THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1897-98.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

14 December, 1897.

SIR JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S., President,
in the Chair.

(Paper No. 3074.)

“The Great Land-Slides on the Canadian Pacific Railway in
British Columbia.”

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THE great land-slides which have caused so much trouble and expense in working the Canadian Pacific Railway, since the opening of the line in 1885, occur on the banks of the Thompson River, about 41 miles above its junction with the Fraser River and 197 miles east from Vancouver, the western terminus of the railway, Fig. 1, Plate 1. Within a distance of somewhat over 5 miles there are seven large land-slides, all of the same nature, and six crossing the railway line, as well as smaller slips, Fig. 2. About 20 miles further down the river, at a point opposite Spence's Bridge, there is a similar large slide.

The railway occupies the east and south-east bank of the river, at an elevation between 50 feet and 80 feet above low-water level, and follows closely, with one exception, the contour of the river bank. At about 200 miles from Vancouver the railway passes through the Black Cañon Tunnel. This portion of the Thompson River, for a distance of about 20 miles, traverses a gorge about 5 miles wide at the top, and about 2,000 feet deep, with hills and higher ranges rising back on each side to elevations between 5,000 feet and 7,000 feet. In the middle of this gorge the river runs in an inner gorge, with sides between 50 feet and 150 feet above low-water level and close to the river. There is but little bottom land near the river. The surface rises from the water's edge in benches and terraces, varying in height between 30 feet and 200 feet, and extending to a general altitude of about 1,800 feet, or about 1,000 feet above the river. The land

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risers beyond in broken slopes interspersed with hills and peaks. The terraces and slopes are cut by many dry gulches and small streams draining into the river. The largest of the benches, and the lowest flat in this neighbourhood is occupied by the town of Ashcroft.

The terraces of these greater valleys are cultivated for raising winter food for the cattle that range the higher valleys and the open timber of the lower hills, and for raising garden, field and orchard crops for local consumption.¹ Artificial irrigation is necessary, there being no natural growth in the lower valleys, such as those of the Thompson and the Fraser Rivers, except bunch grass (*agropyrum tenerum*) and a few single trees, with stunted bushes. Systems of irrigation have therefore been established by bringing the small mountain streams on to these tracts. The water of the river, running at the bottom of a somewhat deep gorge, is not available; so the smaller streams and lakes of the adjacent mountains are used as the sources of supply, in some instances supplemented by artificial lakes or storage reservoirs. The water is carried on to the land by small rudely-constructed ditches, built almost entirely by the farmers who occupy the land.

The Black Canon of the Thompson River is a narrow gorge about 1 mile in length, where the river has cut its way through an uplifted ridge of black shale, which was raised in the bottom and parallel with the course of the valley. On its eastern side there are two hard sandstone points next to the river. The railway passes through one of these by a short tunnel, and through the northerly one by an open cutting, exposing the greenish hard sandstone rock and the position and dip of the overlying shale. The two greatest slides are situated, one north, the other south of these points, Fig. 3, Plate 1. At both places the country originally sloped up from the river in a series of benches or terraces to the first line of hills. The south slide has an extreme length of 1,880 feet along the railway, and an extreme width back from the river of 1,575 feet. It is of somewhat irregular form, with a semi-circular outline at the back, and covers an area of 66 acres. The north slide has a maximum width at its widest portion of nearly $\frac{1}{2}$ mile, and a length back from the river approaching $\frac{3}{4}$ mile, with the same semi-circular back line. It is of irregular form, and extends over an area of 155 acres. The height of the first bench next to the river, in both cases, was originally about

¹ "British Columbia: its Present Resources and Future Possibilities," published by direction of the Provincial Government at Victoria, B.C.

80 feet above low-water level. The land then rose in successive levels to a height, on the south slide, of 400 feet to the bench at the top, or back edge, where the cave-down broke off the solid ground, and in the case of the north slide it extended to the third higher bench 500 feet above the river. It is impossible to ascertain at what depth these enormous masses of earth and loose rock broke, or in other words, the depth of the plane on which the mass moved towards the river; but it is estimated that at the back edge of the south slide the break fell almost vertically for a distance of over 300 feet, and on the north slide perhaps over 400 feet.

