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AN EFFORT TO CONTROL A GLACIAL STREAM*

RALPH S. TARR AND LAWRENCE MARTIN

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GLACIERS AND TRANSPORTATION ROUTES IN ALASKA.—Throughout the coast region of Alaska there are many relationships between glaciers and man's attempt to establish transportation routes. The junior author has previously discussed before the Association of American Geographers some of the glacier highways in Alaska,¹ and

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The authors shared equally in the field work upon which this paper is based. The lamented death of the senior author on March 21, 1912, occurred before the paper was written in the form here presented. The junior author assumes full responsibility for any errors of interpretation.

¹ Martin, Lawrence, Glacial Highways in Alaska, Chicago meeting, December, 1907, *Annals, Assoc. Amer. Geographers*, Vol. I, 1911, p. 109; *Mastering the Alaskan Glacier Barriers*, *Scientific American Supplement*, Vol. LXXI, 1911, pp. 305-307; *Crossing the Alaskan Glaciers*, *Colliers Weekly*, Vol. XLVII, July 15, 1911, p. 20; *The National Geographic Society Researches in Alaska*, *Nat. Geog. Mag.*, Vol. XXII, 1911, pp. 541-548.

both authors have previously described the complications of glaciers and railway building along the Copper River and Northwestern Railway.²

The combination of (a) lofty mountains along the Pacific coast, (b) heavy precipitation including much snowfall, resulting in large ice tongues which completely fill or project into the passes across the coast range, and (c) geographical distribution of harbors in relation to resources of the region inside the coast ranges, has resulted in the necessity of (1) using the glaciers as temporary highways, as at Valdez Glacier and several other ice tongues, or (2) following valleys partly barred by ice tongues, as along the Copper River and Northwestern Railway, or (3) building railways and roads over snowy passes, as on the White Pass and Yukon Railway and several other routes to the interior.

The case described in this paper is of a different sort. The transportation route in question does not cross a glacier, but it goes so close to one that the glacial streams cause decided complications. Railway engineers have not previously had to deal with this sort of stream, and the locating engineer so thoroughly misunderstood the habit and power of glacial streams that his successor has had a grave problem to deal with. He was at work upon this problem at the time of the visit of the authors to the Alaska Northern Railway in 1911, in connection with the third glacial research expedition of the National Geographic Society.

THE ALASKA NORTHERN RAILWAY.—The Alaska Northern, originally called the Alaska Central Railway, extends from the town of Seward, on the Kenai Peninsula just west of Prince William Sound, toward the Matanuska coal field. Only seventy-two miles of this railway were built up to 1911 but it will doubtless soon be constructed the remaining seventy-eight miles to this coal field. This railway may eventually be extended to the Tanana and Yukon valleys in the interior of Alaska, especially if it is purchased by the government, as was recently recommended by the Secretary of the Interior.

The Alaska Northern Railway, as it was built, crosses two passes, the highest of which is about 1,080 feet above sea level. Each of these passes was considerably lowered by glacial erosion. In descending the northern side of the higher of these passes it has been necessary to construct several great curves and loops including one spectacular, high spiral trestle, close to the large, inactive Bartlett Glacier. A little farther north the railway line descends out of a hanging

² Tarr, R. S. and Martin, Lawrence, *Geographical Aspects of Alaskan Glaciation*, Cambridge meeting, December, 1909, *Annals, Assoc. Amer. Geographers*, Vol. I, 1911, p. 121; *The National Geographic Society's Alaskan Expedition of 1909*, *Nat. Geog. Mag.*, Vol. XXI, 1910, pp. 1-54.

FIG. 1.—Map showing Alaska Northern Railway and its relationship to the Turnagain Arm of Cook Inlet and the Passage Canal fjord in western Prince William Sound.

valley into the main valley occupied by Spencer Glacier. The lip of the hanging valley is gashed by a deep, post-glacial gorge. The railway follows the side of the gorge, whose sides are so steep that six short, curving tunnels have been dug. Below the northernmost of these tunnels the railway reaches the level of the main valley and passes close to the front of Spencer Glacier (Fig. 3).

