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GM Dawson and the Glaciation of Western Canada

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See table of contents

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Article abstract

This paper examines the contributions of G.M. Dawson (1849-1901) to our understanding of the glaciation of the Interior Plains and Cordillera of Western Canada. Dawson is highly esteemed in the history of Canadian geology for his extensive explorations beginning in 1873, which contributed greatly to our knowledge of geography and the geology of Western Canada. The distances travelled and the areas described by Dawson were truly astonishing - hard to comprehend as the accomplishment of a man who was stunted in growth and deformed in stature by a childhood spinal disease,which was indirectly responsible for his early death. Dawson is most widely recognized for his conception of a "Cordilleran glacier" over BritishColumbia, which has proved correct, and continues to be refined rather than revised. This should have placed him squarely within the group of later nineteenth century Canadian geologists who switched their allegiance from the Drift Theory to the Glacier Theory, or who matured wholly with the latter.However, from this first detailed examination of Dawson's works on glaciation, it emerges that, except for the "Cordilleran glacier" hypothesis, in amajority of cases he argued not even the most obvious objections or the plainest of alternatives to his 'Drift' explanations, although he cannot have been unaware of them. No explanation of this rigidity readily presents itself, other thanpossible filial respect for the reputation of his scientifically conservative father,J.W Dawson. Dawson's later contemporaries, including Bell, Low and Tyrrell, ignored rather than challenged his interpretations, developing 'Glacial' theory along paths it has followed to the present day.

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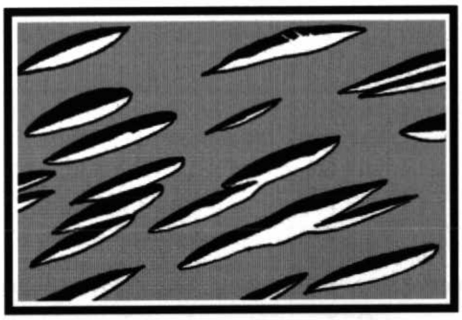

GM Dawson and the Glaciation of Western Canada

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SUMMARY
This paper examines the contributions of G.M. Dawson (1849–1901) to our understanding of the glaciation of the Interior Plains and Cordillera of Western Canada. Dawson is highly esteemed in the history of Canadian geology for his extensive explorations beginning in 1873, which contributed greatly to our knowledge of geography and the geology of Western Canada. The distances travelled and the areas described by Dawson were truly astonishing – hard to comprehend as the accomplishment of a man who was stunted in growth and deformed in stature by a childhood spinal disease, which was indirectly responsible for his early death. Dawson is most widely recognized for his conception of a "Cordilleran glacier" over British Columbia, which has proved correct, and continues to be refined rather than revised. This should have placed him squarely within the group of later nineteenth century Canadian geologists who switched their allegiance from the Drift Theory to the Glacier Theory, or who matured wholly with the latter. However, from this first detailed examination of Dawson's works on glaciation, it emerges that, except for the "Cordilleran glacier" hypothesis, in a majority of cases he argued not even the most obvious objections or the plainest of alternatives to his 'Drift' explanations, although he cannot have been unaware of them. No explanation of this rigidity readily presents itself, other than possible filial respect for the reputation of his scientifically conservative father, J.W. Dawson. Dawson's later contemporaries, including Bell, Low and Tyrrell, ignored rather than challenged his interpretations, developing 'Glacial' theory along paths it has followed to the present day.

RÉSUMÉ
Le présent article porte sur l'apport de G.M. Dawson (1849–1901) à la compréhension du glaciaire des plaines intérieures et des cordillères de l'Ouest canadien. Dawson est une figure emblématique de l'histoire de la géologie canadienne de par l'importance des travaux d'exploration qu'il a débuté en 1873 et qui ont tant contribué à notre connaissance de la géographie et de la géologie de l'Ouest canadien. Les distances qu'il a parcourues et l'étendue des régions qu'il a décrites étonnent vraiment, d'autant qu'ils ont été réalisés par un homme dont le développement avait été entravé par une maladie spinale d'enfance responsable d'un handicap morphologique et indirectement responsable de mort prématurée. On le reconnaît surtout pour son concept de "glacier cordillérien" recouvrant la Colombie-Britannique, dont la réalité s'est avérée et qui fait l'objet de raffinement plutôt que de correction. Par ses idées, il aurait dû faire partie intégrante du groupe des géologues canadiens de la fin du dix-neuvième siècle dont l'allégeance est passée de la "théorie marine" à la "théorie glaciaire" ou dont la carrière s'est dans le cadre de cette dernière. Cependant, des résultats de cette première étude détaillée des travaux de Dawson sur le glaciaire, il ressort qu'hormis l'hypothèse du "glacier cordillérien", dans la majorité des cas, il n'a par discuté des objections les plus patentes ou des possibilités les plus évidentes à ses explications "allochtones", et cela malgré qu'il soit inconcevable qu'il n'en n'ait pas été au courant. On ne voit pas d'explication de cette rigidité intellectuelle, autre que celle possible du respect filial pour la réputation de son père, J.W. Dawson, scientifique conservateur. Les contemporains de fin de carrière de Dawson, dont Bell, Low et Tyrrell, ont tout simplement ignoré ses interprétations au lieu de les contester, en développant la théorie autochtone selon des voies suivies jusqu'à nos jours.

