he said: "The theory that the 'leads,' as the lodes are locally called, are contemporary beds with the slates and quartzites has not since been generally accepted; nor has it gained ground with the further knowledge derived from working, nor been adopted by any of the miners, among whom are men experienced in other gold-producing countries." The only persons contributing to the discussion on this occasion were J. Arthur Phillips, who "confirmed the views of the author as to the leads of Nova Scotia being true mineral veins," and Warington W. Smyth, who stated that "he thought the author of the paper had rendered a most useful service to geology in completely upsetting the theory (based on imperfect observation) of the bedded origin of the leads." Thus a fallacious idea was given its quietus; in later descriptions and discussions the notion that the lodes were interstratified sedimentary deposits is conspicuous by its absence.

In referring to the Waverley deposit, Poole says:

"In the overlying stratum the position of the plication in the quartz is marked merely by a moderate undulation. The quartz having yielded in the greatest degree to the lateral pressure would indicate that, at the time of the upheaval, it was then in a more plastic condition than the containing rocks, and the more when it is observed that the rolls contain angular fragments of slate, and send off shoots and tongues of quartz up into the superjacent stratum."

The notion that the extraordinary serpentine folds characterizing the 'barrel' structure must have been rendered possible by a plastic condition, assumed by the quartz by reason of excessive pressure, is not undeserving of respect; it affords one of the explanations most favoured by other geologists who came to Nova Scotia long after Poole; but it is rendered untenable by the evidence submitted by me in the first half of this paper. The "offshoots and tongues of quartz" penetrating "the superjacent stratum" require us to suppose that the quartz was not only sufficiently plastic to permit deformation without crushing, but also to imagine that the silica was in a molten or fluid state. If that condition had been attained owing to excessive pressure and temperature then the slate and quartzite also, both of which are more susceptible to the same physical change, would show it. They would not have remained so hard as to be traversed by cracks into which the liquefied or viscous silica could be injected.

Edwin Gilpin.

After Poole came Edwin Gilpin, the Provincial Inspector of Mines, who contributed a paper on 'The Gold Fields of Nova Scotia' to the North of England Institute of Mining and Mechanical Engineers in 1881. He drew attention to the comparative smallness of the lodes. "The worked veins vary in thickness from ½ in. to 6 ft. The usual width being from 4 to 8 in., and a 20-in. vein is considered a large one." He spoke of "beautiful specimens of gold" to be "secured by treating nodules of pyrites with acid, which presents the metal in curiously interlaced plates and films, when by a previous examination no gold could be detected." Thus by strong acid is obtained swiftly a reaction such as ensues in nature slowly when the oxidation of pyrites yields a soluble sulphate, which is removed by weathering, leaving the gold in honeycombed pockets. Gilpin also gives a section across the Belt lode at Montague, illustrating how the 'pay streak' or enriched portion of the quartz lode is found at the intersection with a cross-vein.

John William Dawson.

Next we come to an authority of the first rank, John William Dawson, the chief of the Geological Survey of Canada. As early as 1878 he stated that "the gold deposits seem richer in the vicinity of the granite," and at the same time he re-affirmed his view that "the granite intrusions and gold veins are roughly contemporaneous." In 1891, by which time he had been knighted, and was known as Sir William Dawson, he published 'The Geology of Nova Scotia, New Brunswick, and Prince Edward Island.' In that book he refers to the deposit of gold-bearing conglomerate at Gay's river, an occurrence important as affording evidence concerning the age of the gold deposits. He says:

"It was described in *The Canadian Naturalist* for 1864, by Mr. C. F. Hart, and Dr. Honeyman has favoured me with manuscript notes of a visit to the place in 1866. From these sources I extract the following information: The locality is at the junction of the Lower Carboniferous conglomerate with the slate and quartzite, forming the extremity of the ridge separating the valleys of the Stewiacke and Musquodoboit rivers. The slates belong to the Silurian gold-bearing formation, and contain small but rich auriferous quartz veins. The conglomerate is formed of the debris of these older rocks, and gold occurs in it exactly as in modern auriferous gravels, being found in the lower part of the conglomerate, and also in the hollows and crevices of the underlying slate. The fact is interesting, as showing that the gold veins existed in their present state at the beginning of the Carboniferous period, and that the causes which produced the modern gold alluvia were then in operation. By a later repetition of this process, the drift or boulder clay which overlies the conglomerate is at this place also slightly auriferous."

