ON THE GLACIATION OF THE NORTHERN PART OF THE CORDILLERA, WITH AN ATTEMPT TO CORRELATE THE EVENTS OF THE GLACIAL PERIOD IN THE CORDILLERA AND GREAT PLAINS.

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ON THE GLACIATION OF THE NORTHERN PART OF THE CORDILLERA, WITH AN ATTEMPT TO CORRELATE THE EVENTS OF THE GLACIAL PERIOD IN THE CORDILLERA AND GREAT PLAINS.

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Broadly viewed, the Cordilleran region of British Columbia and the adjoining part of the Canadian Northwest Territory to the north of that province, may be said to constitute an elevated mountainous zone bordered by two dominant ranges—that of the Rocky mountains proper on the northeast and that of the Coast ranges on the southwest. The width of this zone is about 400 miles, and on one side of it lies the wide area of the great plains, on the other the Pacific ocean together with a partially submerged outer mountain-range of which Vancouver island and the Queen-Charlotte islands are projecting parts.

In a communication which has already appeared in this journal,[2] the writer has briefly outlined the principal observa-

[1]This article may be considered as a partial abstract of a paper read by the author before the Royal Society of Canada, May 29th, 1890.
[2]Vol. III, p. 249.

tions in accordance with which he has been led to believe that this part of the Cordillera of the West was, in the Glacial period, covered by a great confluent glacier-mass. Evidence of the existence of the southern part of this great ice-mass was, at an early stage in his investigation of the glacial phenomena of the region, obtained in the corresponding part of the interior plateau of British Columbia; and though doubts were at first entertained as to the mode by which the traces of a general, as distinct from the local, glaciation of the region might be explained, these were solved at a later date.[3] Still later, the writer was enabled, while engaged in an exploration in the Yukon district, to find evidence of the northwestward extension of the same confluent glacier and approximately to determine its limits in that direction. Having thus surrounded the area of this great glacier, it was proposed to name it the *Cordilleran Glacier* in order to distinguish it from the second and larger ice-cap by which the northeastern part of the continent was at the same period more or less completely covered.[4]

The Cordilleran glacier, as thus defined, had, when at its maximum development, a length of nearly 1200 miles. The main gathering-ground or *névé* of the *mer de glace* was contained approximately between the 55th and 59th parallels of north latitude, that part of the ice which flowed northwestward having a length beyond these limits of 350 miles, that which flowed in the opposite direction a length of about 600 miles. When at its greatest, a portion of its ice also passed off laterally by gaps transverse to the Coast ranges, and filling the wide valley between Vancouver island and the mainland, the ice there divided and flowed in opposite directions as the subsidiary, but yet large, glaciers of Queen-Charlotte sound and the Strait of Georgia. Ice from the main *mer de glace* does not appear to have crossed the Rocky Mountain range proper, on the other side, though considerable local glaciers were at the same time developed on the northeastward slopes of this range.

That portion of the Cordilleran glacier which moved southeastward along the interior plateau of British Columbia, is now known, from numerous observed instances of striation crossing high points, to have covered the summits of isolated mountains of 7000 feet and over in hight; a circumstance which implies that the ice reached a general thickness of 2000 to 3000 feet above even the higher tracts of the plateau, while it must have attained a thickness of over 6000 feet above the main river-valleys and other principal depressions of the surface.[5]

[3] Quart. Journ. Geol. Soc., Vol. XXXVII, p. 283.
[4] Geol. Mag., August, 1888.

The existence of this great Cordilleran glacier is naturally the first event of the period of glaciation of which evidence has been found in the region, as its ice-mass was competent to remove all signs of the more local growing glaciers which must have occurred during the early stages of the period of cold.

The object of this paper is to sketch briefly, in the first place, the subsequent history of the events of the Glacial period in this part of the Cordillera, and in the second, to endeavor to show in what way these events may be connected with those of the same period found on the Canadian great plains. In so doing it will not be possible to pursue the inductive method by which the propositions here stated have been reached, nor even to do more than to refer to the nature of the evidence upon which the various statements are based. Much of this evidence has however already been published in several papers written during the past fifteen years, and a summary of that which has not yet been made public is contained in a forthcoming more detailed memoir on the same subject. For this reason, the writer feels that he must claim the indulgence of the reader to some extent, in here advancing hypotheses without adequate proof, and without even giving in detail the reasons which have led him to modify suggestions already made by himself at various stages in the investigation.

During the maximum of the Cordilleran glacier, it appears that the Cordillerian region stood at a considerable higher level than it now does, while an important part at least of the great plains was depressed to such an extent as probably to admit waters in connection with, and at the level of those of the sea. The eventual retreat of the Cordillerian glacier was contemporaneous with, if not caused by, a subsidence of the mountain region.