INTRODUCTION
In a historical review of glacial geology in America, Fairchild (1898, p. 165) identified the following "periods in the history of drift-study":

- undisputed reign of diluvial hypothesis — to 1841
- discussion of glacial hypothesis — 1841–1848
- gradual adoption of glacial theory — 1849–1866
- development of glacial geology — 1867 to date

These periods may be recognized in Canadian glacial studies. Reporting on work in Upper Canada (present-day southern Ontario) carried out in the first two years of operation of the Geological Survey of Canada (GSC), Murray (in Logan, 1845, p. 89) made a diluvial interpretation of grooves and scratches on bedrock, loose sandy deposits and perched boulders, concluding that "at some remote period the surface has been covered with water having a current from the north". Falling within Fairchild's "diluvial" period, this adhered to Lyell's interpretation for the same area, made while he was travelling in North America at the same time (Lyell, 1843).

In the following "discussion" period, in the Temiscamingue district, northwest of Ottawa, Logan, the Survey's first Director (1842–1869), interpreted parallel grooves and scratches on bedrock, and hummocky deposits he identified as "moraine" to mean that "this part of the valley of the Ottawa [River] may have been the seat of an ancient glacier" (Logan, 1847, p. 74). This was the first attribution of such features in Canada to glacial action, in advance of much American thinking on similar and associated features. In Canada, after Logan's glacial interpretation, Murray was more circumspect in Survey reports through the 1850s, eschewing hypothesis and restricting himself to description.

In the monumental 'Geology of Canada', reviewing the first twenty years of work by the GSC, Logan (1863) acknowledged "a young civil engineer", Robert Bell, as author of the chapter on "Superficial Geology". Regarding the "rounded, grooved, and polished surfaces" of rock outcrops, Bell, in only his early twenties, wrote that "the evidences ... appear to favour the supposition that they have been caused by the action of glaciers" (Logan, 1863, p. 888). As for ubiquitous loose boulders, Bell's accounts in this volume do no more than imply his belief in a glacial origin, although when he once ventured an explanation he left room for some to have "dropped from icebergs" (p. 896).

Even before he became a full-time officer of the Survey in 1869, Bell surveyed extensively, as a GSC assistant and solo, in the St. Lawrence valley, the Gaspé Peninsula, and Manitoulin Island. On permanent staff, he explored a great variety of terrains, the best-known being those across the Shield from its southern edge to Hudson and James bays. His reports on these surveys leave little doubt of his belief in the glacial origin of polish, striae, grooves, and lake basins in bedrock, as well as 'boulder clay' (today known as 'till') and erratics. (See Ami, 1927 for an appreciation and bibliography of Bell, a short biography by Waiser, 1998, and Zaslow, 1975 on Bell's career with the GSC.)

Bell can therefore be said to have led Canada into Fairchild's "gradual adoption" period. Whereas Bell continued in the 'Glacial' rather than the 'Drift' mode in his work in central and eastern Canada beyond the end of the century, at the same time the influence of G.M. Dawson's continuing adherence to the 'Drift' Theory for superficial deposits in western Canada led to an interpretive disjunction which, rather than being resolved, was swept aside near the close of the century. These interpretations are the subject of this paper, the object of which is to examine the arguments Dawson used, their development, and their assumptions, as well as to reveal arguments that were available but not used. First, a brief introduction to the man and the background to his work.

G.M. DAWSON

George Mercer Dawson was born in 1849 in Pictou, Nova Scotia, and educated in Montreal and at McGill College, where his father, J.W. Dawson, was Principal from 1855 to 1893. In childhood he developed a spinal disease that deformed his stature and stunted his growth after about twelve years of age (Zeller and Avrith-Wakeam, 1994). At home and at the college he would have been strongly influenced by his father's diluvialism, preponderant in turn during his education in Scotland, and through his close personal and scientific relationship with Charles Lyell. The elder Dawson was to publish an epochal work on the geology of Nova Scotia (J.W. Dawson, 1855), and, as well as other books and papers, a series of papers on 'Drift' phenomena in Canada, summarized in his final synthesis (J.W. Dawson, 1893; for biographical and bibliographical sources, see Adams, 1899; Eakins and Eakins, 1994; Sheets-Pyenson, 1996).

The GSC was based in Montreal from 1842 to 1881, but the influence on Dawson Jr. of Logan's glacialist views seems to have been small, if we rely on Dawson's writings, which throughout remained determinedly in the 'Drift' mode. From 1869–1872 he studied at the Royal School of Mines in London, where he likely would have shared 'Diluvial' and 'Drift' exchanges in formal and informal settings, reflecting the dominating influences on British geology of De la Beche, Lyell, and Murchison. The influence of glacialist A.C. Ramsay, on staff at the School, seems to have been as negligible as that of Logan.

Dawson returned to Canada in 1872. On his father's recommendation to Selwyn, the second Director of the GSC (1869–1895), he was appointed to the British North American Boundary Commission (1873–1875), and charged with investigating the geology and botany, and evaluating the settlement potential of the region between Lake of the Woods and the Rocky Mountains (Dawson, 1875a, b). This work was a response to the combined stimuli of (i) the accession of former Hudson's Bay Company lands, the vast Northwest Territories, to the new Canadian confederation of 1867; (ii) Manitoba's (1870) and British Columbia's (1871) joining the confederation; and (iii) American railroad and settlement surveys west of the Mississippi. Earlier western expeditions, the British 'Palliser' survey of 1857–1860 (United Kingdom, 1859, 1860) and the Canadian-sponsored Red River and Assiniboine expeditions of 1857 and 1858 (Hind, 1860) did not meet later Canadian requirements, nor were they specifically 'boundary' surveys.