This is suggestive evidence. As Dawson says, a placer deposit was formed in the Carboniferous by the concentration of the debris eroded from the gold veins formed in the Silurian period, and in a long subsequent era the Carboniferous gravel, hardened to conglomerate, became degraded and distributed in the drift of the Glacial period, and this in turn is washed into the river-beds of to-day. Dawson calls the prevailing formation 'Silurian.' A generation ago it was the fashion to impute Silurian age to gold-bearing slates of unknown geological antiquity; this tendency is to be debited to the example of Sir Roderick Murchison, who ventured the rash prophecy that gold was confined to rocks of Silurian age. We may also demur to Dawson's assumption that because gold derived from the quartz veins is found in a Carboniferous conglomerate, that therefore "the gold veins existed *in their present state* at the beginning of the Carboniferous period." This is an assumption echoed by later observers, but it may well be questioned. All that the facts prove is that the gold in the superficial parts of the veins was in a condition similar to that in which it is found today in the outcrops, but the outcrop of a geological today is not the outcrop of a geological yesterday; the processes of nature do not rest in idleness; solution and precipitation, re-solution and re-precipitation are continually at work. It is not safe to assume that because gold is found now at two or three hundred feet below the surface that it existed there in its present state before several thousand feet of overlying rock was removed by erosion and denudation. That false assumption vitiates many of the theories of a much later date.

Dawson quotes from notes made by him on a visit to Waverley in 1866. He says:

"The appearances showed that the barrel arrangement had constituted the crumpled crown of an anticlinal bend or arch—an explanation already given by Professor Silliman, and on one side the vein could be seen following the beds downward on the side of this arch. The arrangement indicates great lateral pressure; and, which is of more importance, proves conclusively that the quartz veins are contemporaneous with the folding of the rock, since they have perfectly followed its folds without fracture. That the auriferous quartz veins are not beds is evident from the manner in which they send off branches into the neighbouring rock, as well as from their own crystalline structure and the character of the imbedded minerals. They are undoubtedly true veins, but not veins formed by fracture of the containing rocks when in a hard and metamorphosed state. They have been formed and filled in the very act of the contortion and altering of the strata, and are thus of the nature of segregation veins, gradually formed as the spaces containing beds were bent without fracture and with but little crushing. The barrel quartz is most instructive as an illustration of this peculiar mode of formation, which must have occurred in the disturbance and metamorphism of sediments."

Here we have another reasonable theory. A sedimentary origin for the quartz is not entertained, but the folding of the quartz must have been contemporaneous with the regional plication that made the saddles and domes. The addition of segregation as a factor in the formation of these curious lodes aids the theory undoubtedly, but it is not convincing in the light of later evidence. Dawson says that "the quartz veins have perfectly followed the folds (in the rock) without fracture." This is not a fact. They do not follow the bedding-planes perfectly, but transgress those lines of structure most palpably. Returning to the question of origin, he adds:

"No geologist who examines these veins can, I think, doubt their aqueous origin; but different opinions may be entertained as to the precise mode of introduction of the metallic minerals. The facts already stated . . . appear to me to prove conclusively that the veins were formed at the time of the disturbance and alteration of the containing beds, and in consequence of the mechanical and chemical changes then in progress. In this case the gold and other metallic minerals were probably contained in a state of solution in alkaline sulphurets in the silica-bearing heated waters which penetrated the whole of the beds, and from which, as from a sponge, these silicious and metallic matters have been pressed out in the folding and contortion of the beds."