THE SPENCER GLACIER.—The Spencer Glacier flows northwestward from unexplored snowfields in the Kenai Peninsula, terminating seven miles south of the Turnagain Arm of Cook Inlet. It is nearly a mile and a half wide at the terminus. The glacier is clean, is only moderately crevassed (Plate II, a) and is flowing forward so slowly that the ice at the terminus was melted back thirty-six feet between 1905 and 1911. Four large streams emerge from the glacier, three of them on the western and one on the northern margin. The latter, which is the only one of especial interest in this paper, flows into a box canyon a few hundred feet from the point of emergence, continuing in this rock gorge for over a mile.

THE TERMINAL MORaine.—A terminal moraine was built by Spencer Glacier at a period of recent expansion. Part of this moraine has been destroyed by the glacial streams, and the remaining portion is over a mile in length and an eighth to a sixteenth of a mile wide. It rises to a height of twenty to twenty-five feet and is made up chiefly of rounded stream gravels, evidently the material of an older outwash gravel plain pushed up by the glacier in its recent advance, when a little till was added. The eastern edge of this moraine has been cut up into half a dozen disconnected hillocks, separated by stream channels. The remainder of the terminal moraine is a solid, somewhat knobby mass, with marked lobes on the outer edge (Plate II, b). The glacier has retreated about one thousand feet from the outer edge of the terminal moraine, and a few youthful shrubs have taken root upon its surface.

THE OUTWASH GRAVEL FAN.—Extending northward from the terminal moraine of Spencer Glacier to the head of Turnagain Arm is a broad valley train of outwash gravels which fill this mountain valley from side to side. The outwash gravels also fill most of the area between the terminal moraine and the present edge of the glacier. Where the eastern portion of the terminal moraine has been cut away by the glacial streams an alluvial fan of steep slope extends northward (Plate II, b, and Plate III, a) and merges with the valley train. This alluvial fan is made up of rather coarse outwash gravel and slopes northward at the rate of seventy-three feet to the mile (Fig. 2). Close to the ice front the gravels have been laid down upon the outer edge of the glacier and the buried ice has melted, giving rise to a series of kettles. At the very margin of the glacier the ice has

recently shrunk away from the gravels; forming a long narrow fosse with one wall of ice and one of gravels underlain by ice.

THE BARREN ZONE.—The terminal moraine and adjacent outwash gravel plain are practically without vegetation and there is also a barren zone on either margin of the glacier (Plate II, a), where melting has caused it to shrink away from the valley slopes. This lateral barren zone is a surface of practically naked rock, forming a striking contrast with the higher slopes, which support a dense, mature forest of conifers, with a thick carpet of moss. The trees attain diameters of forty-six to fifty inches and are a century or more of age. In the barren zone the soil, the moss, and the trees have all been removed by a recent advance of Spencer Glacier. In some of the hollows a little gravel and till have been left during the retreat of the glacier margins. Scattered through this and lying upon the bare rock ledges are many logs and fragments of stumps of trees, together with quantities of finely-shredded wood. Here and there, in parts of the barren zone where soil is present, small alders and willows have sprung up since the zone was vacated by the ice. The oldest of these shrubs were twelve years of age in 1911.

RECENT EXPANSION OF SPENCER GLACIER.—The barren zone and the terminal moraine show that in comparatively recent times this ice tongue has had a period of expansion. During this expansion the glacier was larger than it had previously been for a century or more, for the mature forest was eroded away in what is now the barren zone. The youthful shrubs in the barren zone prove that this expansion was at least twelve years before 1911, or not later than 1898 or 1899. Our observations in similar barren zones of Alaskan glaciers show that such periods of expansion are short-lived and that vegetation springs up immediately, suggesting that the period of expansion was not over a year or two before 1898. There are no observations by visitors to Spencer Glacier to tell anything further as to the exact date of this latest period of glacial expansion.