Upon completion of this work, Dawson joined the GSC in mid-1875, a position possibly reserved for him in the previous arrangement between Selwyn and his father (Zaslow, 1975, p. 136). He concentrated his work in the Cordillera for four years, returning briefly to the Plains in the early 1880s and in 1894, but fieldwork was sacrificed to administration and writing government reports after his appointment as Assistant Director of the Survey in 1883, then as Director from 1895 until his death in 1901 (Adams, 1901; Zeller and Avrith-Wakeam, 1994; Zaslow 1975).

DAWSON IN THE SHIELD

Lake of the Woods, starting point of the Boundary Survey (Fig. 1, and for all place names), lies astride the rough, crystalline upland of the "Laurentian Axis" (as the Precambrian Canadian Shield was then known) and smoother Paleozoic sedimentary terrain to the west. By 1873 evidence had grown, in large part from Bell's explorations, that the Laurentian Axis had undergone glacial erosion and deposition by what Dawson (1875a) termed "a great confluent glacier". This had formed parallel scratches and grooves in bedrock, and the '*moutonee*' shape of rock knobs, and had transported erratics from distant sources. Dawson, however, found fault with the notion of local glaciation of the Axis, arguing that land with maximum elevations near 500 m was quite low to be considered the seat of such a glacier (glaciers 'traditionally' being thought of as issuing from highlands). Moreover, the regional slope of the Axis in the direction of striae "is scarcely sufficient to account for the spontaneous descent of an ordinary glacier" (Dawson, 1875a, p. 216).

Dawson solved this problem by proposing prior uplift of the Axis on which the glacier grew – more than 500 m would be necessary – then later subsidence to return it to its present level. The positive 'epeirogenic' movement (vertical in sense over sub-continental areas) was, in turn, opposite to that which, as explained in the next section, subsided the Plains to allow inundation by the polar ocean. Elevation was then required to return the Plains to dry land. As discussed more fully later in the paper, Dawson proposed similar opposing crustal movements between the Plains and the Cordillera.

These crustal 'ups and downs' should not be thought of as similar to the 'convulsions' conceived by earlier diluvialists. It is, however, easy to see an ideological connection to those movements that were supposed to have given rise to 'waves of translation', a scientific synonym for the Biblically loaded term, 'debacles'. In early 'Drift' schemes these waves, bearing icebergs, were supposed to be responsible for the scratching, grooving, loose sediments and boulders scattered over boreal regions. Here, it is enough to recognize that these crustal 'see-saws' maintained overall balance, an essential element of Lyell's uniformitarianism. I suspect that such balance was seen, at least implicitly, as a Divine expression, however free of religious bias these scientists claimed themselves to be.

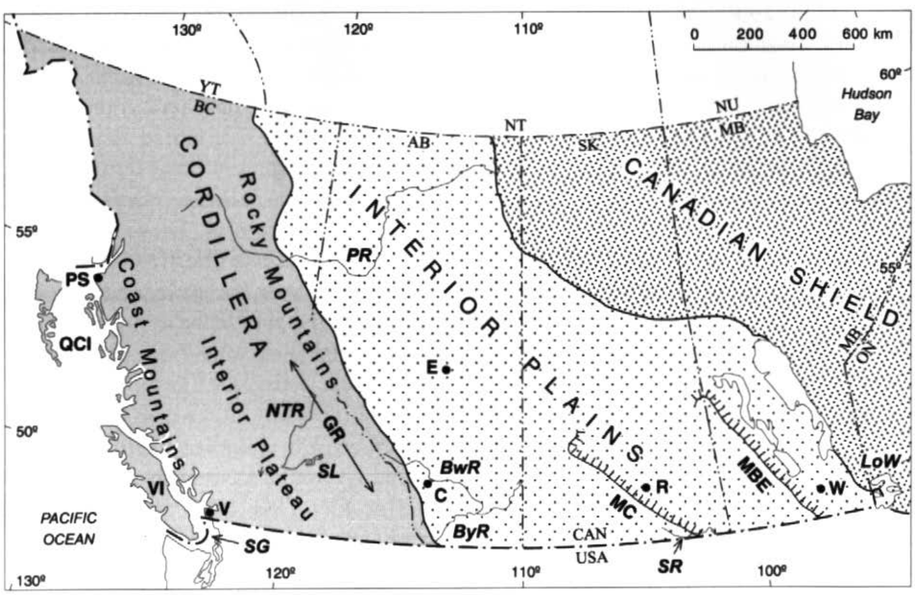

Figure 1 Western Canada: modern political boundaries, major cities, first-order physiographic regions (Shield, Plains, Cordillera), and location of places mentioned in text. *Settlements*, C - Calgary , E - Edmonton, PS - Port Simpson, R - Regina, W - Winnipeg; V - Vancouver; *rivers and lakes*, BwR - Bow River, ByR - Belly River, LoW - Lake of the Woods, NTR - North Thompson River, PR - Peace River, SL - Shuswap Lake; *other topography*, GR - Gold Ranges (Columbia Mountains), MBE - Manitoba Escarpment, MC - Missouri Coteau (in Canada), QCI - Queen Charlotte Islands, SG - Strait of Georgia, VI - Vancouver Island.