"Sulphurets" is used for sulphides. This old term still lingers in California. At one time it was employed to designate the sooty products of decomposition resulting in the early sulphatization of base-metal sulphides. However, that is by the way. The foregoing paragraph of Dawson is but supplementary to the one preceding, and elaborates the theory on which I have already animadverted.

W. R. Thomas.

In 1893, W. R. Thomas, in 'Notes on Practical Mining,' made some remarks in regard to the persistence of rich ore. He said:

"When one looks around at the many gold districts and sees a large number of mines that were once successful closed down, the first question that presents itself is: What is the reason why operations have been suspended? The usual local reply generally consisting of: Could not cope with the water, reckless management; had a barren streak for a few feet, and just before closing down, rich quartz was discovered right at the bottom of the deepest shaft; never should have stopped, etc. It is, in fact, nearly impossible, according to local opinion, to find a mine that has been really closed down through barrenness. I have found, when making the inquiry, that the approximate depths of abandoned Nova Scotia mines is from 200 to 300 ft."

This statement can be readily corroborated by mining engineers who have investigated abandoned mines in other regions besides Nova Scotia. In discussion, John E. Hardman stated that he had

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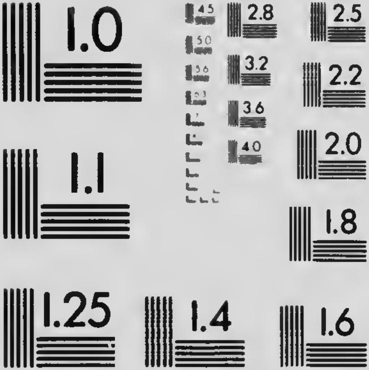

cut the top of the 'pay-streak' in the Standard Co.'s mine, at Oldham, at 520 ft. on the incline, or a vertical depth of 340 ft. The Wellington and Rose mines also are instanced as examples of profitable ore to a depth of 300 to 350 feet. This testimony only tends to confirm Thomas's generalization. The point is that the best ore did not reach far below the surface of today, although optimistic theorists would ask us to believe that the gold as now found existed in the same quantity and in the same ore at a time when the present surface rocks were covered by several thousand feet, since eroded, and they therefore expect us to infer that the rich ore may persist to an equal depth below the surface of today.

B. C. Wilson.

In 1894, B. C. Wilson read a paper before the Mining Society of Nova Scotia. He described the Waverley deposit as follows:

"In 1862, some drift quartz carrying gold was found on the top of the hill, and further search revealed the outcrop of a sheet of quartz lying nearly horizontal, covered with two to four feet of soil, and a corresponding amount of rock, and continued workings disclosed what might aptly be termed a blanket of quartz overlying the hill, and gradually dipping south, west, and north, but most decidedly to the west, or towards the lake at the foot of the hill, and several small owners soon made numerous openings on it, each apparently intent on forming open reservoirs for the local watershed, and, discounting the future for immediate results, soon got it in such a condition that no one could work it, notwithstanding the ore at one time was very remunerative."

Eventually, in 1892, an adit 635 ft. long was driven from the lake and cut the lode on the crown of the anticline at a depth (on the pitch) of 200 to 250 feet below the old surface workings. Wilson proceeds to say:

"At the outcrop the lode was crimped or folded together upon itself and if smoothed out like a sheet of paper would have presented a vein not over 10 to 12 in. thick, but folded together it filled a space of 20 to 30 in., and with associated slate occupied a working belt of about 48 in. between the upper and lower enclosing walls of hard metamorphic rock, and when denuded of the overlying rock presented the appearance of rows of barrels, and hence the name 'barrel lode' was applied."