The terraces on each side of the valley of the Thompson River along this section consist of the soil on the top of each bench of light sandy loam to the depth of between 1 foot and 8 feet. Below, in places, is found between 3 feet and 10 feet of clean coarse river sand. Next occurs loose and nearly clean stratified gravel and boulders, and below this a partially cemented gravel with larger boulders. The material which holds together the gravel and stones of this formation is boulder clay, a porous arenaceous clay silt, through which water passes freely, yet which, in a dry state will stand in vertical walls to a considerable height. It extends to a greater depth on the higher terraces; in places it is perhaps 500 feet deep. The boulder clay is here found in two forms: in its original form as first laid down, and, especially upon the lower benches next to the river, in a secondary or re-arranged form. Under the lower benches, particularly under the slips, there is a deposit of silt or imperfect clay, which shows in places to a depth of between 50 feet and 200 feet. It is the same silt that forms and binds the boulder clay, but is entirely free from gravel or boulders. These have been named the white silt deposits. "They are generally fine and uniform in texture, and are usually well bedded in perfectly horizontal layers from $\frac{1}{4}$ inch to 4 inches in thickness," with occasional sandy seams and small pockets of coarse sand, formed locally, appearing in places.

By the continued application of large quantities of irrigation water upon the cultivated fields above, and upon the upper portions of what are now the slides, almost the entire surplus not absorbed by the plants or evaporated, sank down freely through the loose soil, sand and gravel; and while not as readily, yet with considerable ease, through the boulder clay, and reached the underlying silt. After some years this water saturated the argillaceous silt and converted it into the form of river mud of about the consistency of thick pea-soup. Long before the whole mass, or even

a very large part of it, reached a state of perfect saturation, the silt would lose its power of sustaining weight. In the two places here referred to, on account of the peculiar topographical and geological contour of the country, the water applied at the back was concentrated, comparatively speaking, into one channel of descent (in each place) to the body of silt below, and thence it penetrated in every direction. The process of saturation required many years to produce any results, for if a considerable quantity of the silt had become saturated to the point at which it would lose all cohesion, it would not move, on account of there being so great a distance to any point of outlet, together with the self-supporting power of the boulder clay in its confined position, which was nearly all absolutely dry over the slip; hence a large extent of the underlying silt became more or less saturated before it could find an outlet in any direction, even with a considerable weight upon it in its more or less semi-liquid state. Finally, when a large body of the silt had become saturated to such an extent that it could not sustain even its own weight, except in its confined position, and the limit of resistance, possibly in the form of an arch, of the boulder clay had been reached, the great mass of earth and boulders above—in the case of the south slide, estimated as weighing some 32,000,000 tons, and of the north slide approaching 100,000,000 tons—the whole mass dropped almost vertically, while the immense tracts of broken and mixed material seeking an outlet forced their lower sides out on the line of least resistance and found their way into the river. This action is distinctly shown by the almost vertical walls in the boulder clay along the outline of these two slides. While at their foot there is now a talus slope of crumbled material, these walls stand vertically to a height of between 50 feet and 200 feet, more clearly shown in the north slide, where the vertical cliffs of boulder clay, and in places of the silt itself, extend round the whole slide for a distance of over $1\frac{1}{2}$ mile. It is also shown by the present position of large sections of the original surface of the highest bench, which broke off at the line of the back wall, and which now stand in the sunken mass at an angle of about 45° , with their former level surfaces tilted back away from the river. The back edge thus dropped first and lower than the portion some distance in front of it. In dropping and pushing out towards the river, the whole tract was broken into sections by great cracks, which still exist. The larger cracks run parallel with the river and at right-angles to the line of movement, while other and smaller cracks run in

every direction, cutting the whole into blocks of boulder clay and dry silt.

Both these larger slides, together with some others of the kind, occurred before the railway was built. Others have also occurred in entirely new places since that time. On the land above the south slide (and on most of the others also) irrigation has continued since the railway has been working, and this has kept up a continual movement of the south slide, with a number of others, towards the river. This movement is much more marked for 500 feet or 600 feet in the centre of the slide, where the water seems now to be concentrated. Thus the railway is being continually pushed out into the river. At times the road-bed has sunk 4 feet and has moved out twice that distance in a night, so that a constant rebuilding of the line has been necessary for the last 10 years. The movement is continuous, though it is greatest in the months of July, August and September. An extra force of section men, watchmen, construction trains, &c., are continually required on this section. At the south slide alone over £10,000 has been spent on such work. This section of 5 miles or 6 miles of slides has cost the Canadian Pacific Railway Company directly and indirectly £100,000, in keeping up a safe road-bed, and in other necessary expenses. At one point a train-load of tea was thrown into the river, and completely lost, by the sudden movement of a portion of the road-bed, caused by an extra amount of water being put upon an already saturated field. The most careful guard by extra watchmen is kept on this part of the road, and trains run over it at only 6 miles an hour. A few years ago, after the watchmen had passed over the line, and an east-bound train had also passed over it in safety, a west-bound train came suddenly upon a section of the line sunken out of sight. The train fell into the river and the engine-driver was killed. This also was caused by the excessive irrigation of a small field above the line.

