and carried it out harmlessly. That was twenty-five years ago, and he believed the bank was now as safe as could be desired. Colonel Pennycuick.

Sir JOHN WOLFE BARRY, President, thought some idea of the cross-section could be formed from a passage of the letter-press in the Paper, which stated that the bluff, where the break-off took place, farthest from the railway appeared to have been about 400 feet in depth, so that it might be imagined a considerable cliff had there been formed to begin with. Sir John Wolfe Barry.

Correspondence.

Mr. JAMES R. BELL had had occasion to study the problem dealt with by the Author on a no less gigantic scale at the Mud-Gorge slips in Beluchistan, where in early geologic times a dam of solid limestone rock some 2,000 feet high must have upheld a lake of mud some 10 miles long and 3 miles or 4 miles wide. How far the sides of that lake squeezed together and pressed up the centre of the clay lake hundreds of feet above the dam, or in what other way the clays were upheaved above their original level, their crests on either side of the valley were now far higher than that of the Chappar Mountain which formed the dam. The dam had not failed as a whole, but it had seemingly had a tunnel bored through it by (probably thermal) springs, and the roof of the tunnel falling in while the bed scoured deeper and deeper, the mountain was now cleft in twain by the famous Chappar rift, one of the most remarkable cañons yet encountered by any railway. The present Mud-Gorge Valley had been formed in the clay by the action of a small stream, which had carried away the mud from its bed through the rift. The bed of this stream was alternately raised locally when squeezed up by slips and lowered by cataract-like retrogression of the river-levels. Here and there narrow strips of level "bottom" occurred beside the river, but for the most part its banks conjugated every tense and mood of the verb "to slip" except the past pluperfect. The valley was now about 3,000 feet deep and about 3 miles wide; and beyond the fact that in a recent sequence of droughty years there had been less trouble than in average rainfall, there was no reliable indication of amelioration. The case might admit of remedies, but such skill as the Government of India had been able to bring to bear on this crux had not yet offered any more promising remedy than to watch the place, and put in deviations of the line as stoppages threatened. It turned Mr. Bell.

Mr. Bell. out (now that the country was getting settled beyond the valleys occupied by the railway) that this part of the Suleiman plateaux teemed with rifts even grander than the Chappar, and doubtless with mud-gorges of corresponding mobility. It was especially noteworthy that both in the Mud-Gorge Valley and in that under consideration the clays contain a considerable proportion of gypsum in crystals, liable to expand when slaked by water, and thus to create "slip-planes" analogous to the greased launching-ways used by ship-builders. Although the railway through the Chappar rift offered grades of 1 in 40, the Government of India, in view of the vast military and political importance of a railway to Quetta, had recently determined to build at great cost an alternative line with ruling gradients of 1 in 25 in another valley, whose paramount advantage consists in its having well-nigh completed its processes of denudation in their more active phases. He alluded to the Mushkaf-Bolan Railway, recently described by Mr. James Ramsay.[1] Compared with Indian experience in a hostile and newly-acquired territory, Mr. Bell was very favourably impressed by the thoroughness of the geological diagnosis, which the Author quoted from Professor G. M. Dawson. He saw little need for the hypothesis that the ancient pliocene river scoured out the beds of the lakes of white silt that now underlay the boulder clay, but that was a mere detail. The Author appeared to consider that it was necessary for water to entirely saturate vast masses of such silts before any motion would occur. On the strength of Mud-Gorge experience, any such extent of hydration as that indicated on p. 4, where the catastrophe was finally attributed to a large body of the silt being saturated till it could not support itself, far less the superposed clay which spanned it like a bridge, seemed quite unnecessary. It was quite clear that at Mud-Gorge the slip did not occur because more or less saturated and semi-liquid silt had found an outlet, but, on the contrary, slurry only found an outlet in consequence of a slip being established. He was far from contesting, in offering this experience, the practical view that water was the proximate cause of all slips, and that buying out the irrigation might effect a material amelioration of the Canadian Pacific Company's difficulties. Indeed, he was only at a loss to conceive the arguments that had seemingly prevailed for years against this treatment and until £100,000 had been spent in remedies of an imperfectly successful class in the teeth of a neighbouring example. Stopping the irrigation would certainly check the

[1] Minutes of Proceedings Inst. C.E., vol. cxxviii. p. 232.

slipping of the valley flank, whether it checked those slips that immediately affected the line or others more remote in the first instance. Mr. Bell.