The same observer makes an interesting reference to the effects of glaciation as evinced in Nova Scotia. He says:

"When, in the surface workings, the soil was removed from the rock overlying the quartz at or near the outcrop, the striæ or glacial footprints were such as to rejoice the heart of an enthusiastic geologist, and in fact many are yet visible on portions of the undisturbed rock. In one spot, where the auriferous vein protruded through its metamorphic covering, a strip of quartz probably 25 ft. long by 8 or 10 ft. wide had been exposed to glacial scouring, the inequalities worn down, and the quartz polished like a piece of ivory, and eroded creases, half-an-inch deep, cut into the retaining rock on either side, were continued straight on across this polished quartz, showing the continuous striæ or track of nature's great planing mill."

W. H. PREST.

In April, 1899, the prevailing idea of the persistence of gold in the lodes, independent of the surface of a recent geological period, and as being due to causes operating long before erosion had removed a great thickness of overlying rock, is voiced by W. H. Prest. He says:

"The original surface was many thousands of feet above our present shallow mines. But owing to the slow and ceaseless operation of denuding agencies, deep mining on a truly magnificent scale has been carried on. Stope after stope, and level after level were quarried by frosts and milled by icefields, but the gold and tailings were deposited in the broad Atlantic; 10,000 ft. was thus mined from the gold-bearing rocks before the present Caribou mines were exposed, and the present Moose River mines were not reached until 17,000 ft. more were removed in the same way. Although such an immense distance separates the respective geological horizons of these two mines, they are only five miles apart geographically. Now, are we to believe that any attempt, could it be made, to deepen the Caribou mines to the same geological level as the neighbouring mines of Moose River, will forever blot out the rich veins that have yielded so magnificently in the past? Are we to believe that the particular level reached by denudation in the present era of the earth's history limits the depth at which paying mines are to be found? And also that the veins and spots thus exposed by nature at such various depths, and almost where they begin, and that neither above nor below them has there ever been, or is there, any veins of value? This can only be maintained in connection with the theory that our present mines were originally but comparatively small spots in the centre of immense bodies of otherwise barren rocks and wholly unconnected with any source of hydrothermal action from below. To even the most superficial amateur in the study of practical geology this position will seem untenable."

This is a popular idea in Nova Scotia, and elsewhere. Unfortunately it is a fact that the orebodies found by man do constitute "small spots in the centre of immense bodies of otherwise barren rocks"; it may be that if the exterior of the earth could be penetrated by the radio-active vision of a magician we should see how few of these spots we had detected, but as to the relative smallness of them we should assuredly gain further proof. But those who recognize the sporadic distribution and the comparative insignificance of the miner's treasure-troves do *not* assume that they are "wholly unconnected with any source of hydrothermal action from below."

The fallacy is to assume that because the action to which ore deposition is due is deep-seated therefore the ore must reach to a great depth. Because a river flows from a source 2000 miles distant we do not assume that the pebble in the estuary has been carried 2000 miles; it may have come from as far, but more probably it was torn from a bank less than 100 miles up-river. The language used by Mr. Prest is as expansive as his imagination; the mines to which he refers have not "yielded magnificently in the past." They were profitable little mines, but they did not uncover large orebodies; on the contrary, as compared to the masses of ore exploited in the Homestake, Alaska-Treadwell, Mount Morgan, and other famous mines, the gold-bearing quartz extracted in Nova Scotia represents little patches, mere fly-specks in the great thickness of pre-Cambrian rocks. If 10,000 and 17,000 ft. respectively have been eroded at Caribou and Moose River, and if the little quartz veins to be seen at the surface of the present geological period are the stumps of veins that once reached two and three miles, respectively, to the surface of a former period, then, of course, these same little veins may persist a few miles deeper and mining in Nova Scotia is in its infancy. But if we dig for a couple of hundred feet into the ground and find that most of these little veins die out or become barren, we shall have serious doubts about the advisability of sinking a shaft 5000 ft. deep to exploit orebodies of imagined persistence. However, it is scarcely worth while to beat a dead dog; the subject will recur when further quotations have been presented.