The great north slide happened in October, 1881. Irrigation had been carried on above it for some years, and some time before the final catastrophe occurred, a reservoir 2 miles distant in the hills from which the irrigation water came, broke its dam, and most of the water liberated spread over the upper benches of this land, already well soaked. The whole tract of 150 acres sank vertically in one movement to a depth, at the back edge, of over 400 feet. The lower portion, about 2,000 feet wide, was forced entirely across the river, a distance of 800 feet to 1,000 feet; and coming against the steep bluff on the opposite side, it filled

the whole inner gorge of the valley, and formed a dam fully 160 feet high, completely stopping the flow of the river for several days, so that men walked dry-shod across the river-bed below the dam. The Thompson River carries in the autumn 15,000 cubic feet to 20,000 cubic feet of water per second. The dam formed a lake over 12 miles in length, which is roughly estimated to have contained 7,000 million cubic feet of water, Fig. 2, Plate 1. As soon as the water rose above this dam of loose broken material it was swept away, and caused a terrific flood in the valley below.

All the arable land above the north slide was carried down by the first break, and hence irrigation was stopped at that point. After some years the water drained out so completely that the movement practically ceased and the land became again stable. The railway crosses this slide 500 feet or 600 feet back from the river, and since the water has drained out, little trouble has been experienced, for the land has settled firm and dry. At the south slide, irrigation being maintained, there has been a continuous movement ever since the railway was built across it. The central portion has advanced toward the river about 800 feet since it first fell. As the material is forced forward the river washes it away, a new road-bed is built further back, and the line is moved inland to it. This new bed gradually sinks and moves forward, and the line must be continuously raised and moved in, to keep a safe passage across the broken and moving ground. Such work is in progress to a greater or less extent over the whole series of some 5 miles or 6 miles of slide. The expense and difficulty are so great that, to use the words of the general superintendent of the road, it has become "almost impossible to work the railway."

At Spence's Bridge, some miles down the river, a slide occurred from the same cause on the west side of the river. It crossed entirely over the stream and deposited a number of acres of land on the east side of a bench 25 feet above the river, between it and the railway, covering an Indian burying-ground.

At one time the tract of land on which the town of Ashcroft now stands began to move towards the river. The Dominion Government bought out the farmers who were irrigating above the town; the irrigation ceasing, the movement soon stopped, and the town has since remained in the position it then occupied.

Physical Geography.—The Province of British Columbia, extending from lat. 49° N. to lat. 60° N., forms the northern extension of the Rocky Mountain region of North America. The two principal

mountain systems are the Rocky Mountains proper and the Coast Ranges. These form the north-eastern and south-western boundaries of an interior section of the province. "Between these two limiting systems are found, on the side next to the Rocky Mountains, several less regular though often equally lofty mountain ranges, which may be collectively referred to under the name of the Gold Ranges, being west of the Selkirk Range, and between these and the inner margin of the Coast Ranges lies the region called the Interior Plateau."¹

The Interior Plateau, across the southern part of British Columbia, is nearly 200 miles wide. It has an average width of about 100 miles, with a length from south-east to north-west of about 500 miles. The general level declines towards the north and west, having an average elevation in its southern portions of 4,500 feet, sinking as stated to the north-west to a much lower level, and having an average height above the sea of about 3,500 feet. Only in contrast to the lofty and rugged mountains which border it, can this interior region be properly called a plateau. "More carefully examined, it is found to consist, particularly in its southern part, of numerous blocks of plateau-like contour, separated by important depressions, and differing considerably in their actual elevations. But there is every reason to believe that, in the early Tertiary period, the area of the interior plateau had become reduced by prolonged denudation to the condition of the nearly uniform plain. . . . Though never absolutely flat, the surface of the country thus became an approximate plain or what is called a 'peneplane.' It appears further that the peneplane at this time formed has never since been entirely obliterated, although it has passed through several stages of elevation and depression, and has been subjected to more or less deformation due to earth-movements. At certain periods it has been an area of deposition of strata, and the theatre of great volcanic eruptions. At times the natural forces of waste have been engaged in reducing the superadded irregularities toward the old plain; but during the latter part of the Pliocene Tertiary period, with the country standing at an elevation higher relatively to the sea than at present, the greatest erosive changes, tending to the destruction of the ancient plateau, occurred. At this time the great valleys by which the interior plateau is now conspicuously trenched—those of the Fraser River, the Thompson

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¹ "Geological Survey of Canada," vol. vii. part B. Annual Report, G. M. Dawson, C.M.G., LL.D., F.R.S., Director.