DAWSON ON THE PLAINS

Red River plain

From the Shield margin the Boundary Survey descended into the Red River plain, which Dawson, like Keating (1825) and Hind (1860) before him, recognized was underlain by thick lacustrine clay. Because the clay contained no erratics, and thus was not 'boulder clay', Dawson saw that no icebergs were required for its formation. This, despite the proximity of "a great confluent glacier" to the east, and despite the fact that, to explain the 'drift' of the Plains, Dawson extended an iceberg-laden glacial sea from the calving margin of this glacier all the way to the Rocky Mountains – i.e., across the Red River plain. Dawson easily accommodated erratic stones at the surface of this plain as dropped from lake-ice floes.

As Upham (1890) was to conclude, following a Canadian invitation to extend his studies across the International Boundary into Manitoba, the Red River plain had indeed been the site of a lake, the glacial origin of which he surmised from the relations of shorelines to moraines. Although a "great confluent glacier" was supposed to cover the Laurentian Axis, and iceberg-deposited 'boulder clay' could therefore have been expected in the Red River plain, Dawson offered no comment on its absence.

Prairie Steps and The Coteau

The western beaches of this lake mark the lower slopes of the bedrock Manitoba Escarpment, which divides the First from the Second Prairie Step[pe] (please note that 'Step' and 'Steppe' are used in various sources, but the meaning is the same) . These "step[pe]s" were first recognized by the Palliser survey's geologist, Hector (United Kingdom, 1859) and confirmed by Hind (1860). Together with the Third Step[pe] , they are known today as the Manitoba, Saskatchewan, and Alberta plains, respectively (Bostock 1970). Dawson had little to say about the higher (second) level, concentrating his attention on the Missouri Coteau, which divides it from the Third Step[pe]. Crossing the 49th Parallel with a SE–NW trend, the Missouri Coteau (Fig. 1) is a subdued escarpment on Upper Cretaceous shales. Late Tertiary pediments slope eastward from an ancient divide behind the scarp crest, where morainic topography and patches of Tertiary fluvial conglomerate mask the plateau aspect.

Dawson described three topographic zones of the Coteau, the first characterized as "tumultuously hilly ... based on a great thickness of drift, ... forming the Missouri Coteau [proper]". On a geological section (Dawson 1875a, Pl. XIII, opp. p. 230) he showed thick drift banked against the buried escarpment to form a ramp about thirty miles (50 km) wide, and remarked on abundant Laurentian erratics there. Believing that the action of a glacier over these plains lacked an impelling gravitational force (i.e., there was no highland source), Dawson proposed that the hilly terrain and bouldery deposits surmounting the Coteau were built by icebergs drifting from the north and east on Arctic currents and grounding on the escarpment (Dawson 1875a, p. 237-238). Dawson later refined this interpretation, proposing that, on final eastward withdrawal of the sea from the Plains, the shore had paused at the Coteau, permitting bergs and floes to ground on it over a longer interval, piling up the erratics. The recognition of boulder concentrations on the Coteau and their interpretation as 'morainic' were earlier made by Hind (1860) based on the 1858 expedition, but Dawson (1875a,b) made no mention of this.

Allowing for various constraints such as time and coordination of activity on the accuracy of a survey such as Dawson's, it appears that he did not recognize the almost bare foot-slopes of the Coteau along the Boundary, preferring to emphasize the heavy 'drift'- and erratic-covered aspect, which would suit an iceberg scenario. Nor apparently was he aware that long segments of the Coteau scarp and plateau to the northwest, some not far from the Boundary Survey's track, are almost completely bare of 'drift', clearly displaying Late Tertiary pediment remnants sloping eastward between valleys descending on to the second prairie step. Had Dawson included these in his observations, his hypothesis of berg- and floe-grounding and 'drift' deposition may have been reworked.

The Plains Drift

There are several additional sources of confusion in Dawson's explanation of the glacial deposits in the Plains region. Dawson (1875a) repeatedly referred to westward and southwestward transport of erratics from their ready source in the "great confluent glacier" over the Laurentian Axis. Erratics of "Silurian" limestone were also obvious, from their pale colour and large size, hundreds of kilometres from source, so this "glacier" must have covered the Paleozoic outcrop, although this is not mentioned.

While westward transport is plain from lithological comparison, Dawson knew that atmospheric circulation over western Canada was from west to east, referring to the action of ice floes driven from the northwest and southwest by "prevailing winds" (Dawson, 1875a, p. 238). Later (although he probably knew it earlier), he referred to the Cordillera as the "condenser of the Pacific" (Dawson, 1890, p. 27), the source of moisture for his Cordilleran glacier. Dawson's icebergs, however, drifted *against* this circulation.

If ocean currents rather than winds are considered the prime mover of icebergs (with their draft nine times their freeboard), a current entering the Plains from the Arctic Ocean down the Mackenzie Valley (the only possible entry path) would have been deflected by the Coriolis effect against the foot of the Rocky Mountains. If the ridge forming the present Saskatchewan-Missouri drainage divide acted as even a partial barrier, the current would have turned eastward, away from the mountains, opposite to the direction Dawson required.