E. R. Faribault.

In March, 1899, a comprehensive paper on 'The Gold Measures of Nova Scotia and Deep Mining' was read before the Mining Society of Nova Scotia by Mr. E. R. Faribault, an officer of the Canadian Geological Survey. This distinguished cartographer said, in part: "The metamorphic rocks of the Atlantic coast form a continuous belt, from one end of the Province to the other, a distance of 260 miles, varying in width from 10 to 75 miles. . . . They cover about half the superficies of the Province, exclusive of Cape Breton island, and their extent may be roughly estimated at 8500 square miles. Of this area, probably 3500 square miles are occupied by granite masses, barren of gold, leaving an area of about 5000 square miles of gold measures."

Incidentally, I demur to the term "gold measures," which suggests the continuity and uniformity of a coal seam, qualities by no means characteristic of the manner in which gold is found in nature.

From his own accurate and comprehensive surveys, Mr. Faribault has ascertained that in the eastern portion of the Province the thickness of the gold-bearing series of rocks is five miles, the upper slate group being two miles thick and the lower quartzite division three miles. He says that "some of the sharpest and highest folds have been truncated (by erosion) to a depth, as far as we know, of over eight miles, exposing at the surface a section of gold-measures of over five miles in thickness." The extrusion of the granite "occurred after the folding of the gold-measures and the deposition of the quartz veins; for the granite dykes and veins have been observed to always cut the interstratified quartz veins wherever they come in contact with them. The granite has thus no relation to the auriferous character of the veins and need not again be referred to."

This important point cannot be so summarily dismissed; apart from detailed evidence, which I shall be glad to proffer, it is not safe to conclude that the later age of the granite intrusion compels us to reject it as a factor in ore deposition. Quite the contrary. Ore deposits are not made at one fell swoop and then let carefully alone by all the geologic agencies that may in long succeeding periods come that way. If we allow that a gold-bearing quartz vein was formed at the time when the granite intruded we may infer that the igneous irruption was accompanied by structural changes and by the circulation of thermal waters, both of a kind likely to modify the character of the pre-existing vein, especially as regards distribution of the gold. The ore found by man represents a long series of solutions and precipitations, diffusions and concentrations, brought about by chemical and physical conditions that varied frequently during that long time in which Nature has been at work. From the Devonian age of the granite to the human period so much time has passed as to stagger the imagination of a student with a test-tube in his hand. Nature is rarely content to let alone. Her processes are ever at work in a laboratory where the chemicals and apparatus have a potency that is rendered effective because the operator can draw a blank cheque on Time.

Mr. Faribault makes sundry comparisons between the lodes of Nova Scotia and those of Bendigo. Such comparisons are instructive, if made without prejudice; if distorted by misconception, they serve but to darken investigation. He says: "The Nova Scotia section of 35 miles gives 11 anticlinals, or an average distance of three miles between each anticline, and a maximum distance of nearly five miles; while in the Bendigo gold district it ranges from 300 to 1300 feet. So that in Nova Scotia the amplitude of the folds is nearly 20 times greater than in Bendigo." This fact is mentioned as "a matter of eat encouragement" to those mining in Nova Scotia, as if the amplitude of a fold were in direct ratio to its richness in gold. By the same reasoning the huge fractures constituting regional faults would be more likely to contain valuable metallic ore than the small fissures in which the miner occasionally finds a reward for his persistent search. Mr. Faribault proceeds to say: "In Bendigo, where the folds are, on an average, twenty times smaller than in Nova Scotia, the legs of quartz are said to very seldom extend to greater depth than 100 ft. below the cap of the saddle-reef; which would correspond proportionately to 2000 ft. in Nova Scotia." In the Shenandoah mine at Bendigo, it is true, an east leg was stoped continuously for a length of 550 ft. and to a depth of 180 ft., from above the 496-ft. level to the 665-ft. level. That is the maximum recorded. Mr. Faribault's figure is quoted correctly from my own description of Bendigo. Yet, even in theory, the height of a fold is not dependent on its amplitude, for steep folds are usually sharp. If the object of geological survey be the discovery of ample folds and big anticlines, then it is worth while to institute such comparisons between Bendigo and Nova Scotia, but as the more immediate object is to facilitate the search for the precious metal, such discussions are as profitless as the ruminations of a scholiast. If an individual saddle-lode persists in depth to about 100 ft. at Bendigo, and proportionately, on the basis of a geological theory, the same kind of lode should persist to 2000 ft. in Nova Scotia, we may ask: Where is the latter to be found? The object of mining is to exploit profitable ore and therefore to follow such ore as long as it persists. In Nova Scotia no mine has been operated profitably to 2000 ft., or anything like that depth. It is futile to assert that the leg of a saddle should last to 2000 ft. in Nova Scotia. It does *not*, unfortunately.