River and their main tributaries—were cut.”¹ Thus, considering its origin and former condition, the present appearance of this interior plateau, when seen from a sufficient elevation, is that of a number of high plateau areas, which run together everywhere in the distance, shutting out from view the great lower valleys; and while these areas differ considerably in elevation, they do not so differ materially as between adjacent parts. Even with the more marked irregularities on its west or south-western side, this interior section may be considered in general as a plateau, and particularly as a country peculiar to itself, not only as to its origin and partial present form; but also with reference to its general climatic characteristics, its vegetation, rainfall, &c.

Climatic Conditions.—Situating with its western border within 100 miles of the Pacific coast, where the rainfall at Vancouver attains 62 inches, and at other points even exceeds 150 inches per annum, the average rainfall of the larger part of the interior plateau is only 6 inches to 12 inches per annum. The Coast Ranges form an almost complete barrier between the Pacific and the inner country, so that the moisture-bearing winds from the ocean become desiccated before they reach the latter region. “A study of these conditions will show how it happens that the lower valleys and those nearest the Coast Ranges form the most arid part of the district, while the humidity of many of the higher parts of the plateau, particularly those situated to the eastward, is at the same time still considerable, enabling them to be the sources of perennial streams which may be employed in the irrigation of the lower and drier tracts.” The climate of many parts of this section seems out of relation to the geographical position of this far-north country. It is largely governed by the close proximity of these mountain ranges. The difference of temperature during the year, and even during the day, is very great. In the valley of the Thompson River it ranges from 120° in the summer to, at times, 50° below zero in winter.

Larger portions of the higher hills and valleys are covered with dense forests, including among their trees the black pine (*Pinus Murrayana*), white spruce (*Picea Engelmanni*), Douglas fir (*Pseudotsuga Douglasii*), and balsam spruce (*Abies subalpina*). The mountains range between 8,000 feet and 9,000 feet in height. The timber limit is about 7,000 feet. Below this, for some distance, the hills and valleys are but sparsely wooded on account of the extreme depth and long duration of the winter snows.

¹ “Geological Survey of Canada.” Annual Reports, vol. vii. part B.

Below the denser forests, the valleys are but partially covered with trees, for the opposite reason—the want of sufficient moisture; while the lower and larger valleys, up to an elevation of about 3,000 feet, are almost entirely devoid of trees on account of the extreme dryness of the climate. The lower valleys with their slopes and terraces only produce naturally a few shrubs and grasses, the most abundant being the bunch grass (*Agropyrum tenerum*).

Geological Formation.—The geological formation of the section within which the land-slides have occurred embraces the cretaceous formation of the Ashcroft area, and the triassic formation lying immediately south of that, with a small portion of the carboniferous formation lying still further south. In considering the real nature and causes of the slides, the solid geology does not have so important a bearing on the matter as the present position and condition of the superficial or drift deposits due to the glaciers, which now partially cover, and at one time largely covered, the interior country. In the case, however, of the two largest slides at the Black Cañon, which have already been described, the underlying rocks (at that point cretaceous) are important in establishing a correct estimate of these causes.

The Glacial Drift.—The most important and extensive deposits of drift are the boulder clay and the white silts. The former, which in many places resembles a partially cemented gravel, consists of a paste of hard sandy clay silt, with a large amount of sand or coarser silt; through it, in close proximity to one another, gravel, stone and boulders are found, from the finest pebbles up to boulders between 2 feet and 3 feet in diameter. Some are glacial, marked and polished, but the larger part are shaped by ordinary water action. The stones and boulders in places have come from one locality, and in others they are of varied origin. It is impossible to give the general thickness of this deposit, though it is evident that in some low portions, and in the valleys, it attains considerable thickness, and, on the other hand, that the higher parts of the districts were never covered with this deposit. The greater part of the boulder clay deposited in the larger valleys was removed at a later period by denudation. The white silts were deposited at a subsequent time. They reached an extreme elevation of 2,500 feet above the present sea-level, while the highest levels of separate deposits of these silts are found at other distinct levels, in different localities, down to 1,700 feet, showing possibly an uplifting of parts of the country during their depression. The extent of this silt deposit was

at first very great, but much of it has been removed, as was the case with the boulder clay, by denudation.