Another elementary objection absent from Dawson's reasoning on the Plains 'drift', and not raised subsequently, lies in the inability of icebergs to entrain bottom sediment. "The boulder clay of the plains, besides its far-travelled constituents, always includes a considerable and often a large proportion of relatively or quite local material" Dawson (1890, p. 64). From explorations in polar seas it was common knowledge in Dawson's day that bergs carried only material eroded before they calved. It could readily have been argued that it was impossible for 'drift' of Plains lithologies to have been eroded or deposited by bergs calved from ice over the Laurentian Axis.

A possible objection to a glacial sea over the Plains that Dawson did, however, raise, but quickly dismissed, was that no marine fossils were found in the drift, except for Cretaceous ones (Dawson, 1897). He noted that marine fossils were similarly absent in sediment cores from the Southern Ocean. Moreover, he argued (Dawson, 1875a), the glacial sea over the Canadian Plains would have been far from open ocean salinities, and would have been diluted with glacial meltwater from the Laurentian Axis and Cordillera. As well, where grounding bergs and floes disturbed soft shoreline sediment, high turbidity would have been inimical to marine life. This, despite his undoubted familiarity, mostly through his father's studies, with abundant marine fauna (from forams to walrus) in the drift of the St. Lawrence valley. There, a glacial sea, now known as the Champlain Sea, was distant from the open-ocean, nearly surrounded by melting ice, and floored and bordered by erodible sediment.

Over the Third Prairie Step[pe], Dawson commented on the paucity of 'drift' deposits, and, staying close to 'drift' assumptions, chose to emphasize recognition of quartzite erratics near the Rocky Mountain front. Now known as 'The Foothills Erratics Train' (after Stalker, 1956), and derived during the last glaciation from mountainsides above the Athabasca River valley, where it transects the Rocky Mountains (Roed, 1975; Jackson *et al.*, 1997), these enormous blocks were first mistaken by Hector (1861) for Huronian (next youngest to Laurentian). Hector, a diluvialist much in favour with Murchison, viewed them as having drifted westward in icebergs. Dawson readily concurred, using them as evidence for the western limit of marine submergence, at an elevation of about 1000 m.

With the 'Drift' argument thus gaining momentum, Dawson went on to propose a marine origin for mountain-front terraces in Kootanie [Kootenay] Pass, rich in rounded pebbles of purple Rocky Mountain quartzite (Dawson 1875a, p. 244, 258). But, in places along and beyond the Rocky Mountain front, Dawson also recognized quartzite-rich moraines and outwash terraces of Rocky Mountain glaciers, particularly near Waterton and in the lower Bow valley, east of present-day Calgary. For Dawson, there was no problem postulating glaciers here, with the mountains so close and remnant glaciers visible. Soon after, in the Cordillera, he made use of that association to postulate extension of mountain glaciers on to the Interior Plateau, but distinguished the plateau 'boulder clay' as of 'Drift' origin.

On the Third Prairie level, between the Coteau and the Rocky Mountains, Dawson recognized another prominent terrain feature: the widespread occurrence, far out into the Plains from the mountain front, of rounded quartzite gravel, both in unsorted drift deposits and in terraces. Even though he had seen the huge Foothills Erratics as Huronian, Hector (1861) had correctly concluded that quartzite "shingle beds" atop the Cypress Hills had a mountain source. Agreeing with Hector, Dawson had to seek a mechanism for *eastward* transport of quartzite gravel, opposite to the supposed westerly iceberg drift. The common association of the quartzite gravel with terraces, and thus with what he interpreted as "shorelines" (according to the Drift Theory, of course, they *had* to be shorelines), allowed him to postulate deposition, not from bergs in this case, but from ice-floes. These supposedly picked up the shingle from coastlines to the west, then drifted and occasionally grounded, as on the Coteau crest, in a glacial sea as it withdrew eastward (Dawson, 1875a, p. 238). It could have been asked why Laurentian surface drift and large erratics over the Plains had not been buried by this later floe-ice drift, but Dawson did not argue the point.

Alternatives?

Dawson was sufficiently confident in the Drift scheme as he applied it to the Canadian Plains that he was able to dismiss as an alternative a scheme proposed by Belt (1874) to explain vast level plains in Siberia, underlain by sand and loam. Belt argued that these superficial deposits had been laid in large lakes dammed by "an overflow of polar ice" (p. 495) toward the south. He did not specify in the first instance whether this was river, sea, or glacier ice, but he did argue that Siberia was too continental to support glaciers in the glacial period, so it may be supposed that he favoured sea-ice overflow. Dawson (1875a), however, mistakenly saw Belt's ice-dam as a polar ice-sheet, which made it appear more unlikely, since Agassiz' original polar ice dome had by this time lost favour.

Winchell (1873a, b) had arrived at a lacustrine hypothesis for the origin of clay plains in similar terrain in the American "Northwest" (present Minnesota). He argued deductively, from scenarios of ice-sheet retreat over basinal topography, for the development of proglacial lakes, noting similarity with the glacial geography of the Great Lakes. There, Whittlesey (1866) had developed a similar scheme, which holds today, thus opening the 'development' stage of investigations into the deglacial geography of the North American interior. Dawson, however, misconstrued the number and scale of Winchell's lakes, apparently believing only one, subcontinental lake had been proposed to cover the entire plains (like his ocean), believing also that it was dammed by an ice-sheet retreating northward into the Arctic down an inclined plane, the lake having only one outlet (southward through the Red River valley). Each of these misconstructions Dawson saw as inconsistent with several of his interpretations on the Plains. Strangely, he found that "the interpenetration of eastern and western drifts" (Dawson, 1875a, p. 262) near the Rocky Mountain front was not explained by such an ice-sheet, but (a) this was not the configuration Winchell proposed, and (b) why would Dawson's berg-laden polar ocean adjacent to Cordilleran glaciers be a better explanation for this interpenetration?