In 1903, the Government of Nova Scotia published a pamphlet on 'Deep Gold Mining,' by Mr. Faribault; this was in connection with an Act of Parliament intended to encourage further exploration by granting money in aid of shaft-sinking. The author's recommendations have been allowed to carry great weight, for the reason that he has accomplished a large amount of most useful work in the surveying and mapping of the goldfields of the Province. Unfortunately the stratigraphical geologist is not often well qualified to advise on lode mining, and in this case a stratigraphical geologist of great ability has been incapacitated for such a task by being unacquainted with the realities of gold mining in other regions. Mr. Faribault writes as one intimately acquainted with the mines of Nova Scotia, but unfamiliar with the many and varied aspects of ore deposition elsewhere. He rides his hobby hard, and his steed appears neither to shy at the facts of experience nor to be affrighted by the sweeping statements of the rider. In this Government pamphlet he summarizes his views thus:

"The knowledge now gained by a detailed survey of the principal gold districts of Nova Scotia proves conclusively: That the veins which coincide with the stratification and outcrop at the surface are the remnants of north or south legs of superimposed 'saddle-veins' occurring on anticlinal folds, the apices of which have been truncated by extensive denudation.

That these saddle-veins are underlaid by a succession of other superimposed saddle-veins, which do not outcrop at the surface, but occur deeper down on the axis-plane of the anticlinal folds.

That all the mining done for the last 40 years has been confined to the saddle-veins outcropping at the surface, and the richest and most workable portions of these are now mostly exhausted. It is therefore desirable that the succession of underlying saddle-veins should be developed in depth, as it affords an extensive field for deep gold mining.

From the analogy of the gold-bearing saddle-reefs of Bendigo, Australia, occurring in a similar manner and profitably operated to depths reaching 4000 ft., it may be inferred that the Nova Scotia underlying saddle-veins will be found as large in size and as rich in gold as those cropping at the surface.

It is difficult, however, to induce capitalists to invest money in such extensive mining developments in Nova Scotia, unless similar undertakings have already proved successful in actual practice. It is, therefore, very gratifying to know that the recommendations of the Geological Survey have already been put into practice at the Doliver Mountain, Richardson, Blue Nose, and Dufferin mines; and although the developments are as yet limited, the results obtained are most satisfactory and conclusive, and testify to the accuracy and value of the work done by the Survey. They prove that auriferous saddle-veins may be found to recur underneath one another to even greater depth, and in much closer succession than in Australia, and what has been accomplished at these mines can also be done in many other districts in the Province where the conditions are favourable."

It would be difficult to place in more compact form so many general statements the truth of which required proof at present not available. During the seven years that have elapsed since these confident forecasts were made, the four mines that were supposed "to testify to the accuracy" of such a geological diagnosis of Nova Scotia have failed, three of them miserably. "The developments" were "conclusive," indeed, but in a manner far different from what was expected on the basis of theories predicating a succession of profitable saddle formations, for even an exploration limited in depth to three or four hundred feet sufficed to indicate that "the auriferous saddle-veins" *do not* "recur underneath one another to even greater depth than in Australia," that is, if 'auriferous' bear any relation to the economics of mining.