The western part of Canada was covered by the great Cordilleean glacier,¹ which attained a maximum length of nearly 1,200 miles, and over the higher tracts of the interior plateau of British Columbia reached a general thickness of between 2,000 feet and 3,000 feet, while in the main river valleys (cut out during the Pliocene Tertiary period) it must have been 6,000 feet in thickness. During the maximum of this glacier, the whole region stood at a much higher elevation than at present. Eventually there came a subsidence of the mountain region, and a retreat of the Cordilleean glacier. During the retreat of the great ice-sheet lakes were probably formed on its surface, which increased in size as the subsidence progressed, and after their final drainage, and the further retreat of the great glacier, the interior plateau was covered by gradually deepening waters which were connected with the ocean. It was during this retreat that the boulder clay of this section is supposed to have been formed. The next great change was a re-elevation of the whole territory and the forming of the higher terraces of British Columbia. During this elevation much, and in some parts all, of the boulder clay deposit was washed out of the larger river valleys, such as those of the Thompson and Fraser, as the rivers for a second time cut a channel for the waters draining from the lakes and glaciers, and pouring out into the ocean now below their level. Later, in consequence of this elevation, the country was again covered to a considerable extent by glaciers, though these were local in character. Then occurred a second subsidence, less than the first, but which lowered the level of the region about 2,500 feet below the present one. At this time, with glaciers of considerable size occupying the mountain valleys, the land remained nearly stationary for a long interval, and remarkable and important silt deposits, well bedded and of considerable thickness, were tranquilly laid down in different low tracts, scattered along the Cordilleean region for a length of some 1,200 miles. These have been termed the white silts. The final retreat of the glaciers was not connected with subsidence, but was either during, or soon followed by, a general elevation of the region, and is supposed to have been chiefly due to a general amelioration of the climate, the cause of which does not seem clear. Following this elevation the present large rivers cut for a third time a channel for themselves, this time principally in the white

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¹ G. M. Dawson.

silts, which had been deposited in their gorges and over the remaining boulder clay. In some places the silt has been completely washed out of the original gorges, while in others it still covers the whole floor of the valley. In most places it remains only on the sides of the valleys, and stands in terraces along and far above the river. These terraces of silt, next to the large rivers, in places stand to a considerable height with only a thin soil above them. Others farther back are covered by a heavy deposit of re-arranged or secondary boulder clay, and again, still further up, are found large sections of silt over the original deposit of boulder clay, these in turn being covered by the secondary, re-arranged boulder clay.

Local Conditions.—The various actions during the glacial periods, as related above, are almost entirely responsible for the condition of that portion of the Thompson River valley in the neighbourhood of the Black Cañon. The great gorge cut during the Pliocene Tertiary was at first filled by the boulder clay. This is found at the elevation of nearly 2,000 feet above the present river, and is shown in cuts of the railway close to the water. When the river cut its channel through the boulder clay, large masses of this material were left on the east side of the river, both above and below the Black Cañon. The boulder clay here found is of two kinds. The first deposit as first laid down, and the secondary or re-arranged deposit as formed from the original by the action of the river at its various heights, and also by the submersion and re-elevation during the laying down of the white silts.

From a careful examination of this section it would seem that possibly the ancient pliocene river ran, when at its lowest levels, to the east of the present Black Cañon, and east of the two prominent points noted above, and that, when cutting its second channel through the boulder clay, the current was thrown to the west, cutting its way through the shattered shales west of the two higher and hard sandstone points, leaving a great mass of boulder clay to the east or back of them. This action of the river would form, both north and south of the Black Cañon, great bays washed out from the boulder clay. These bays were subsequently filled with silt, and the river, cutting its third channel through the silt, followed in a more direct line to and from the Black Cañon. These are the conditions found at these two points, great bays of white silt extending in the case of the south slide, 1,600 feet back from the river into the original mass of boulder clay, and covered by the loose gravel and secondary or re-arranged boulder clay. In the case of the north slide, this

bay of silt extends back nearly $\frac{3}{4}$ mile, while no silt, at low elevations, is found at all across the whole section of the valley at the point between them, that is, east of the Black Cañon tunnel. The silt deposit in these two bays accounts clearly for the peculiar form and action of these two great slides, and for the immense vertical drop in each case.

While the white silts were being deposited, there was much re-arrangement of the boulder clay. At two points, one on the south side of the north slide, and the other on an exposed section of Nelson's Creek, are found deposits of silt on the original boulder clay of the higher benches, and entirely separated from the larger masses of silt below, and also covered to a considerable depth with the re-arranged boulder clay during the latest elevation of the territory.

CAUSES OF THE SLIDES.

I. Natural Precipitation upon the Lands in and around the Slides themselves.—The natural precipitation upon these lands would not exceed 6 inches per annum, and could have no effect upon the clay or silt lying between 100 feet and 400 feet below the surface of the higher benches. Even thousands of years of such precipitation could not reach the underlying stratum of silt. On a nearly level plain, a few miles north-west of the city of Denver, in the State of Colorado, where the surface drainage was not nearly so perfect as on the benches of the Thompson River, and where the precipitation is much greater than at that point, in sinking a shaft through fine sandy soil for the purpose of opening up a coal mine, it was found that for some 50 feet down to the rock the soil was absolutely dry and flew into dust and floated in the air when struck with a pick.