Mr. H. J. Cambie[1] observed that on p. 5 the Author stated that "at times the road-bed has sunk 4 feet, and has moved out twice that distance in a night." His experience as engineer of the western division of the Canadian Pacific Railway led him to the conclusion that this statement would convey an erroneous impression of the safety of the railway. A movement had occurred in 1894, but it was not nearly so rapid as that described, and no such motion had occurred before or since that time. It was also stated by the Author that "this section of 5 miles or 6 miles . . . has cost the Canadian Pacific Railway £100,000." Such an assertion was not warranted by the evidence, and it was doubtful in his mind if the cost had reached one-fifth of that sum. Again, it was stated that "at one point a train-load of tea was . . . completely lost, by . . . an extra amount of water being put on an already saturated field." No tea-train had been wrecked within 100 miles of the slides referred to, or anywhere on account of irrigation. On the same page the Author stated that "after the watchmen had passed over the line . . . 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." In 1886 a slide occurred which disconnected the line, but no watchman was then kept on that part of the railway. The engine ran a short distance down the bank, and the driver was scalded, but he was still at work on the line. Of the rest of the train, only the front end of one carriage left the metals. He also considered that the Author's statement that "at one time the tract of land on which the town of Ashcroft now stands began to move towards the river" (p. 6) was misleading; it had not, so far as he was aware, shown signs of moving. Mr. Cambie.

Prof. Boyd Dawkins, F.R.S., agreed entirely with the general conclusions of the Author as to the origin of the landslips and the best means to be adopted for preventing their recurrence in the future. It was perfectly clear they had been caused by the access of water to the argillaceous silt underneath the glacial strata which formed the surface. It was equally clear from their having followed the establishment of irrigation works, that they were due to the introduction of water in sufficient quantities to Professor Dawkins.

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[1] This communication was received subsequently to the remainder of the Correspondence, and too late to be placed before the Author for comment or reply.—Sec. Inst. C.E.

Professor Dawkins. soak down into the silt, which naturally was dry and hard, and ultimately to carry it away in the direction of least resistance into the nearest river. Had the natural *régime* not been disturbed there was no reason to suppose they would have occurred, as there were no traces of them in the strata which had not been artificially dealt with. The best way, and in these strata the only way, to stop them was to restore the natural conditions by putting a stop to irrigation in those portions of these strata which commanded the railway. Similar slips, it might be remarked, had from time to time occurred in Great Britain from the access of water to sandy beds resting upon clay, and had been remedied by cutting off the surface water from the beds in question. This was done many years ago in Bath, under the direction of William Smith, father of British geology. The solid geology of the valley of the Thompson River, carboniferous, cretaceous, triassic and other, had nothing to do with the cause of the slips.

Mr. Crowell. Mr. Foster Crowell remarked that artificial disturbances of soil formation were rarely produced upon such a vast scale as in the cases so well described in the Paper; and the occasions were still rarer in which irrigation works might bring about destruction of such magnitude as occurred on the Thompson River. Nevertheless these land-slides formed striking and valuable object lessons to every engineer who had to deal with earthwork, and especially with the location and construction of railroads in new countries. In these cases the ultimate controlling cause was the admixture of water with a formation that was stable only when dry, thereby disturbing the conditions of equilibrium which had been reached in the processes of nature. Other causes might produce similar results in any given mass of soil that was in a state bordering on motion; among such causes were such obvious ones as the excavation of natural support and the imposing of the weight of embankments. He had seen a number of cases wherein the last-mentioned cause had been productive of great and long-continued damage to surrounding interests, which could have been avoided by due attention to the Roman dictum "quieta non movere" on the part of the engineer, either by adopting a change of location or by due precautions in distributing the additional weights. He would quote three instances; one occurred at Point of Rocks, near Brinton, on the Pennsylvania Railroad at the time of the rebuilding under his direction of the line to accommodate four pairs of rails, where formerly there had been but two; the original location had been balanced so that one line was established upon an excavated ledge and the outer one upon embankment, the formation being argillaceous rock with a very steep escarpment; the permanent way was elevated about 70 feet above the foot of the cliff, extending from which were clay bottom lands of Turtle Creek—a sluggish stream which at that point was about 150 feet in width, and was spanned by an iron highway bridge resting upon substantial stone abutments; between the cliff and the stream was a village built along both sides of a single street extending parallel to the direction of the railroad; in building the two additional lines it was found desirable to place them symmetrically with reference to the old centre line and that brought the toe of the new slope, composed of rock from the cutting, close to the backs of the houses which were protected from it by a properly-designed retaining wall of masonry; the only feasible alternative would have been an undesirable tunnel or gallery through the Point of Rocks; soon, but not immediately, after the new embankment and retaining wall were completed complaints were received that houses in the village were being displaced because of them, but check measurements from the centre line proved that no movement had taken place in either the wall or the embankment, and the complaint was for the time dismissed; but there actually was a movement of the houses, on both sides of the street, some of which being of brick were ruined; those of wood were eventually moved back to their former positions; the entire material of the street and of the highway leading at right angles to the bridge, the near abutment of the bridge and the superstructure were all moved laterally several feet; the back wall of the far abutment was broken off above the bridge-seat by the movement of the superstructure, but beyond that no damage was apparent across the stream. Further investigation showed that the additional weight of embankment, acting vertically within its limits, had disturbed the equilibrium of the clay formation, on which a portion of it rested, and the pressure had expended itself in the line of least resistance laterally at a lower elevation than that of the toe of the embankment; the remedy, if it could have been applied in time, would have been to either avoid the overloading or carry the support down to the bottom of the clay. The second instance was that of a high embankment, also on the line of the Pennsylvania Railroad, across a level valley where a lateral movement, similar in its manifestations to that just described, was still active very recently, and had not ceased since the road was constructed, nearly fifty years ago. The third had come under his observation during an examination of the works of the Panama Canal, in 1889, several years after the abandonment of the excavation of the primary Culebra cutting. In Mr. Crowell.