The first effect of the decay of the great glacier appears to have been the production of lakes upon its surface or within the central part of the southern portion of its area, in

[5] These statements depend in part on facts published in the Geological Magazine, August, 1889; in part on additional evidence yet unpublished.

the relatively dry region of the interior plateau. Along the borders of one or more such englacial lakes, terraces, composed of material resembling boulder-clay, were formed on projecting highlands.[6] The best marked and highest terrace to which this origin is attributed, has an elevation of about 5290 feet above the present sea level, and this terrace, (or others at or about this level,) has now been recognized in a number of places. Such englacial lakes continued to increase in size and to become lower in level, for some time, while the general subsidence also progressed. There is also some evidence to show, that after the final draining of these lakes and as the great glacier retreated from the interior plateau, it was followed by gradually deepening water which was in communication with that of the sea. The boulder-clay deposit of the interior plateau is believed to have been formed during this retreat, at, or in water contiguous to, the retiring ice-front. The lower boulder-clay of the littoral was laid down under similar circumstances, but at a somewhat earlier stage in the glacial decadence, and as the submergence became deeper, stratified interglacial silts were formed above it in the same region.

The nextchange is supposed to have been a re-elevation of the Cordillera, during which most of the higher terraces of British Columbia were formed, and some further evidence of which is offered by the removal at about this time of much of the previously formed boulder-clay from some of the larger river valleys.[7] The land eventually stood probably as high and possibly higher than it now does relatively to the Pacific, and in consequence of its elevation and the severe general conditions of the climate of the period, it became again covered to a considerable extent by glaciers, which, however, were as a rule, of a local character and in evident relation to the various mountain ranges.

Following the maximum of this second period of glaciation, came apparently a second subsidence, less in amount than the first, but sufficient to depress the Cordilleran belt generally, to a level about 2500 feet below that which it holds at the present day. At this stage, and while glaciers of considerable size still occupied the mountain-valleys, and the position of the *névé* of the former Cordilleran glacier was probably held by an ice-cap

[6] These must at the time have resembled the *Nunataks* of Greenland.
[7] The date assigned to this removal depends on the existence and relations of the silt deposits next alluded to, in the same valleys.

of some size, 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 Cordillera region for a length of about 1200 miles. These deposits, the writer has in previous publications referred to as the *White Silts*, and as observations accumulated, it at length became evident that these silts possess more than a local significance. They appear in fact to constitute a well marked formation, characterizing a definite and long maintained stage of stability in the glacial history. In the various more or less completely separated basins in which they occur, their level is so nearly identical, as apparently to show that this must be referred to a common cause, which it is believed, in consideration of all the circumstances and particularly in view of the vast area which the observations here referred to cover, can have been no other than the elevation of the sea at the time. No morainic or other accumulations have been found such as to account for the production of lakes in which these silts might be supposed to have been deposited,and had they been formed in separate lakes held in either in the manner suggested or by glacier-dams, they would, in a region of such bold relief as the Cordillera, be expected to occur at different levels in each basin.[8]

The level which is obviously the important one in dealing with this subject, is that of the upper limit of the main White Silt deposit in each basin, and in order to present the salient facts of this important episode in the glaciation of the Cordillera, the significance of which is here for the first time pointed out, the general result may be given as in the subjoined list.[9]

[8] The occurrence of two such areas at the same level, under the circumstances, might be characterized as a remarkable coincidence, of three as an extraordinary coincidence and if several as a coincidence of an astounding character, unless under the influence of a common cause as here suggested.

[9] In classing together the principal occurrences of silty deposits of the Cordillera, under the name of the White Silt formation, it should be noted that the silts so included are not the only ones of the region. Occasional small and local occurrences of silts at considerably higher levels, are found, and some of these are known to be due to glacier-dammed lakes of an earlier stage. The lower level of the White Silt formation, is also to some extent indefinite, as it is probable that some portions of it were deposited in relatively deep water, while in other places, rearranged silts have since been formed at lower levels, and these it is not always possible to distinguish from those of the original main deposit.

Normal upper level of the White Silt formation in various points of the Cordilleran region.

District.	Normal highest level in feet above sea, of main silt formation.
Columbia-Kootanie valley, between Rocky mountains and Gold ranges. (Opens to the south.)	2700.
Southern part of Interior Plateau. Silts here chiefly confined to main valleys. (opens to the south and to the Pacific.)	2500.[10]
Northern part of Interior Plateau. Silts here cover an area of about 1000 square miles. (Opens to Peace River plains and to the south.)	2400.
Peace River Plains. Silts here cover surface of plateau (In drainage basin of Mackenzie river.)	2500.
Upper valley of Stikine. (Opens to Pacific.)	2200 to 2300
Upper Liard Basin. (Opens to Mackenzie.)	2400.
Upper Yukon Basin. (Drains to Behring sea.)	2700.