ORIGINAL LOCATION OF ALASKA NORTHERN RAILWAY.—The portion of the railway near Spencer Glacier was surveyed some time before January 8, 1906 and the track was laid in August, 1907. The original location has three conspicuous defects. First it goes within the barren zone on the southwestern margin of the glacier, where the northernmost tunnel goes through a rock spur over which the glacier extended in its period of recent expansion (Fig. 3). This is on the side of the rock gorge by which the stream from the Bartlett Glacier near the pass descends from its hanging valley to the valley of Spencer Glacier. Between the two previous tunnels this stream is reinforced by a glacial stream which plunges over a beautiful waterfall to the gorge, the retreating edge of the glacier being only a few

hundred yards from the gorge in 1911. Between the two northernmost tunnels, however, the edge of the barren zone crosses the track, crossing it again directly above the roof of the last tunnel. At this locality a renewal of activity as slight as that just before 1898 would destroy this portion of the railway.

The second defect in original location is where the railway, after crossing the westernmost and largest of the streams of Spencer Glacier by a high trestle, continues northeastward by a long tangent which is built on the terminal moraine itself for over half a mile (Fig. 3) and then goes on across the northern alluvial fan of outwash gravels. To have located this railway upon the terminal moraine of a living glacier which has retreated less than a quarter mile from the moraine built by it not much over a dozen years ago, shows a lack of knowledge of glaciers and an unwarranted belief that continued recession is inevitable. Our own study of ice tongues, bringing out the facts that (a) sixty-nine glaciers in Alaska have advanced since 1786, forty-eight of them since 1899 and (b) that the terminus of one glacier has moved forward a mile in ten months, two others one and a half and two miles, respectively, in less than three years and probably in a single year, lead us to regard this railway location as extremely ill-advised.

The third poorly-considered feature of the railway location near Spencer Glacier was the building of the railway line across the northern alluvial fan of outwash gravels. Here the mile and a half of railway immediately northeast of the terminal moraine is located so close to the glacier that the streams from the retreating ice tongue have already done thousands of dollars worth of damage to the grade and the bridges. This would continue with inactivity and retreat of the ice and would be even worse if the glacier should advance, making itself felt long before the ice moved forward to the railway itself.

It should be said in justice to the railway engineers that these are errors of location which any engineer without experience with the habits of glacial streams might have made, in the belief that glaciers in Alaska are generally retreating. When built, the railway was elevated on piles above the surface of a good part of the alluvial fan and an adequate number of bridges and culverts, most of them with openings fourteen feet high in the center, was built to accommodate the existing streams. What was overlooked was (a) that the fan is still being built up, and (b) that the glacial streams, like all streams on alluvial fans, are shifting rapidly in their courses.

DISADVANTAGES OF ORIGINAL LOCATION.—The disadvantages in the original location of the portion of the Alaska Northern Railway near Spencer Glacier soon became apparent, especially in the railway grade upon the outwash fan (Plate IV). The anastomosing streams from the northern part of the glacier soon abandoned their channels

beneath the bridges and culverts and established new courses across the railway track. These streams flow with great velocity and carry much coarse sediment. They rapidly filled the elevated portions of the trestle so that a section of the track which was originally so high above the fan that a team of horses could be driven underneath soon had the gravels at the level of the track. Bridge openings which were two to nine feet high and thirty-six to two hundred and eight feet long were completely filled (Plate IV, a) in the three years before August, 1910.³ The gravels were laid down in some places to a depth of six to fifteen feet above the level of the rails. Bridge No. 93 was filled to a depth of six feet, bridge No. 94 to a depth of five feet, and others to a depth of nine to fourteen feet. The twenty bridges and culverts in a distance of one and a half miles were all filled solid and abandoned and the streams flowed over or cut away the track in a score of new channels.