Mr. Faribault refers to large lodes as preferable for deep mining. He says:

"It is acknowledged by the best authorities that the development of the goldfields in Nova Scotia has been retarded by the persistence of the prospector in neglecting for years the problem of large supplies of low-grade ore in favour of isolated rich veins. It is believed that the districts presenting the largest workable saddle-veins offer the best prospects for permanent and deep mining, and should receive the preference. The deepest mines in the Australian goldfields are operated on the largest saddle-reefs."

Of course, the prospector seeks for ore that is profitable, and, like a sensible man, he neglects the opportunity to solve a geological problem. An "isolated rich vein" may yield bigger dividends than "a large supply of low-grade ore." In all talk of this kind there is a lamentable confusion between quartz and ore. The miner wants gold, not silica. The deepest mines in Australia were sunk to exploit profitable lodes, the ability to yield a profit being dependent on the two factors of size and richness. Many large bodies of quartz, at Bendigo and Ballarat, for example, have not been exploited because, after trial, they were found not to contain the proportion of gold required for a profitable mining operation. This idea of size, when divorced from a definite knowledge of richness, has been the cause of much foolish work in Nova Scotia, as in other countries. It may be a stimulant to flamboyant finance, but is not a basis for sound business. The "best authorities" who advocated the grandiose exploitation of large bodies [illegible] poor in gold, knew less of mining than the simple pr[illegible]o kept his eye on pay-ore, extracting it by aid of a w[illegible]s or a whim; while the big companies, led by pseudo-scientific advisers, erected expensive mills and sank deep shafts in the expectation of finding large bodies of ore, the existence of which was only an unsubstantiated surmise.

All rules for the development of a mine based merely on geological structure, without such knowledge as comes from careful sampling and assaying, are worse than futile. It has been said, by the Canadian geologist whom we have been quoting, that "underground developments on vertical folds will thus require to be less extensive and will cost much less than inclined folds, and they should generally receive the preference for deep mining." The experience of mining, which antedates the science of geology, has demonstrated that deep mining is remunerative only where profitable ore has been proved to persist sufficiently to warrant further exploration by vertical workings. The purpose of mining is not to elucidate theories but to make money. If the geologist will show the miner how to find ore, he will dig the necessary holes, but he cannot afford to do so for the purpose of ascertaining academic facts. Old Mining is distinctly utilitarian and makes friends with young Geology only when the latter shows sympathy with the purpose of his labour. That sympathy American and Canadian geologists have tendered to a marked degree, and if in Europe geology still adopts toward the miner a pose more polite than practical, it is no wonder that the economic development of the science remains relatively insignificant.

J. Edmund Woodman.

Another recent student of the subject is Mr. J. Edmund Woodman, formerly Professor of Geology in Dalhousie University, Halifax. On May 18, 1903, he presented a paper on the Moose River district, and on March 18, 1905, another on the 'Distribution of Bedded Leads in relation to Mining Policy.' Both of these were read before the Nova Scotia Institute of Science. He proposed the name of 'Meguma' for the gold-bearing series, and divided it into a lower quartzitic division called the 'Goldenville,' and an upper or black slate division called the 'Halifax.' In the first of these two papers Mr. Woodman uses the term 'crenulation' to label the barrel structure. He shows that the crenulation is not always parallel to the stratification. Even undoubted cross-veins will exhibit this structure, although less frequently than those of the bedded type. In the second paper he states that in the Nova Scotian gold region there are 26 well-marked anticlinal crests, and exactly one-half of them show domes that have been tested by mining. Any one anticline, owing to cross-folds, may have several domes, but five is the largest known number on the same anticline. He states that only "one or two cases of gold-bearing bedded veins are so far known to exist in the trough of a syncline; and from the mechanics of the mountain-building and attendant vein phenomena, it is not to be expected that such deposits will occur along the synclinal axes to any extent." Hence "it is probably safe to neglect these folds entirely in exploring for new deposits." He emphasizes the association of gold-bearing quartz with the slate, and asserts that "no prospector wastes his time on country definitely known to be all whin." His use of the term 'whin' for quartzite is regrettable, especially as he refers to the fact that this word "was originally employed by Hutton, in Scotland, to designate certain sheets of trap, and in Cornwall still has a similar meaning."