Natural Surface Drainage from the Watershed above the Land.—Barns's Creek and Nelson's Creek, together with the depression between them in which lie the natural lake and artificial reservoir, designated in Fig. 4, Plate 1, Barnes Lake, cut the tracts off completely from the mountain region to the east. On the slopes above and immediately east of the north branch of Nelson's Creek springs show upon the surface above a ledge of bed rock running north and south near to the surface—and at some points exposed—along the ridge next east of the creek. No such springs or any evidence of drainage water show to the west of this north branch of Nelson's Creek. This north

branch, which is cut deep into the gravel and rock, and also a smaller drainage system which abuts against and runs directly north from the source of this same north branch of Nelson's Creek, are, even in the driest season, as continual running streams, in places on clean rock. These natural drainage systems carry off all surface water from the mountain water-shed, and also any that may flow through the soil from the springs above, and being thus cut off it would in no way affect the lands lying below and to the west of these drainage channels.

Natural Drainage by Subterranean Streams.—(Fig. 4, Plate 1.) "This (Ashcroft) area is about 4 miles in average width, with a length of about 11 miles, and for the greater portion of this length the Thompson River follows its axial line. . . . No fossils have been found in any part of this area, but its lithological identity with the cretaceous formation of adjacent parts of the Fraser valley is sufficient to fix its cretaceous age. The rocks consist of sandstones, conglomerates, and dark shales, the shales here apparently predominating in the upper part of the series, and occupying in the main the central part of the area, while the sandstones and conglomerates are more abundant and characteristic in the lower parts. . . . The sandstones are usually greenish or greenish grey in colour, being largely composed of debris of the underlying diabases and felspathic rocks, and seldom or never purely siliceous. . . . The shales are blackish, and their sombre outcrop along the Thompson has given its name to the Black Cañon. . . . The rocks are nearly everywhere much disturbed and crushed, and no satisfactory general section has been obtained of them. Nearly all of the observed dips are to the westward, but as a rule those on the eastern side of the middle line of the area are comparatively low, ranging from 10° to 40° , while those on the western side are often at angles of 60° and from that to vertical. It is probable that the structure of the area as a whole is that of a syncline, of which the western limb has been more or less completely overturned by pressure acting from the west."¹ One of these minor folds is the black shale ridge through which the Thompson River has cut its way and has formed the Black Cañon. This fold here lies on the eastern limb of the general syncline, its trend being north and south, and having its anticlinal axis on the east side of the river and just east of the railroad tunnel and cutting. This shale ridge is somewhat over 1 mile in length

¹ "Geological Survey of Canada," Annual Report, part B, vol. vii. pp. 154 and 155.

where the river is cut through it. Its abrupt termination is shown at both ends on the west side of the cañon where its wall terminates abruptly in the boulder-clay deposit, and for that distance and to the height of 100 feet and more is composed entirely of black shale, dipping abruptly to the west, and at an angle much greater than the general dip of the eastern limb of the main syncline.

On the east side of the river, and forming the eastern side or wall of this little cañon are two lesser folds of this one "minor fold." The anticlinal axis of one is at the point through which the tunnel runs and the other at the centre of the open cutting just north of the tunnel. The direction of these axes are nearly east and west. The hard greenish sandstone rock under the black shale is raised and exposed in the tunnel, and cut some 50 feet above the railway line, and in both cases it terminates abruptly close to the eastern wall of the cañon. On the top of these points is a stratum, 20 feet to 30 feet thick, of the black shale (on the wall of the cañon the shale shows over 100 feet thick), dipping over the points very abruptly into the river, and folding down north and south round these points, with also some dips showing as inclined to the east away from the river.

These facts and the additional evidence that immediately east of the tunnel (Fig. 3, Plate 1) is the break of the south slide and east of the open cutting is the break of the north slide, and several hundred feet below the top level of these two elevated points no rock appears, but simply a mass of boulder clay and silt, led the Author to conclude that it is most likely that the ancient pliocene river ran, when at its lowest levels, to the east of the present Black Cañon, and east of the two points here described, and that when cutting its second channel through the boulder clay, the current was thrown to the west, cutting its way through the shattered shales, and leaving such a mass of boulder clay as is formed east of the cañon. This ancient channel was but a short distance east of the cañon, for on this cross-section east of the two slides, about 1 mile from the river, the rocks are exposed in place and dipping again to the west.

The fact that the rocks are nearly everywhere much disturbed and crushed; the numerous indications of faulting; the volcanic nature of many parts of the section, these volcanic rocks showing both north and south of this point; the minor and lesser folds in the immediate neighbourhood, with a possible older and lower channel of the river, in which the great masses of silt and boulder

clay which compose these two slides were deposited, and from which channel there would be an outlet lower down into the present river, would seem to entirely set aside any possibility of underground streams upon or in the seams of the rock reaching the silt and causing the slides in the manner in which they occurred. Leaving out of consideration any possible older or lower eastern channel, it cannot be assumed that at the two particular places where the slides occur the underlying rock strata are uniformly inclined and unbroken, and that over them or through their seams the water reached the silts and caused the slides; for it must be at once asked why this action did not occur centuries ago.