UNSUCCESSFUL ATTEMPT TO DIVERT THE GLACIAL STREAM.—The railway engineers at once took measures to divert the glacial stream from the northern margin of the glacier so that it should flow north-westward and cross the railway near the terminal moraine where the track was elevated some little distance above the gravels. It was thought that by throwing two dikes (Fig. 2) across the stream course this diversion would be possible.

Consequently a dam of piling twelve feet high, filled with coarse rubble, was built westward from the valley wall to an isolated rock hill one hundred and seventy feet distant. From this hill a dike twenty-one hundred feet long was built northwestward to a point north of the railway. This dike was made of a double line of heavy piling driven deeply into the gravels. The two lines of closely-set piles were tied together by heavy log cribwork. The twelve foot space between the piles was filled with large fragments of heavy, angular rocks. Small wing dams projected at an angle from the upstream face of the dike to keep the stream from undercutting the piles.

The short upper dam held, but was filled by the glacial stream to a height of ten to eleven feet. The long dike did divert the stream for a time but it was impossible permanently to turn from their courses glacial streams flowing down a slope of seventy-three feet to the mile and armed with coarse gravel for cutting-tools. The streams, therefore, soon broke through the dike not once but in half a dozen places, as is shown in Fig. 2, resuming their normal courses down the north-eastern slope of the alluvial fan. The havoc which they wrought in the dike is shown in Plate III, b.

Since the failure of the dike, the railway has undergone a continual struggle with the stream. The building of new bridges, the

³This and the following figures were furnished us in the summer of 1911 by Col. A. W. Swanitz, chief engineer of the Alaskan Northern Railway.

shovelling of gravel from the track, the raising of the grade to accommodate the upbuilding of the fan, and the replacing of rails has been a continual source of trouble and expense, to say nothing of the interruptions of traffic on the railway. Several log cabins occupied by the workmen on the railway in 1907 were half buried in the stream gravels in 1911. The conditions along the railway when the authors visited Spencer Glacier in 1911 are suggested by Plates IV and V.

FIG. 2.—Contour map showing the northern alluvial fan of outwash gravels at Spencer Glacier, the dikes built to divert the glacial streams from the Alaska Northern Railway and places where streams broke through the dikes (after a map by the railway engineers).

In some places the heavy steel rails had been bent into sinuous curves, and when it is remembered that the stretch of track across the alluvial fan is a tangent or perfectly straight section of the railway the pictures speak for themselves. We wondered in some places whether we could safely take a handcar over some portions of the track, but, as the rails were bent in parallel curves, we afterwards rode over some of these snake-like curves, first in a heavy gasoline-propelled railway car, and later on a freight-train behind a standard locomotive. On June 25th when the junior author made the map reproduced here

as Fig. 3 one mile of track had thirteen dry bridges, filled flush with gravel and four or five streams were flowing beneath the track where there was no bridge, one stream having shifted half way from under its bridge (Plate V, b), and another flowing over the tops of the rails. These conditions called for prompt, efficient action; and the railway was then fortunate enough to have a chief engineer fully capable of coping with the situation.

THE PLAN FOR CONTROLLING THE STREAM IN 1911.—This engineer, Col. A. W. Swanitz, worked out in the summer of 1911 a new plan for controlling the glacial stream. Col. Swanitz, it should be said, was not connected with the railway at the time of the original location and the attempted diversion by the dikes. The authors are deeply indebted to Col. Swanitz and to the present President of the railway, Mr. O. G. Laberee, for entertainment at the engineer's camp on the terminal moraine of Spencer Glacier at the time this ingenious plan of glacial stream diversion was being carried out in June, 1911.

Col. Swanitz' plan was (1) to dam the stream at the point where it emerges from the glacier and plunges into the marginal gorge, (2) to divert it along the present glacier margin for two miles, and (3) to send it under the railway at a point in the terminal moraine (q. Fig. 3) where there is a high trestle.