Mr. Crowell. preparation for the disposal of the spoil a series of parallel railways, built on successive benches at the mouth of the cut between Culebra and Paraiso, had been provided; some distance farther on, the line of the Panama Railway crossed the valley at a much lower elevation upon an embankment; comparatively little of the material had been taken out and deposited when the work terminated, but enough had been done to start a gigantic lateral movement in the entire width of the valley that not only wrecked all the extensive system of spoil railways, but displaced and destroyed the Panama Railway itself, so that for years thereafter it was necessary to maintain constantly a large force of section men to restore the line after the passage of every train, as was done at the time of his visit, and under his observation, twice in one day at an interval of rather less than eight hours. He had frequently seen cases of slips of serious nature resulting from unnatural saturation of the soil, though nothing approaching in magnitude those which the Author gave, and he had been the instrument of contributing to the cause of some of them by failure to properly intercept and lead off drainage water, or to take steps to prevent it from concentration in injurious quantities. These were often regarded as needless refinements of construction, except in cases where outside interests were to be considered and protected, but experience showed that no part of the cost of any earthwork was better expended than that judiciously applied to the matter of drainage. The Paper showed forcibly how widespread might be the results of a seemingly trivial agency, and how important it was not to lose sight of the destructive elements in the forces of nature.

Professor Gaudard. Professor JULES GAUDARD, of Lausanne, thought the Paper shed new light on the causes of instability of ground subject to the percolation of water. The slides on the banks of the River Thompson were remarkable for their vast extent, for the fact of their being a result of artificial irrigation, for the length of time which had elapsed between the originating cause and the ultimate effect, and for the continuance of the movement as long as irrigation was carried on, so that the only remedy appeared to be to stop this irrigation, the extent of the slides being too great to be dealt with by drainage. Irrigation, in addition to its direct value for agricultural purposes, frequently formed a safeguard against disastrous effects of flood, as it permitted the retention and storage of at least a portion of the superabundant water, which, if allowed to flow away direct, would become destructive, instead of being gradually dissipated in agriculture and by evaporation. But it might be seen here that, in combating a danger in one direction, the effect might be to bring another into existence, although the original intention was simply to fertilize a district otherwise arid. This danger did not arise from that portion of the water which was actually utilized for agricultural purposes, viz., for the fertilization of the layer of vegetable soil, as the slopes of this layer were not so steep as to be capable of sliding, but was due to the remainder of the volume filtrating into the ground, and, having penetrated the permeable sub-soil, reached a stratum, the character of which was altogether changed by the fluid. It might, however, be easily imagined that it would be difficult to deal effectually with this troublesome and disaster-working waste, for the ideal arrangement for a network of irrigation-channels was that the latter should gradually diminish the supply from its point of origin to the limit of the area affected. Although the extreme ramifications were laid out, as they should be, strictly in proportion to the demand upon them for irrigating the surface-layer of vegetable soil and no more, this did not apply to the channels nearer the point of origin of supply, which served as main ducts, or partially so. The beds of these ducts might, however, be lined with puddled clay. The delayed production of movement of land-slides had been exemplified in other instances. On the railway from Brunoy to Bois-le-Roi, in France, movements had taken place more than 4 years after the excavation of the cutting which had caused them. This might be explained by the extreme slowness of the process of percolation into a porous substratum (at a considerable depth) and without outlet; there it was subject to various influences, such as capillary attraction, &c., besides the action of gravity. This latter was far from being aided by the high pressures exerted by hydrostatic columns in deep fissures in the ground, for, as the liquid reaching the bottom of such a fissure penetrated further, it must open out a space to occupy; it could not do this by heaving up the ground, as its weight was less than that of the latter. The only way for it to penetrate a dry soil was by expelling the air in bubbles; but, in addition to the fact that the ascent of these bubbles became the more difficult in proportion to the distance they had to traverse, which was constantly increasing with the advance of percolation, the pressure itself diminished their volume and, consequently, their ascensional power of escaping through the liquid. Thus the pressure of a column of water, which acted so powerfully in detaching solid masses, imperfectly connected, seemed to have but little effect in accelerating infiltration in the depths of the earth; it was evident that it was not until more or less relative displacement of the component parts of the mass, pro- Professor Gaudard.