Effect of Surface-Streams Running by the Land.—This effect is intimately connected with the questions coming under the fifth and last division of the subject, and can only be partially treated as a separate item. Two streams—Nelson's Creek and the Thompson River—run by, and come in partial contact with, the south slide. In the case of the former, the present stream runs in a deep gulch, partly (the north branch) in a trench cut down through the boulder clay, where the banks stand in nearly vertical walls, and further down the stream it flows on clean bedrock, and still lower over a bed formed on the debris of the boulder clay and silt. Even in the driest season this is a continual running stream fed by springs. At its upper end on the north branch, these springs come in from the east side, while the west side is absolutely dry. In its lower section they come in from both sides, but more especially from the irrigated land, which is much higher than the bed of the stream, as there is a section of unbroken land lying between Nelson's Creek and the slide itself, the only way this stream could affect, or could have been the cause, or partial cause of the slide, would be by soaking through this mass and into the underlying silt. By two careful measurements of the water flowing in this stream, made in November, 1896, one being at a little fall on bedrock above the slide, and the other at the railway bridge, just before the creek enters the river, it was shown that there was 18·6 per cent. more water running in the stream at the lower point of measurement than at the upper, these points being about 1 mile apart; and further, that 90 per cent. of this increase came from the side next to the slide and from under the present irrigated fields—a result entirely opposite from what would occur if this stream were supplying the water to flow into the slide and thus keeping up the present action. It was also shown that at least 95 per cent.

of the water running into Nelson's Creek during that dry season was irrigation water from the upper fields, and that the surplus water applied upon the fields and orchards to the east of the north branch did not to any extent sweep down under the creek, but came out into the stream and was thus carried to the river.

The Thompson River flows along and against the foot or toe of all the slides, and in their present condition, that of a broken and moving mass, gradually pushing their way into the river, has a more or less marked effect upon them. At the south slide, especially during high water, the action of the river is most marked. The condition of the material, as described above, cut in every direction by huge cracks and being forced into the stream in detached and broken blocks of boulder clay and dry silt, invites the water to enter the cracks and seams. Thus getting in behind and around these blocks it readily melts the argillaceous silt, and the rapid current washes the material away. The river, even during high water, carries away only that portion that is delivered to it in this crushed condition by the force of the continually moving slide. It would be impossible, within any reasonable limit, to place any protection from the river upon the toe of this slide. The force from the millions of tons above is practically irresistible.

That the river, running as it does at the foot of these slides, has in no degree been the original cause of any one of them is clearly shown by the fact that there are hundreds of places close by and between the several slides, and at other points, where the banks of the river are walls of boulder clay and even of the clean unprotected silt, which stand in almost, and in some cases in actual, vertical cliffs between 10 feet and 100 feet in height, against which the river has run for many centuries without any material effect, and in no case causing slides where no irrigation has been done above them (in places small cave-downs have occurred); while, on the other hand, in every instance along the Thompson (and in other sections also) where irrigation has been practised above such a formation of boulder clay and silt, after a few years of application of the water more or less great land-slides have occurred.

Artificial Irrigation of the Lands Upon and Above the Slides.—By the testimony of Indians who had lived in the country all their lives and that of some of the original white settlers, no slides had ever occurred at any point along the Thompson River before the white men began to irrigate the land, although one or two small cave-downs existed before that time. In every instance noted, these

slides occurred between 3 years and 6 years after irrigation began at each point. In the case of the largest one, the great north slide, the final catastrophe was hastened by the bursting of the reservoir. A very large amount of water was necessary for raising crops, on account of the sandy nature of the soil and the nature of the subsoil. The topography of the several benches assisted materially toward the final result. Each field being in the form of a shallow basin, around which the irrigation ditches were built, little of the surplus water was drained off, hence the greater part of that not taken up by the plants or evaporation, ran towards the centre of the field and soaked down in one channel.

As to the action of the water upon the peculiar masses of silt which at present underlie the benches and terraces along the Thompson River, a number of curious facts were noted in and around the south slide, which at first seemed most difficult to explain. The silt or imperfect clay, which lies in masses between 200 feet and 1,000 feet in thickness, is generally fine and of uniform texture, and usually well bedded in horizontal layers of from $\frac{1}{4}$ inch to 3 inches or 4 inches thick. In its natural state it is hard and dry, like a soft sandstone, and, when held between the fingers and struck with a light hammer, rings like stone. A large piece of this silt, however, placed in a basin of water dissolves after a few minutes and falls down, not in a lump as clay, but it mingles with the water, forming a semi-fluid mass like thick pea-soup. The same soft mixture was observed oozing out at many points along the foot of the slide, forced out by pressure from above; so the question arose, how it was that this silt stood in vertical walls between 10 feet and 100 feet in height along the Thompson River and Nelson Creek, with the waters of these streams running along and against their base, and at high water some distance up them, and yet they had stood for ages, and were but little injured, except by slight atmospheric disintegration?