DETAILS OF THE STREAM ADJUSTMENT.—*The Upper Dam.*—The marginal gorge near the outer edge of the barren zone lends itself to the stream diversion (Plate VI, b), for it is a box canyon about ninety feet deep and not over twelve or fifteen feet wide. The engineer and his men planned to blast down rock from the walls of this canyon by one great charge of dynamite and to form a dam which should hold in a small lake (a, Fig. 3). A rise of a few feet in the surface of this lake would allow the water to overflow along the glacier margin. A little work resulted in the clearing out of a channel to accommodate this new outlet. The dynamite was transported up to the head of the marginal gorge by sled on the glacier surface.

The Marginal Channel.—The new marginal channel (m-m, Fig. 3) was to be about a mile long and had one rock wall and one ice wall (Plates II, a, and X, a). A small stream emerged from the glacier margin near the lower end of the proposed new channel but there was no water flowing along the greater part of the edge of the glacier where the new stream was to go.

The Lower Dam and Lake.—A lower dam was built at the southwestern terminus of the new marginal channel. This (n, Fig. 3), connected the western end of the rocky hill of the barren zone with a hillock of gravels underlain by ice and crossed an abandoned stream channel which it was necessary to block. This dam was to hold in a

shallow lake whose new outlet was to be a short ice channel across the margin of the glacier to connect with a natural channel in the fosse to the west. This lower dam was constructed of angular rock. Col. Swanitz' ingenuity was displayed in the construction of this

FIG. 3.—Sketch map of the Spencer Glacier, showing its relationship to the Alaska Northern Railway. Mapped June 25-26, 1911, by the junior author.

dam. He moved a heavy pile driver three quarters of a mile from the railway to a site at the glacier margin, letting the pile driver pull itself along on skids laid upon the gravels of the alluvial fan. This was done by burying a log some distance ahead of the driver and pulling the heavy apparatus up to the log by winding up a steel

cable on the drum of the pile driver. The pile driver dragged behind it a rude sled with a load of coal. The pile driver was set up at one end of the dam and its tower was connected by cable with the rock hill upon which a stone quarry had been opened in the rough, glacially-plucked granite surface of the barren zone. This cable carried the huge blocks of stone to the dam, where small spruce trees were laid in the interstices between the stones. By this method the lower dam was built in a few days.

Dyeing a Glacial Stream.—Another evidence of the ingenuity of the railway engineer was his method of tracing a glacial stream which disappeared beneath the ice just above the lower dam and which was thought to be identical with a geyser-like stream which boiled up a quarter mile to the southwest in the fosse.

Col. Swanitz purchased a quantity of red aniline dye which the junior author put in the stream where it disappeared beneath the glacier (Plate VIII, a), the senior author and Col. Swanitz watching for the red color at the geyser-like stream a quarter mile below (Plate VIII, b). They were not absolutely certain that the red water was recognized, as a barrel rather than a pail full of dye would be better for this sort of experiment in a rapidly-moving glacial stream. The identity of the stream was established later, however, by sending fragments of trees through the sub-glacial channel. So far as we know no one has previously attempted to trace a subglacial stream by this ingenious method.

The Ice Channel.—The shallow lake, held in by the lower dam had to have an outlet for a few hundred yards across the edge of the glacier (o, Fig. 3). Accordingly Col. Swanitz set his men to work cutting and blasting a channel in the ice. As much as four boxes of dynamite were set off at a time in blasting away the glacier, a task such as no engineer had probably ever undertaken before. After each blast, which hurled fragments of ice and stones hundreds of feet into the air, the men set to work with shovels and picks to remove the ice loosened by the discharge (Plate IX, a). The abundant water from the melting ice carried the ice blocks away after the channel assumed form (Plate IX, b), making it unnecessary to throw the ice out of the deep channel. The men in the channel had to be relieved frequently because they could not stand long in the ice-cold water, only a degree or two above the freezing point.