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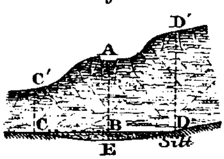
ducing disintegration, &c., took place, that the water could penetrate further and the process of infiltration became more and more advanced. On the other hand, although the flow was so imperceptibly small, it was also unceasing; and the small supply necessary kept it constantly in progress, and the water being unchanged, and practically immovable in the subterranean interstices, it had the effect of reducing the silt to slurry without removing any of its constituent elements. A soil with an inclined surface could only keep its form by the power of cohesion; all moisture, although it might be only partial, penetrating deeply into it had an inevitable tendency to reduce it to the level. Let it be supposed that from a ditch A, *Fig. 6*, there descended, through a permeable soil, filtration following the line A B, which at B reached a deposit of silt; there it spread out in all directions over the surface C D, and liquefied the silt to some depth, formed a semi-fluid layer or pocket C B D E, and consequently produced a change in the general conditions of equilibrium. On account of its incompressibility, a confined liquid was able to support a uniform load, whatever might be the pressure, but as it had lost its cohesion and frictional resistance, it had become incapable of sustaining an unequal load on the various points of a level surface, since it now followed the laws of hydrostatic equilibrium. Although, in the solid state, the layer C D supported at its extremities the varying heights of D D′ and C C′ of the permeable ground, it could no longer do so when it had become liquid; it then tended to become changed in form and to move, so as to lower the general centre of gravity of the mass. The superincumbent mass changed its shape; it sank at D′, it rose at C′; the fluid layer ran towards the lower end, it rushed from D, where it was compressed; it flowed to C, where it expanded and set up fresh percolations and opened up a passage for them.[1] This natural process went on and on; the subterranean liquid layer, or pocket, continued to increase in magnitude and to advance nearer and nearer to the valley, the movements at the surface of the ground continuing at the same time without cessation, and if in place of a regular slope the natural surface found a series of steps, the movement, instead of

Fig. 6.



[1] The existence in certain places, notably in some districts of Algeria, of veritable subterranean lakes, appeared to be established. It seemed certain *à priori* that the surface of the ground above these sheets of water ought to be flat or nearly so; every elevation would not fail to sink in expelling the water situated below its heavy mass.

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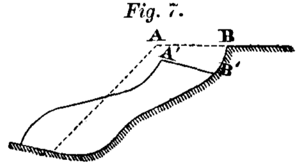
being continuous, would progress in a jerky or intermittent manner, a character which might be equally caused by the heterogeneity of the ground. As the water carried with it the silt which it had already dissolved, it was, in fact, a transport of solid matter, which was carried on under ground and which tended to reduce to the horizontal the visible surface. For this to raise itself at C′, above the original extremity of the saturated layer, it was necessary, however, that it should be sufficiently supported at the lower end. Should it happen that the point of upheaval, as it was displaced, approached the cutting of a road or railway or the ravine of a river, affording no support on the lower side, then the result would be a sudden sliding of the whole mass which had been rent vertically by the subsidence at the upper side; the mass would be more or less overturned and broken up in every direction by deformations and undermined at its base by the formation of a slippery plane surface, lubricated throughout by the slurry. In these sudden and extensive subsidences, which were presaged by comparatively small movements, the settlement was general over the whole surface; occasionally, however, it was noticed that the subsidence was unequal in extent, and, in the case of small land-slides, a portion, originally horizontal A B, *Fig. 7*, would, after the slide has occurred, assume the inclination A′ B′ sloping downwards towards the hill at the back; the face slope might also bulge outwards near the foot, the acquired momentum also permitting of its partial ascent of the counter scarp. In the case of the Canadian Pacific Railway, the origin of the land-slide being on the uphill side of it, it was altogether out of the question to attempt a remedy by carrying out simple works on the lower or valley side. Suppose, for example, an immense retaining-wall were constructed in the slope of the cutting, or in that of the river, it could only retard, to a very slight extent, the general subsidence, and as the surface of the ground would still possess a tendency to become horizontal; by travelling downwards, the upheaval of the lower ground would ultimately extend to the neighbourhood of the wall, and even if the latter were not bodily carried away, it would not prevent the disintegrated ground from being squeezed over its summit and obstructing the cutting or river. In order to grapple with the evil at its source and stop the slides, it would be necessary to drive a heading or culvert at B (*Fig. 6*) parallel to the irrigation duct A, with suitable gradients,

Fig. 7.