DAWSON IN THE MOUNTAINS

G.M. Dawson investigated four regions in British Columbia: north-central in 1875–1876 (Dawson, 1877), southern interior in 1877–1878 (Dawson, 1879), Queen Charlotte Islands in 1878 (Dawson, 1880), and across the Cordillera from the coast at Port Simpson to Edmonton in 1878–1879 (Dawson, 1881b). Here in the Cordillera, where he was surrounded by mountains and by landforms resulting from alpine glaciation, often still glaciated, similarly to Agassiz' Alps, Dawson's reliance on 'Drift' assumptions ironically is as obvious as it was in the Plains.

"The Cordilleran Glacier"

Dawson is universally applauded for conceiving the idea of the "Cordilleran glacier", but only a few of the features that he associated with this glacier (now known as 'ice sheet') demanded its existence. In Washington and Idaho, for example, a lobate terminal moraine required a large ice mass to the north over central British Columbia. Even in this case, however, in order to account for boulder clay over southern B.C., Dawson (1879) postulated regional subsidence to allow inundation by the deglacial polar ocean into the interior. Finding no sufficiently low inundation routes from the south, Dawson looked to the northeastern Rocky Mountain passes.

Secondly, in southeastern Vancouver Island, Dawson (1879) attributed shelly boulder clay, southerly striae, and grooves in bedrock to a large, south-moving glacier in Strait of Georgia. Astutely, Dawson saw that neither the Coast Mountains nor the Vancouver Island mountains could have supported glaciers large enough to feed it, so he drew an ice divide eastward to form the crest of an interior ice sheet – the Cordilleran – which, he proposed, discharged outlet glaciers through the Coast Mountains to the Strait glacier. Thirdly, Dawson (1881a, 1889) found glacial striae on mountain summits in the "Gold Ranges" (Columbia Mountains of Bostock, 1970, Fig. 1 this paper), which he realized required high-level passage of glacier ice. The remaining 'glacial' features of the Interior Plateau and its margins Dawson attributed to erosion or deposition in water bodies, for the impoundment of which a wasting Cordilleran glacier was required.

Terraces

Dawson's first two expeditions in British Columbia focussed on the northern and southern parts of the Interior Plateau. In the north, he recognized south-north striae, and boulder clay, which was distributed over the plateau, and occurred as terrace-like features flanking the hills and mountains rising above the plateau, and valley terraces composed of stratified silts. Since the boulder clay, according to the Drift Theory, had to be assigned an aqueous origin, and since it underlay what he saw as high-level terraces, a water body had to be raised to the terrace level, over 5000 feet above the sea. Prevailing geological thought saw it as more probable that, rather than the ocean surface rising, the Earth's crust had subsided to permit this. Dawson's interpretation demonstrates again the power of assumption over argument: boulder clay was aqueous, therefore so were the terraces.

Purely as an aside, I briefly visited examples of these 'terraces' in the North Thompson River valley, below Clearwater, B.C. Rather than 'terraces', I favour interpreting them there as marking a thermodynamic boundary within a valley glacier, above which ice was too thin and cold to achieve much erosion, and therefore bore little basal debris. Below, ice became thick enough to slide, erode bedrock, and, as it became overloaded, deposited basal debris as a shelf against the valley wall. More recent reports (*e.g.,* Fulton, 1975) show a valley-side upper limit to thicker till, but these features clearly deserve further study. In Dawson's favour, I will note here that nowhere else in his travels and work did he misidentify a feature; misinterpret, yes, but not misidentify.

'Glacial Lake Deposits'

In the southern Interior Plateau, Dawson noted "glacial" erosion of the rock surface (polish, striae), but left open the possibility of glaciers or icebergs, "Cordilleran glacier" notwithstanding. Erosion had been by a north-south movement. To continue in 'Drift' mode, Dawson referred to boulder clay over the interior, which was supposedly deposited in water, the source being marine inundation of the B.C. interior. Thus, the coastal drift (recalling Georgia Strait) would be correlated with its Interior equivalent, both responding to crustal subsidence following the glaciation responsible for the striae.

Interior water bodies then receded, forming 'finger lakes' in narrow valleys, in which thick, prominently stratified, lacustrine sediments – Dawson's "White Silts" – were deposited. He found no glacier or morainic dams for these lakes, although he had identified the silts as deposited by "streams or rivers discharging from glaciers not far removed" (Dawson, 1890, p. 44-45). Dawson noted that these silts were absent from some valleys, *e.g.*, that now occupied by Shuswap Lake, owing to remnant valley glaciers, an explanation confirmed in later glacial schemes (Fulton, 1969; Tipper, 1971). He also noticed that silt deposition in these valleys was interrupted by irregular masses of gravel, to which attention has recently returned, attributing them to contemporary landslips and debris flows (Eyles and Clague, 1991).