The authors found this phase of the work of the engineer's force at the ice channel the most interesting, partly because it is quite unique. In no other way have we ever before gained such a vivid impression of the vast magnitude of a glacier as when we saw and heard the explosions of hundreds of pounds of dynamite (Plate II, a), and watched a score of men busily digging away the loosened ice frag-

ments, with the sum total of a week's work a tiny scratch across a small part of the front of the glacier. The whole work of man was puny in contrast with the vastness of the great ice tongue. Against the hundreds of thousands of tons of ice, moving onward slowly but resistlessly, man could make but little progress. Yet the ice channel was completed and was quite adequate for its purpose.

The Fosse.—West of the ice channel the fosse between the glacier margin and the edge of the gravels required no improvement by man (Plate X). It was half a mile long (p-p, Fig. 3), fifteen or twenty feet deep, and led nearly to the bridge (q, Fig. 3), by which the corrected stream was to cross the railway.

Completion of the Stream Diversion.—All of the work outlined above was carried on simultaneously and, when the ice channel and the lower dam were completed, the walls at the upper end of the box canyon were hurled down in one giant blast and the stream was diverted from its old channel and successfully turned into the new one during the last week in June, 1911.

UNFORESEEN FACTORS IN THE DIVERSION.—Several unforeseen factors came out when the diversion was accomplished,⁴ each one, however, tending to make the stream adjustment more satisfactory.

When the rock walls of the box canyon were blasted down the ice in the adjacent portion of the glacier was severely shattered and broken. Accordingly the stream from the little lake held in by the upper rock dam did not flow all of the way along the glacier margin, as was anticipated, but disappeared beneath the glacier for eleven hundred feet. The lake was quickly drained and at its upper end a hole (Plate XI), at least one hundred feet in depth was produced, into which all of the drainage of the northern margin of the glacier disappeared.

The second partly-unforeseen factor was the behavior of the stream at the ice channel. Instead of merely flowing in this channel and enlarging it laterally as Col. Swanitz anticipated, the stream rapidly cut down until it broke into the subglacial channel whose course we had traced with the dye, forming an ice canyon fifty-five feet deep which was rapidly enlarged by the stream (Plate XII). Six hundred feet of the channel was subglacial and the rest was a great open canyon in the ice. Col. Swanitz assisted nature with dynamite where it seemed desirable, but left most of the lower subglacial channel leading to the fosse, not thinking it necessary to unroof it since it carried away ice blocks as large as a small cabin without being blocked.

Between the last of June and the first of November, 1911, four hundred and fifty feet of the roof of this subglacial section of the

⁴We ourselves did not see all of these but were informed concerning them by later correspondence with Col. Swanitz.

stream was removed by erosion and melting, leaving only one hundred and fifty feet of roofed channelway. The larger portion of the ice channel, which was superposed upon the original subglacial channel, was cut down to bedrock, forming an ice canyon forty to sixty feet deep.

The new channel crosses the railway under a two hundred and sixty foot bridge in a single stream one hundred and sixty-five feet wide, five to ten feet deep, with a velocity of eight miles an hour and seemed to be deepening rather than filling its channel throughout the summer of 1911. The channel was deepened two feet from July to November.

PERMANENCY OF THE STREAM ADJUSTMENT.—Up to November 1, 1911, the diversion of the glacial stream was a thorough success. It is impossible to say how many years such an adjustment of heavily loaded glacial drainage may continue, but we see no reason to suspect that it should not continue as long as the glacier is in a stage of relatively-slow forward motion, accompanied by recession of the margin by melting. It is certain that the accelerated rate of recession of the ice edge, which this interference by man will produce, will also bring about the supply of much more water than normal during the summer months. This should result in erosion rather than aggradation by the glacial stream, provided it is deeply enough entrenched in its new course so that it cannot escape over the surface of the outwash gravels or break out in a new subglacial course at some point in the portion of the outwash fan still underlain by ice.