The material of the White Silts was evidently afforded by streams flowing from adjacent glaciers, the approximate limits of which at the time are shown by the termination of the Silts as they approach the various ranges at levels lower than those elsewhere attained by these deposits.[11]

The evidently somewhat rapid retreat of the already reduced glaciers of the second period, was apparently not in relation to subsidence of the Cordillera, but on the contrary, seems to have been contemporaneous with, or was soon followed by, a progressive movement in elevation. It is supposed that this final decay of glaciers occurred rather in connection with a general amelioration of climate, by which the close of the glacial period as a whole was brought about, as to the cause of which no opinion is here offered.

[10] The greatest development of silts here is below 1700 feet, which with other facts, is supposed to indicate partial local elevation, during the progress of the deposit. The upper level here given is, however, well marked.

[11] Mr. I. C. Russell, in a valuable paper entitled *Notes on the Surface Geology of Alaska*, proposes to name the body of water in which the silts of the Lewes have been laid down, 'Lake Yukon.' Holding as I do that this water was not that of an isolated lake, I would suggest the name 'Yukon Inlet.' The silt formation on the Lewes has an upper limit of about 2150 feet, while in the contiguous region of the Upper Pelly, the limit is found at 2700 feet, as given above. The lower level of the higher part of the formation on the Lewis, I believe to be due to the fact that the whole upper portion of this valley was occupied by glacier-ice at the time of its deposition, Cf. Report of Progress Geol. Surv. Can., 1877-78 p. 153 B; Annual Report Geol. Surv. Can. 1887-88, Part B.; Bull Geol. Soc. Am., Vol. I.

It is worthy of note, that most of the long fiord-like lakes of the mountain regions of British Columbia, can be shown to occupy portions of the abandoned beds of the glaciers of the stage of the White Silt formation. To the elevation which began about the time at which we have now arrived, the draining of he White Silt basins, together with the formation of all the lower-level terraces, is supposed to be due. There appears, however, to have been one well marked pause, during which the littoral, at least, was at a hight about 200 feet lower than it now is, and there is in addition some evidence of a succeeding movement in elevation of several hundred feet, which, if it occured, constitutes the last important change of the kind in the region.[12]

Having elsewhere discussed the glaciation of the great plains at some length, [13] the writer may now without attempting any further description of the phenomena which they present, offer the subjoined comparative scheme of events in the areas of the plains and the Cordillera respectively. Under this scheme, he has endeavored to include all the known facts and to deal with these in the light of personal familiarity with the greater part of both regions, and while it can scarcely be hoped that this scheme, here tentatively presented, will be found to stand the test of further investigations in all its details, it is believed that it may at least be accepted as indicating the mode in which the facts met with must be explained. In explanation of the fundamental idea involved in this comparison it may be premised, that already in Tertiary times some evidence is given of correlative phases of elevation and depression as between the Cordillera and the great plains, and these, it is believed, may have culumiated in a series of important correlative movements during the Glacial period, in which the plains were in a position more or less exactly complementary to the Cordillera. The general application of such correlative movements in the Glacial period, has lately been forcibly advocated by Mr. Warren Upham [14], and appears to the writer to hold

[12] Cf. Canadian Naturalist, February 1878.

[13] Geology and Resources of the 49th Parallel, Chapters IX and X; Quart. Journ. Geol Soc., Vol. XXXI p. 603., Vol. XXXVII, p. 276; Report of Progress Geol. Surv. Can., 1884-85, p. 139 C. See also R. G. McConnell, in Ann. Report, Geol. Surv. Can., 1885, Part C., and J. B. Tyrrell Ann. Report Geol. Surv. Can. 1886, Part E.

[14] Wright's Ice Age in North America. Appendix A.

out the prospect of a solution of many of the difficulties which have so far attended the explanation of the facts of this period.

Scheme of Correlation of the Phenomena of the Glacial Period in the Cordilleran Region and in the Region of the Great Plains.