But this lapse need not detract from the undoubted value of his observations. For instance, he makes the important note that the most violent folding takes place where the largest proportion of slate exists. There also the gold-bearing quartz veins are most plentiful. "If one goes out from the centre of a dome, he will proceed from a part in which outcrops and underground cross-cuts show a definite alternation of slate and quartzite beds, rather suddenly into a region in which little, if any, slate is to be found. This is a typical condition."

When, however, Mr. Woodman begins to apply his accurate geological observation to the furtherance of mining, he also (like Mr. Faribault) misses the one economic essential, namely, that mining operations must tend to be profitable, first, last, and all the time. He presents some "facts" to encourage the miner:

"First, while there is an undoubted downward limit to the zone of leads which could be cut by a shaft sunk on the apex of a dome, we have no evidence that in any given district it is within the range of moderately deep mining, or that many valuable saddles may not be cut by such a shaft. The experiment has never been seriously tried. Second, while a very definite surface lateral extent is known for each true dome, there is many a district in which there are enough paying belts to keep one or a very few large plants for more years than any of us will see. Third, while there is a definite downward limit to each leg of a saddle, at which the vein dies out, it has yet to be shown that anyone has reached that limit in a characteristic case."

Here, as in the case of Mr. Faribault, the scientist who applies geology to mining ought to be assisted by a sampler and assayer. No new deep shaft is necessary to prove that the profitably gold-bearing veins of Nova Scotia do not persist. Shallow mining to three or four hundred feet vertically has sufficed to ascertain that fact. The "experiment," as recommended by Mr. Faribault, was tried at the Blue Nose mine, at Goldenville, and it failed utterly. I venture to deny that "there is many a district in which there are enough paying belts to keep one or a very few large plants for more years than any of us will see." Yes, breaking stone for roads, but not winning gold profitably for the shareholders whose money was subscribed for the erection of the large plant. It indicates obtuseness to unpleasant realities to assert that "it has yet to be shown that anyone has reached the downward limit to the leg of a saddle," if Mr. Woodman is referring to a leg or quartz vein that is profitably gold-bearing. Certainly those of us who are engineers would not urge the miner to follow the leg of a saddle for the sake of white quartz. Perhaps I speak roughly, but I do so in the interest of ascertainable knowledge. Spencer said that Huxley's idea of a tragedy was a beautiful theory killed by an ugly fact. Assuredly facts, ugly from one point of view, have massacred these theories of visionary geologists, who confuse the making of holes in the ground with mining, and the persistence of quartz with the continuity of gold-bearing ore.

Conclusion.

The foregoing citations from writers who examined the same region at successive intervals during fifty years is interesting as illustrating the growth of geologic thought. They serve to remind us how young the science is, and how infantile is that branch of it applied to the search for valuable ores. Errors in petrography were natural before the microscope was introduced, and mistakes in chemistry were not surprising before laboratories became easily accessible, but it is apparent that the worst errors are not caused by the lack of apparatus or other artificial aids, but by careless observation and reckless generalization. Keen eyes and a logical mind enabled several of the older investigators to arrive at remarkably correct inferences, while the multiplicity of instruments has not availed to prevent some of their successors from gross blunders. The general trend has been to discard catastrophic ideas and to apply the principles first enunciated by Lyell in 1830. The history of geologic thought as regards the Nova Scotian goldfields, as elsewhere, indicates a growing disposition to judge the unknown by the known, and the past by the present, with due allowance for varying conditions. Geology has become less visionary, while appealing no less to the constructive imagination. Knowledge does not kill theory, it serves but to discipline. If geology has so often failed to guide the miner in his groping underground, it has been because the science was allowed to drift too far from the safe anchorage of fact. All gold-bearing quartz is not ore, and every hole in the ground is not a mine.

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