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so as to intercept the percolation and allow it free outlet, the water would then be carried away without doing any damage. This subterranean aqueduct could prevent the water coming into contact with the silt by a lining of cement, but even if the water flowed over the silt, unprotected, it might be fairly assumed that, forming a rapid current, its effect would be to cause no more erosion than the River Thompson below did upon its banks, and that a protective covering of pasty clay would be constituted. Yet the custom was to put a concave bed of cement concrete, as more secure. Unfortunately, it was easily explainable why, in the presence of such extensive land-slides as those at the Black Cañon, recourse to treatment by drainage had been avoided, although it had so frequently done good service upon railway works elsewhere. In presence of the absolute necessity of keeping the permanent way of the Canadian Pacific in running order, it would appear as if for the time being at least, the cutting-off the supply of water was contemplated, as soon as it was feasible to do so, although it would entail a serious loss of money to sacrifice in this way the benefit of an established system of irrigation. It must also be remarked that drainage culverts, especially in those portions of the system where their direction was perpendicular to that of the general movement of the ground, run a great risk of being disturbed and broken, in which event they would be rendered worse than useless. Where there was a probability of this occurring it was advisable to construct the culvert in such a manner as to be accessible throughout its length, so that it could be kept in repair and free from obstruction.

It was upon railway-construction works that considerable success had been attained in dealing with the slips which so frequently occurred in the slopes, but the circumstances in these cases were different from those of the valley of the Thompson, and, in some respects, opposite in character. It was not, as in the latter case, the artificial introduction of water into an area unsuitable for carrying it off which constituted the disturbing element and the direct cause of the land-slides (the valley and ravine of the river having existed before), but, on the contrary, in the case of railway construction, it was the subterranean water which was originally present, a state of things having been evolved under which the earth remained stable; further, the collecting of these waters, due to natural topographical circumstances, could not generally be checked; the disturbing element was the excavation of a cutting, which had upset the equilibrium of the ground, and it was for this reason that works of consolidation,

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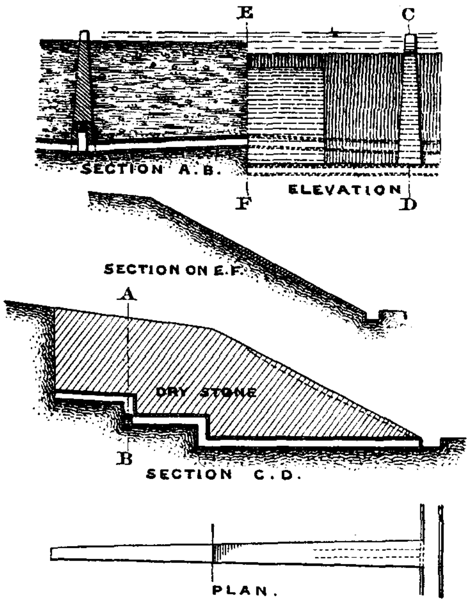
confined to the immediate vicinity of the part interfered with, could, at a moderate expense, prove efficient; for the disasters to be feared took place by commencing at the critical point and extending farther and farther; a primary partial slip was succeeded by a second of greater extent, and so on, so that by stopping the development of the first, the occurrence of the others was prevented, and thus it was only in a small area that provision had to be made for the free passage of percolating water, which would soften beds of silt, &c. The system of buttresses or transverse walls of dry stone, built at right angles to the slope of the cutting or the bulging hill and having a culvert at their base, was recognised at the present time as one of the best, since it supplied a method of drainage which dried and consolidated the surrounding soil, and, at the same time, a force of frictional resistance capable of withstanding the pressure which tended to push the slope into the cutting. With this object these walls, which intersect the unstable mass at regular intervals, should be carried down and founded upon a solid bed, so that they would not yield to the tendency of the adjacent mass to slide. This being so, each distinct portion of earth slipping could not slide without rubbing laterally against the faces of the two buttresses which enclosed it. This friction would afford sufficient resistance under two conditions, viz., (1) That the mass of earth be not converted into slurry, but preserve a certain amount of cohesion; (2) While being sufficiently cohesive, the mass of earth must yet exert against the buttress a lateral thrust great enough to produce the necessary friction. With regard to (1), it was necessary that the buttresses should be carried down sufficiently deep into the side of the hill, and be sufficiently near one another to perform their function of draining the space between them. Where necessary they might be connected together by a culvert or longitudinal waterway (*i.e.*, parallel to the railway) laid out with a falling gradient towards each buttress. However, where these drains ran the risk of occasionally becoming choked or broken, it might be preferable to do away with them, at the same time bringing the transverse walls closer together; they must, however, always be founded on the solid ground and made as accessible as possible. If the slope, although not sliding, exhibited in wet seasons a certain viscosity, the surface between the two walls which contained and retained them might swell and become convex. To counteract this deformation, a layer of stone pitching, either covering the whole slope or in the form of a pointed arch on plan, might be employed. This covering of massive stone restricted the tendency to swell out.