Dawson's prescience regarding the presence/absence of the silts, and their origin, contrasts with his pronouncement that "the mere existence of heavy local glaciers [in the silt-confining valleys]...may be called in to account for the great depths of the lakes *...unless we are prepared to admit that ... excavation of these valleys was produced by the wearing action of the glaciers themselves* ..." (Dawson, 1890, p.50, *my brackets and emphasis*). Dawson knew of the argument forwarded nearly thirty years before by Ramsay (1862), one of his professors in London, in favour of glacial overdeepening of lake basins in formerly glaciated regions: "I am aware that the occurrence of such U-shaped and wide valleys in mountain regions has often been attributed to the action of glaciers in such valleys. This explanation *does not*, however, *require to be resorted to here*, nor am I prepared to admit that it is a valid one" (Dawson, 1890, p. 19, footnote 1, *my emphasis*). Dawson obviously was aware that the silts were derived from the glaciers impounding the lakes, but failed to draw the conclusion that the original sediment was glacially eroded. Simple field examination would have revealed granitic minerals in the silt. Here, again, then, he dismissed glacial action from the argument. Preferring valley deepening under the *weight* of a glacier, however, he may have been sowing the seeds of crustal mobility to be harvested later in his crustal 'see-saws'.

In the southern B.C. interior, Dawson found the highest terraces flanking the mountains at over 5000 feet, so he first called upon a regional subsidence of that order to allow an ice-laden sea access to the interior. Best would be an origin in the Arctic Ocean, coursing southeastward through Bering Strait to join the Japan Current, and entering the B.C. interior via valleys connecting it to the glacial sea over the Plains. Later, Dawson's observations en route from Port Simpson to Edmonton (Dawson, 1881b) showed that these valleys (specifically, the Peace) were too narrow to have admitted the sea, although this valley contains prominent terraces composed of "White Silts". Submergence was further required by the Interior Plateau boulder clay, so again the argument changed, in favour of glacier-dammed lakes formed during wastage of the Cordilleran glacier.

Even this position, however, Dawson abandoned subsequently, but still not finally, for no other reason than, regardless of previous contrary argument, the sea *had* to be given priority. Dawson's interior glacier-dammed lakes he said "involve[s]... the coordination of so many circumstances that it appears to me improbable, while on the eastern slopes of the Rocky Mountains we seem to have clear proof of the invasion of waters which can not have been other than those of the sea to a height not far inferior to that required by the highest water-marks in British Columbia" (1879, p. 152B). He admitted that no marine fossils occurred in the Cordilleran 'drift' deposits, but explained this, as on the plains, as an effect of turbidity and fresh-water dilution. One can hardly escape the feeling that he was building walls of ever-increasing height around his argument, walls that had become more and more difficult to see over.

In Dawson's 1890 summation, difficulties with the origin of interior plateau water bodies in which to float icebergs and deposit boulder clay were given a final twist. Having first brought in the sea, then deciding that narrow passes made this improbable; having then proposed proglacial lakes, but then finding marine inundation logically irresistible; in this address Dawson returned to glacial lakes – a fourth hypothesis. The boulder clay of high terraces against the mountain flanks was now attributed to deposition in "englacial" lakes (Dawson, 1890, p. 41). Without a definition, he probably envisaged a 'supraglacial' position, so that this higher, terraced boulder clay could be seen as slightly older, deposited as the surface of the melting glacier lowered. The lower boulder clay over the plateau could then be seen as slightly younger, deposited in lakes dammed in front of the wasting glacier – in 'proglacial' lakes. My remarks on the North Thompson "terraces" would deny any such aqueous origin, placing them *beneath* the ice.

Two Glaciations

Dawson found undeniable evidence in alpine valley moraines that a second glaciation had occurred in highlands bordering and projecting above the Interior Plateau. But, the older boulder clay of the Plateau could not have been deposited by a greater extension of these glaciers beyond their alpine valleys, simply because 'boulder clay' was assumed to be of aqueous origin. Plateau and mountain glacial deposits are so different in colour and structure that different origins could reasonably have been argued. Ice that had crossed the plateau had travelled several times the distance travelled by valley glaciers descending the mountains, and had carried most of its load basally, crushing and abrading it. This had produced facetted and striated, subangular, even subrounded stones (and therefore mistaken for water-worn), set in a compacted, fine-grained matrix – classical 'boulder clay'. Valley glaciers, on the other hand, carried much of their load marginally and supraglacially, where little or no abrasion and crushing occurred, so that the deposit is coarse-grained, angular, and loose. Additionally, 'mountain tills' are pale grey and tan, derived from pale metamorphic and plutonic rocks; 'plateau tills' are a distinctive chocolate brown, derived from basalts. The absence of any argument from Dawson on this question again shows the strength of his 'drift' assumption.

SUMMARY

To tie together his conclusions about the glaciation of the Cordillera, the Plains, and the Laurentian Axis (Shield), Dawson (1890) devised a scheme of elevation and subsidence. In this scheme, elevation was required to englaciate the Shield and the Cordillera, while contemporaneous subsidence was required to flood the intervening Plains with an iceberg-laden extension of the polar ocean. Two glaciations had been recognized in the Cordillera, a pervasive one followed by a mountain phase, but the boulder clays had been deposited during a closely following subsidence. In the Plains, two glaciations had to be attributed to two submergences (Dawson, 1884, 1895). The boulder clays so produced could not, therefore, strictly be correlated with those of the Cordillera.