Col. Swanitz states that the Spencer Glacier retreated markedly in the summer of 1912, that the subglacial channel choked up in August, 1912, but that the stream broke out a new and lower outlet.

Great credit is due Col. Swanitz for his brilliant campaign against this glacial stream. Costing far less than the unsuccessful diversion by the dikes, it takes advantage of a series of naturally favorable conditions which a less gifted engineer might not have been able to utilize. It is to be hoped that this shifting of the glacial drainage may remain established for many years to come.

POSSIBLE IMPROVEMENT OF RAILWAY LOCATION.—Many of the difficulties in connection with the grade of the Alaska Northern Railway upon the alluvial fan of Spencer Glacier might have been avoided by crossing the streams a little to the north and farther from the glacier, where aggradation is less rapid and where the interference with stream flow by the piles and bents of the bridges would be less liable to result in upbuilding by the streams. Col. Swanitz informed us in 1911 that it would be possible to relocate the whole section of railway near Spencer Glacier by descending from the hanging valley in a new grade on the western valley wall. This would not only avoid the worst glacial streams but would take the railway out of reach of

an advance of Spencer Glacier (a) in the present precarious course over the terminal moraine (Fig. 3) and (b) in the section through the northernmost tunnels which extend within the barren zone.

The loop, spiral trestle, and tunnel near Bartlett Glacier on the pass are also in a very dangerous proximity to a glacier, and as the grades at the pass are very steep and the snow slide problem a bad one it may eventually be desirable to relocate the pass section of the railway near Bartlett Glacier, as well as that near Spencer Glacier.

If the expense of these two relocations is ever considered, it may eventually seem desirable to take up a new route for the Alaska Northern between Turnagain Arm and the Pacific Ocean. In this connection the following considerations are of importance.

The railway route is unusual in two respects (Fig. 1). It leaves tidewater and traverses the whole length of the Kenai Peninsula, crossing two passes and reaching tidewater again at the head of the Turnagain Arm of Cook Inlet. The reason that the seaport Seward is utilized rather than some harbor on Cook Inlet itself, is involved with the swift tides, the storms, and especially the winter condition of ice-covered sea in Cook Inlet. Accordingly, although it is over one hundred miles farther to the Seward terminal, this harbor is used because it is free from sea ice the year round.

The second respect in which the Alaska Northern railway is unusual is that the present, long, mountainous line to the Seward seaport was built at a cost of about \$5,000,000,⁵ rather than a much shorter line from the head of Turnagain Arm to a good harbor on Passage Canal in Prince William Sound (Fig. 1). This would have saved over fifty miles of railway but would have involved one expensive tunnel. The pass which leads from Turnagain Arm to Prince William Sound is now occupied by a glacier which advanced and filled this pass some time between 1794 and 1880.⁶ If before 1794 a railway had been built through this ice-free pass, which rises only slightly above sea level, it would have been covered by over one thousand feet of ice in the subsequent advance of the Portage Glacier, which now occupies the pass.

Another short line for a railway between these same points, by a slightly longer route from Passage Canal through a valley not occupied by glaciers,⁷ has many advantages and certain disadvantages in con-

⁵ Brooks, A. H., *Railway Routes in Alaska*, Nat. Geog. Mag., Vol. XVIII, 1907, p. 185; Bull. 442, U. S. Geol. Survey, 1910, pp. 29-30.

⁶ Martin, Lawrence, *Jour. Geol.*, Vol. XIX, 1911, p. 458.

⁷ See report on the longer of the two short routes from Passage Canal. E. F. Glenn, *Reports of Explorations in the Territory of Alaska*, 1898, War Dep't., Adj. Gen. Office, No. XXV, 1899, pp. 103-104;

Luther S. Kelly, *Ibid.*, pp. 289-293;

J. S. Herron, *Explorations in Alaska*, 1899, War Dept., Adj. Gen. Office, No. XXXI, 1901, pp. 11-17.

nection with snow slides and with the glacial streams which flow through the valley.