The silt is formed of three parts—silica in the form of coarse and fine sand, and alumina in two forms, first disintegrated felspar, simply mechanically separated into grains, both coarse and fine also in the form of sand, and constituting a large part of the mass, and second, decomposed felspar or plastic clay. Under the action of running water, the sand, both the silica and the disintegrated felspar, is washed out, while the decomposed felspar is precipitated, and forms a coating of true plastic clay upon the mass, which soon becomes impervious to the water and is practically indestructible, thus protecting the underlying silt from further action of the

water. The result of a chemical examination of the material will be found in an Appendix. Mr. Warsap, the analyst, also suggests the chemical action and assistance of the carbonic acid of the atmosphere and ammonia, if present in the clay and the lime, in forming this impervious coating. The mechanical action of separation and precipitation noted above accounts for all the peculiar phenomena observed at every point in and around the slides.

The great quantity of irrigation water soaked downwards into the mass of silt. It would absorb 53 per cent. of water without changing its form, yet with only about 35 per cent. it would be incapable of sustaining any great weight except in its confined position. After the final breakdown, and its release into the river with the continual application of water, and still being under pressure, this semi-liquid silt, containing all its original constituents, is forced out at the foot of the slide in great quantities. If a man steps on this ooze he is liable to sink into it, while within only a few feet of such a spot lay, when examined by the Author, a large block of the same silt which had fallen over into the river in a dry state, and over which the last season's high water had run; it stood up 3 feet or 4 feet above the level of the river beach, and the Author walked and jumped upon it without making any impression. Breaking off a piece of this block, it was found that, less than 1 inch under the surface, the silt was in its original form, and easily dissolved in water. In the river, under low water, were also observed great masses of this silt which had fallen over into the river in blocks, over the surface of which the river had run for years without carrying them away. On the other hand, the backwater in an eddy soaking through the cracks and getting behind and around other blocks completely dissolved them, and the river carried them away.

The bed of the lower section of Nelson's Creek, a rapid stream, is formed of this precipitated plastic clay, which prevents any water soaking out of it into the slide. But more noted than these instances is the fact that, on the walls of the gorges, the Thompson River and Nelson's Creek, which in many places are composed of this same silt, is found the same coating of plastic clay and lime—an imperfect cement—formed by the action of the running water. Thus these walls have stood almost vertically (in one place 100 feet high) for ages, withstanding almost entirely the cutting effect of the highest freshets. It is true that these banks of silt gradually disintegrate by atmospheric action upon them, and in the dry season the scale of plastic clay becomes

baked and drops off; but as soon as the stream rises by its assistance, Nature immediately erects a new bulwark against its ravages.

There is no way of preventing the continual disastrous effects of these land-slides upon the railway except by cutting off the irrigation water above. This has been and can be made effectual. The water so easily absorbed as easily drains out, and the mass after a time again becomes firm and solid.

The Paper is accompanied by three tracings, from which Plate 1 has been prepared.

APPENDIX.

Vancouver, B.C., Nov. 14th, 1896.

Mr. ROBERT B. STANTON, M.A

DEAR SIR—The clay, or silt, you handed me for examination absorbs 53·5 per cent. (of its volume) of water without losing its form, and, after absorbing 78·5 per cent., it frets down and mingles with the water.

I have compared it with clay from Warnock, B.C., which takes 49 per cent. and 70·5 per cent. When the clay, or silt, you handed me has absorbed 78·5 per cent. of water, it seems to mingle with the water, whereas the Warnock clay drops into a square heap and remains there. The following analyses of this and other clays are given for comparison.

Yours truly,

H. J. WARSAP,
Chemist.

ANALYSES OF SILT AND CLAYS.

	Silt from South Slide, Black Cañon.	White China Clay or Kaolin.	Warnock, B.C., Blue Clay.	Average English Blue Clay.
Silica (SiO_2)	26·75	46·8	60·05	63·35
Alumina (Al_2O_3), and Iron (Fe_2O_3) }	56·60	37·7	31·08	18·50
Total Sulphur (SO_3) . . .	6·8	..	1·02	4·32
Lime (CaO)	3·24	..	6·25	6·60
Water loss	6·61	15·5	1·60	7·23

[DISCUSSION.

Fig: 2.

Fig: 3..

Fig: 4.