Cordilleran Region.	*Region of the Great Plains,*
Cordilleran zone at a high elevation. Period of most severe glaciation and maximum development of the great Cordilleran glacier.	Correlative subsidence and submergence of the great plains, with possible contemporaneous increased elevation of the Laurentian axis and maximum development of ice upon it. Deposition of the lower boulder-clay of the plains.
Gradual subsidence of the Cordilleran region and decay of the great glacier, with deposition of the boulder-clay of the interior plateau and the Yukon basin, of the lower boulder-clay of the littoral and probably also, at a later stage (and with greater submergence) of the interglacial silts of the same region.	Correlative elevation of the western part, at least, of the great plains, which was probably more or less irregular and led to the production of extensive lakes in which interglacial deposits, including peat, were formed.
Re-elevation of the Cordilleran region to a level probably as high as or somewhat higher than the present. Maximum of second period of glaciation.	Correlative subsidence of the plains, which (at least in the western part of the region) exceeded the first subsidence and extended submergence to the base of the Rocky mountains near the 49th parallel. Formation of second boulder-clay, and (at a later stage) dispersion of large erratics.
Partial subsidence of the Cordilleran region, to a level about 2500 feet lower than the present. Long stage of stability. Glaciers of the second period considerably reduced. Upper boulder-clay of the coast probably formed at this time, though perhaps in part during the second maximum of glaciation.	Correlative elevation of the plains, or at least of their western portion, resulting in a condition of equilibrium as between the plains and the Cordillera, their *relative* levels becoming nearly as at present. Probable formation of the Missouri côteau along a shoreline during this period of rest.
Renewed elevation of the Cordillera region, with one well maked pause, during which the littoral stood about 200 feet lower than at present. Glaciers much reduced, and diminishing in consequence of general amelioration of climate towards the close of the Glacial period.	Simultaneous elevation of the great plains to about their present level, with final exclusion of waters in connection with the sea. Lake Agassiz formed and eventually drained toward the close of this period. This simultaneous movement in elevation of both great areas may probably have been connected with a more general northern elevation of land at the close of the Glacial period.

Referring to the several correlative movements of elevation and of depression of the Cordillera and the great plains, above

set forth, it may be admitted on *à priori* grounds as not improbable that such conditions of oscillation once initiated, in consequence of the interaction of whatever forces, might have a tendency to repeat themselves several times before a stable condition was regained,—a state of equilibrium being in the end attained either by the general decrease in intensity of the operating causes, or by the final ascendency of one class of these. It may also be pointed out that the supposed sequence of events is generally in accordance with the view that the epochs of maximum glaciation of the Cordillera, were those of its greatest elevation, while the decay of its glaciers was in both instances accompanied, if not caused, by subsidence leading to the encroachment of the oceanic waters. The supposed flooding of the great plains (the glaciated portion of which lies almost entirely in the Arctic basin) by cold northern waters, while the Cordillera stood as a much elevated land between these and the warmer waters of the Pacific, in itself goes far to explain the conditions under which the excessive precipitation required for the production of the Cordilleran glaciers might occur.

The sequence of events here advanced is furthermore compatible with the belief that the weight of a ponderous ice-cap may alone be sufficient to produce subsidence of the land, and with the idea that such an ice-cap may thus eventually become self-destructive, by obliterating the elevation to which its existence is in the first instance largely due.

Though independently based upon, and primarily intended to include the observed phenomena of the Glacial period in the northwestern part of the continent alone, it is also worthy of remark, that the elevation believed to have affected the Canadian plains during the interglacial episode, is to some extent confirmed by the fact that Messrs. Chamberlin and Salisbury find evidence of a similar upward movement of the upper Mississippi valley at a corresponding time, to an amount of about 1000 feet.[14] It is further noteworthy that the two great correlative movements of elevation of the Cordillera and depression of the great plains here admitted, correspond in a general way with the principal similar, though less considerable, changes in level, which are accepted by Mr. W. J. McGee as explaining changes which affected the region of the middle At-

[14] Sixth Annual Report U. S. Geol. Survey, p. 214.

lantic slope, and indicated there by the Columbia formation.[15] As in the case of the great plains, both changes in level were there in the sense of depression, followed by re-elevation, but if we may believe that depression in one region is made up for by elevation in another, the only important point to which attention need be drawn, is that both maxima of glaciation, on the Pacific as well as on the Atlantic side of the continent, were coincident with considerable disturbance in level.

It may be added in conclusion, that it is now distinctly known, as the result of work done under the auspices of the Geological Survey of Canada, and more particularly of observations by the writer and his colleagues, Messrs. McConnell and Tyrrell, that the extreme margins of the western and eastern glaciated areas of the continent barely overlap, and then only to a very limited extent, while the two great centers of dispersion were entirely distinct.[16] For numerous reasons which can not be here entered into, the writer does not consider it probable or even possible that the great confluent glacier of the north-eastern part of the continent extended at any time far into the area of the great plains, but erratics and drift derived from this ice-mass did so extend and are found between the 49th and 50th parallels stranded on the surface of moraines produced by the large local glaciers of the Rocky mountains. Recognizing, however, the essential separateness of the western and eastern confluent ice-masses, and the fact that it is no longer appropriate to designate one of these the "Continental glacier," the writer ventures to propose that the eastern *mer de glace* may appropriately be named the great *Laurentide glacier*, while its western fellow is known as the *Cordilleran glacier*.