Professor Gaudard. It was a good plan to concentrate the weight by thickening the pitching at the centre, so that the greatest pressure was at the point of maximum upward thrust. Condition (2) was affected by the well-known uncertainty and difficulty of estimating the thrust of earth. Now instead of giving to these walls a constant thickness throughout, as was the usual custom, it would seem better to widen them out, that was to gradually increase their thickness from the upper to the lower part of the slope, so that the mass of earth (enclosed) between two consecutive buttresses would assume a trapezoidal form in plan. It would then form a wedge, which could not descend without becoming broken up. For similar reasons it would be advisable to give a batter to the upright faces of the walls, as the tendency of the earth is to descend, and this batter aids in sustaining it. *Figs. 8* showed the arrangements described. The pitching is shown as only covering part of the slope.

Figs. 8.



Professor Hull. Professor Edward Hull thought the Paper supplied an excellent instance of the essential interdependence of geological conditions and engineering art. It was remarkable that in this far-off region of Canada the same persistent enemy to engineering work was present as had to be faced in the British Isles; he referred to the boulder clay of the Glacial epoch. Engineers who had deep railway cuttings to construct or maintain in this deposit in Great Britain knew what a treacherous material it was to deal with; and the same appeared to be the case in North-West Canada. When first cut into it was often so solid and tough as to be able to stand like a wall; but a few months' exposure to rain and frost initiated a process of sliding which was interminable; and so it appeared along the line of the Canadian Pacific Railway. This

Professor Hull.

arose from the heterogeneous composition and absence of regular stratification in the boulder clay due to its glacial origin. He was not certain that the means described by the Author were the best for getting over the difficulty. The expense of the process of keeping the line clear over the "north and south slides" was great and continuous, while sudden slips and subsidences, like the case described in the Paper, would probably recur frequently. If possible, the best solution of the difficulty might be to avoid the enemy by tunnelling in the Cretaceous strata—from some point north of Nelson Creek to the eastern bend north of the Black Cañon. The distance would only be 1½ mile, and the work might be spread over several years without interfering with the present traffic. The account which the Author gives of the physical changes which had passed over this part of the Continent were of great interest, showing uprising and depression of the land, the filling to some extent, and re-excavation, of river valleys, the changes of climate, and the advances and retreats of the glacier ice in the Pleistocene epoch. These changes had to some extent their counterparts in Eastern America and Western Europe. From recent investigations[1] by Professors J. W. Spencer, A. Agassiz, Warren Upham, and other American geologists, it had been shown that the eastern borders of the American Continent had undergone great changes of level after the close of the Pliocene period, consisting of uprises of several thousands of feet, and subsequent depression, as shown by submarine soundings. The Paper showed that representative changes (not necessarily absolutely contemporaneous) had taken place on the north-western sea-board, and these went far to account for the occurrence of the glacial conditions of the Pleistocene period themselves.

Mr. Paterson.

Mr. Malcolm Paterson remarked that the porous gravel deposits which formed the bulk of the material of these great land-slides seemed to be those known to English geologists as "Kaims," or "Eskers," in which it was supposed that the substance of moraines, or boulder clay—the "till"—was blended with marine gravels. Glaciers had descended to the sea-level and launched themselves and their burden of débris into tidal waters, by whose action such débris had become so washed and scoured that the angular boulders had become rounded into shingle, and the "till" had been largely changed into a perfectly free and porous gravel, with pockets of argillaceous sand and thrown into mounds and terraces. He had recently driven a short tunnel in an "Esker," parallel with and

[1] Spencer, "Reconstruction of the Antillean Continent," Geol. Mag. 1897; Upham, "Cause of the Glacial Period," Trans. Vict. Inst., 1897.

Mr. Paterson. 12 yards or so from the River Aire at Shipley; in the heading of which the river-water freely entered and as freely flowed out, as the river-floods rose and sank. The movement of so vast a mass of porous material as that described in the Black Cañon upon its inclined bed of silt was a natural result, such silt being converted by saturation under enormous pressure into a kind of soft soap, upon which the "slide" would be aided by the hardness of the material below it. With so slight a rainfall, the natural stability of the gravel and its bed of silt, as explained by the Author, was clear, as also its failure under the artificial deluge caused by irrigation over a surface so porous.