We feel certain that, including the cost of the long tunnel, a railway only eleven or twelve miles long and practically at sea level could have been built from Passage Canal to Turnagain Arm for much less than the \$5,000,000 used in the construction of sixty-five miles of railway from Seward to Turnagain Arm. This would have resulted in a marked saving of grades, a saving of distance, and an elimination of nearly all of the glacier complications which still threaten the Alaska Northern Railway. If the government does purchase and extend this railway it may still be cheaper to adopt the Passage Canal terminal, as could possibly be done with the shortest route and the longest necessary tunnel for less than \$2,000,000.

The harbor in Passage Canal was shown by soundings taken by the junior author in 1910 to be quite as good for ocean steamships as Resurrection Bay, upon which Seward is located. Practically no icebergs float into Passage Canal or Prince William Sound from Port Wells. The possible disadvantage in this respect could never be as great as that which will come to Seward if the Bear Glacier (Fig. 1), at the mouth of Resurrection Bay on the western side, advances a quarter to a half mile and sends floating icebergs into the path of the ocean steamships there. The maximum possible activity of the glaciers tributary to Passage Canal and to the head of Turnagain Arm could never be such a menace to the building and maintenance of a railway, as are the Spencer and Bartlett Glaciers on the Alaska Northern Railway, particularly if the railway were protected by a tunnel in the critical area of snow slides and glaciers near Passage Canal. The Bartlett Glacier, though now inactive, could, by a very moderate advance, completely block the northern pass across the Kenai Mountains. Indeed, the railway goes so close to the glacier that even the slightest of advances will do great damage. The Spencer Glacier constitutes an even greater danger to the railway, as has been described on the preceding pages.

OTHER GLACIAL STREAM COMPLICATIONS IN ALASKA.—That the foregoing is not a unique case of man's struggle with glacial streams is indicated by the following specific cases from other parts of Alaska. At the town of Valdez, where a glacial stream has several times done considerable damage to property, dikes of piling have only resulted in temporary relief. The latest of these raids by the glacial stream came in the summer of 1911. At Castner Glacier, in the Delta Pass across the Alaska Range, traffic was interrupted at the time of our

^aAlthough each of these officers except Mr. Kelly reported adversely on this for a government mail route it is well worth considering for a railway with a tunnel, though to our mind not as good as the shorter direct route, with a tunnel in the mountain wall immediately north of Portage Glacier.

visit in the summer of 1911 because the powerful glacial stream shifted out from under a government bridge. At Kennicott Glacier during the same summer several piles were removed from a railway bridge by a swift glacial stream, a common experience along the Copper River.

Certainly the engineers of the Alaska Northern Railway have now acquired a knowledge of and a respect for glacial streams, as have many others in Alaska. Nevertheless, the respect is not yet adequate. We have never seen mention, for example, that there are grave, glacial stream problems in connection with the proposed railway from Controller Bay to the Bering River coal field. The many streams from the great Bering Glacier, a piedmont ice tongue nearly as large as the Malaspina, might make this route entirely impracticable for a railway. We ourselves should regard the glacial stream problem at Controller Bay as a factor not inferior to the harbor problem. We should feel gratified if the publication of this paper would prevent the building of any more railways or roads in Alaska before adequate consideration is given to the adjacent glaciers and the glacial streams. Because the Copper River and Northwestern Railway, for example, has not yet had grave difficulties with the streams of the Sheridan, Allen, Heney, and Kennicott Glaciers there is no assurance that the next year or two may not bring forth railway problems as grave as those which the Alaska Northern has had to cope with at Spencer Glacier, where the railway engineer so skillfully accomplished the diversion of the glacial stream described in this paper.