Mr. Reade. Mr. T. Mellard Reade thought the land-slides described in the Paper had occurred under very unusual conditions. The silt which appeared to be the cause of the trouble, whether as boulder clay forming the matrix of the boulders or as a secondary deposit without boulders, was described by the Author as being, under ordinary conditions, perfectly dry except near the surface. In every deposit in Great Britain, boulder clays, silts, sand, gravel, or even rock, held a large percentage of water. It was well known to those who had examined clays, and mechanically analysed them, that a moist lump of clay, if thrown into water, would melt very slowly, whereas, if thoroughly dried, and then placed in water, it would disintegrate and fall to pieces immediately. The resistance of moist clay to disintegration was shown by the clay boulders, which were often formed by the rolling of fragments of clay on the seashore. The abnormally dry silt or boulder clay composing the terraces of the Thompson River, when subjected to artificial irrigation, evidently broke up in a similar manner to dried lumps of British boulder clay when immersed in water. That this was the true explanation of the great slides was shown by the fact, mentioned by the Author, that when the clay or silt naturally received a thin coating of moist clay it would withstand the action of water in a remarkable manner.

Mr. Robson. Mr. John J. Robson had practised in British Columbia during 1888–89 and had a fair knowledge of the south part of the province. The cause of the slips was, indeed, no ordinary one, and apparently only by careful observation and experiment in the laboratory could the peculiar action of this silt when saturated with water, and likewise when exposed to the elements, have been discovered. Apart from the dangerous nature of driving tunnels so as to drain the slip in loose moving earth, it would be necessary that such tunnels should be low enough to drain the bed of the slip in order to be effectual; but as the bed of the slip was at or about low-water level of the river it appeared impracticable, and

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even if it were possible another danger would arise when the spring freshets occurred; the river, then rising as much as 70 feet or 80 feet would again surcharge the bed of the slip with water by means of the drainage tunnels, and the last state of the case would be worse than the first. In the final paragraph the Author pointed out the only remedy, viz., to stop the irrigation, and in this he strongly agreed. This he interpreted as an absolute stoppage of the irrigation ranches, and not only cutting off the water. The latter course was impossible, in consequence of the open and porous nature of the top soil, underlaid with sand and gravel. On such land the water soaked in and found its nearest way by underground channels into the back and bed of the slip; and there was also the leakage from the irrigation ditches, which were very rudely constructed by the farmers, and were seldom water-tight, so that the only remedy was to entirely stop the irrigation. In the Paper it was stated that the two largest slides occurred before the construction of the railway, and he would have thought that when it was found to be imperative to carry the railway across these slides, and the cause being known, that the railway company would have at once bought out the ranchers instead of continuing such costly maintenance works, for in those early days of British Columbia all the ranchers of the district could have been bought out for one-half the money which had already been expended. It naturally arose whether these land-slides could have been avoided in locating the railway, and in this case he did not see that it could have been so arranged without carrying it at a higher level by some 300 feet or 400 feet than at present, which, apart from the inconvenience of such a route, would have been a serious obstacle to the general down-grade from Donald to Vancouver (a fall of 2,500 feet in 458 miles). In other cases, however, the railway had been carried over old land-slips which might have been avoided; he particularly referred to one near Port Harvey, on the Fraser River, some 50 miles east of Vancouver, which he had examined; and, although no further subsidence might have occurred, yet he considered that engineers were not justified in running such unnecessary risks in order to save $\frac{1}{4}$ mile of cuttings. The Pacific section of the Canadian Pacific Railway was intensely interesting to the engineer. The route was beset with natural obstacles and difficulties, and some idea of the nature of the work might be imagined from the fact that between Donald and Vancouver there were over 1,900 bridges, some of which were over 200 feet high and others over 2 miles long. Indeed, no engineer would have selected such a route, as there was no doubt that a much easier one existed

Mr. Robson. farther north; but political motives had influenced the selection. The Author touched upon the topography and climate of the country; respecting the former it was a veritable sea of mountains, whilst the interior plateau was only a comparative term, indicating a stretch of high hills and undulating country lying between the more rugged and lofty mountain ranges; it was, indeed, the roughest and most rugged country in the world. When, in addition to the foregoing conditions, the dense forests on the Pacific coast were added, with the trees between 200 feet and 300 feet high, and fallen timber (the accumulation of centuries) so thick in places it was possible to go for miles without touching the ground, the work of the engineer was difficult and arduous in the extreme. The climate was, however, so delicious that such drawbacks as the above were forgotten; it might well be likened to an improved Devonshire (on the coast), the greatest heat registered being about 90° F., whilst in the winter it seldom fell so low as 20° F. The climate was, as the Author stated, rather less genial in the interior, but taken as a whole he had never heard of nor experienced a better.

The Author. The AUTHOR, replying in writing to the Discussion and Correspondence, thought the last paragraph of the Paper had been misunderstood. It had been written with the experiences of the Ashcroft, and with the Great Northern slide fully in mind, as well as the nature of the material to be dealt with in the slide, and hence by "cutting off the irrigation water above" was meant the absolute stopping of all irrigation in the neighbourhood of the slide, for the reason that the nature of the material, as described in the Paper, was such that no other means suggested would be effectual. It was not necessary to add to the description of the nature of the material composing the slides, or the peculiar action of the water upon it. The case was most clearly and forcibly expressed by Prof. Jules Gaudard. He felt gratified at the kind and complimentary discussion of his Paper; but he could not agree with some of the opinions expressed as based upon the facts he had stated. He had had much experience in dealing with ordinary land-slides while in charge of the construction of a portion of the Cincinnati Southern Railway through the coal measures of the Cumberland Mountains in the States of Kentucky and Tennessee, during the years 1874–1880, and he had made a somewhat careful study of the great mud tunnel upon that road. These slides, in most instances, had been caused, during the building of the road, by cutting through the lower edges of the strata, when the heavy rains of the winter wetted the layers of blue clay, thus lubricating the inclined plane on which the superincumbent mass was resting, when in some instances hundreds of acres slid down the mountain side into the valleys below. In other cases solid masonry tee-abutments, built upon clean and solid bed rock, were carried off their foundations and moved bodily down the hill by the force of a slide behind them. These cases were similar to those described by Mr. Foster Crowell, and to these in general were applied the usual remedies, such as drain ditches above, tunnels, drifts and drains below, with very satisfactory results. None of these remedies, however, would be of service if applied to the great slides under consideration in British Columbia, on account of the nature, condition and position of the material composing them. The cutting of a drain ditch around the back of the slip to take the water off would be more than useless: (1) The water causing the damage was that applied upon the cultivated fields (p. 3), and after being once applied could not be collected into a drain, for it rapidly percolated downwards into the boulder clay and silt underlying the top soil (p. 4). (2) If the water was collected into an ordinary ditch it would work more damage than good in such clay and silt. This method, a ditch filled with water running around the back of the mass, was that used in England, and especially on the great clay banks of the Isle of Wight, for the purpose of bringing down great masses of clay for commercial purposes. If, as had been suggested, this ditch, and also the small canals leading to the farms, were lined with puddle, cement, or asphalt, and the water kept in them, no irrigation could be accomplished, for, as soon as the water should be taken from the ditch and spread upon the fields, the damage would be done. Hence this remedy, if carried back far enough to be effectual, meant simply cutting off the diseased tail of the dog close up behind his ears—which was the true and only real remedy. Careful study of the nature of the material, as explained in the Paper, and so forcibly expressed by Prof. Jules Gaudard, would show that no system of tunnel drains, drifts or surface drains through or at the lower side of the slide would be of value in such a moving mass of silt, there being no "stable bed inclined towards the river" on which it slipped; but "the mass would be more or less overturned and broken up in every direction by deformations and undermined at its base by the formation of a slippery plane surface lubricated throughout by the slurry." If such drains and tunnels were partially successful for a time, they would not be permanent, for in such material no system of tunnel drains would carry off all the water unless built so close together as to form one complete cellar under the whole mass, which would be out of the question. Hence a portion of

The Author. the water would sink lower—even below the level of low-water in the river. After a time a new "subterranean liquid layer or pocket" would be formed lower down, and the whole operation would be repeated. As stated in the Paper (p. 9) and remarked by Prof. Boyd Dawkins, "the solid geology of the valley . . . . had nothing to do with the cause of the slips." But the position and the condition of the solid geology at this time underlying the great mass of silt became a very important matter of study in determining the proper methods to be applied for curing the evil as it now exists. Therefore he could not agree that the position and action of the ancient Pliocene river was unimportant. It was only by the study of every known detail, both ancient and modern, in such a problem as that under consideration, that a true knowledge of the facts could be arrived at, or the proper estimate of the proper remedies formed. It was from the study of this ancient Pliocene river bed that had led him to conclude that no tunnels or drains from below would be effectual, for on examining other details it seemed that the mass of silt under the slides extended below the present bed of the Thompson River, and was being forced up into the river at its edge. The neglect by the Dominion Government of the mere detail that above this one old south slide a 35-acre field was being constantly irrigated—a field at that time worth perhaps £35—had cost the railway company some £10,000. It was not his purpose to criticise the Dominion Government, which first built the railway, or the Canadian Railway Company, which had since worked it; but, in justice to the engineers who first built and had since had charge of the railway, it must be said that they at first and continually recommended the purchase and wiping out of the farms entirely. Whether this want of action had been due to false economy, neglect of detail, or political necessities, was unknown. The possibility of locating the railway on the opposite side of the Thompson was out of the question. The nature of the ground was the same, and, since being irrigated, large slides had occurred also on that side. As far as the old slides were concerned, the location was correct; but the land should have been bought at first, and the farms, as such, wiped out of existence. The absence of sufficiently accurate borings precluded his illustrating his reply by cross sections through the slides; he did not, however, consider they would add to the information he had given in the Paper in elucidating the subject. He could only repeat his conclusion that there was no way of preventing the disastrous effects of these land-slides upon the railway except by stopping entirely all irrigation of any lands whatsoever above them.