Dawson's B.C. field studies were subsequently limited by his appointment as Assistant Director of the Survey in 1883, Acting Director in 1885–1886 and Director in 1895. He presented his summation of the Cordilleran work to the Royal Society of Canada (Dawson, 1890), establishing relationships between glacial events there and on the Plains. In this report he maintained the originally proposed disposition of ice within the "Cordilleran glacier", with its northern and southern movement from a central divide, its passage across mountain tops, its discharge through Coast Mountain valleys to the Pacific, and through Rocky Mountain valleys to the Plains. This is where we need to recognize his prescience, since the concept of what is now called an "ice-sheet" over the Cordillera has stood to the present day, with details of its dynamic behaviour still emerging (Clague, 1989; Ryder and Maynard, 1991; Stumpf et al., 2000).

Finally, Dawson's tectonic explanation for glacier growth and wastage explicitly dismissed consideration of other causes of climate change, such as the astronomical theory of Croll (1867, 1875). We might argue *a posteriori* that the absence of chronological data prevented correlation of glacial and astronomical oscillations, but this proved no obstacle to the palaeoclimatic curves of European glacials (Zeuner, 1945) before chronometric methods were applied.

CONCLUSION

Appraisals of G.M.Dawson (Adams, 1901; Cole and Lockner, 1989; Zeller and Avrith-Wakeam, 1994) recognize a man of indefatigable energy, in spite of physical deformity, with immense talent widely applied to huge areas of Canada as well as to different disciplines and activities: geology, biology, ethnology, drawing and painting, and administration. One cannot, then, escape the question of what lay behind his rigid adherence to the defunct 'Drift' hypothesis. Even while he was working in the field, the general adoption of glacialism was energizing conceptual advances, some along lines that continue today. As mentioned earlier, Logan had adopted a glacial explanation in 1847, Bell by 1863 and continuing beyond the century. On his 'home turf', therefore, with Logan retired, Dawson had only Bell with whom to exchange ideas in most of the period during which he was writing his Plains and Cordilleran works. Relations between Bell and Dawson were, however, strained (Zaslow, 1975), inconducive to collegial debate, so both went their separate ways scientifically. South of the border, glacialism was promulgated by many prominent geologists from the mid-1860s (Fairchild, 1898); examples of glacial works can be found listed chronologically in memorials to three of the most prominent Americans, Chamberlin (Willis, 1929), Gilbert (Mendenhall, 1919), and Hitchcock (Upham, 1919). Dawson's 'Drift' interpretations cannot, therefore, be seen as guided by prevailing ideas. Admittedly, it was later in Dawson's career, when he had become burdened with administration, and was unable to expend time and energy on a 'paradigm shift', that new permanent and contract staff of glacial bent worked for the Survey, with, ironically, Dawson as its Director:

- R.J. Chalmers - first GSC glacial report 1885
- A.P. Low - 1885
- R.G. McConnell - 1886
- J.B. Tyrrell - 1888
- F.B. Taylor - 1894 (U.S., private)
- W. Upham - 1890 (USGS)
- A.P. Coleman - 1890 (Victoria Univ., Toronto)

Be that as it may, it is still noteworthy that Dawson could see fit to present to the Royal Society of Canada a synthesis of his ideas on glaciation of the Plains and Cordillera (Dawson, 1890) which was unchanged from what he wrote ten to fifteen years before.

It has been suggested to me that Dawson's unswerving advocacy of the marine origin of Plains 'drift' arose from his frequent encounters during the Boundary Survey with the obviously marine Cretaceous Bearpaw Shale, and with Cretaceous microfossils in the boulder clay (Dawson 1897). Dawson, however, knew that 'glacial' deposits were "post-Pliocene" in age; they had been the subject of previous papers, his father's included, with titles using this age descriptor (*e.g.*, J.W. Dawson, 1871). He therefore knew that the whole of the Tertiary period had intervened between deposition of the Bearpaw and the 'drift' deposits. Although it wasn't measurable in years, more than enough time was available for the conversion of marine Cretaceous conditions in the Plains to continental, even more than once. In fact, in his interpretation of Plains glacial history, Dawson (1890) did convert marine to terrestrial conditions — twice.

Another explanation, suggested by S. Zeller (pers. comm., 2001) may lie in Dawson's acceptance of Darwinian evolution, whereas his father was always opposed. Adherence to the Drift Theory may have been in recognition of his father's benificence (the Boundary Commission and GSC appointments), and a devoted reluctance to add to the injury Dawson Sr. had suffered in his dealings with The Royal Society (Sheets-Pyenson, 1996: p. 107-118).

G.M. Dawson accomplished an enormous amount of geological exploration, of which his work with superficial deposits and landforms was but a part, albeit an important part. One therefore feels disappointment that he did not ultimately join that pantheon of late nineteenth century glacialists who are seen today as the trail-breakers and on having to conclude that he erected some of the scientific barriers himself. If only he had 'seen over the next hill' while he was working in the mountains, his work would have added thrust to the 'development' stage of glacial geology in Canada, rather than prolonging the 'discussion' stage (Fairchild, 1898). Meanwhile, Robert Bell's extensive explorations over forty years, encompassing Dawson's field career, had added enormously to the picture of the ice-sheet glaciation of Canada. Then, closing in on the century's end, glacialists swelled the Survey's ranks, among them A.P. Low and J.B. Tyrrell, who delineated ice-sheet dispersal centres in, respectively, northern Quebec (Low, 1896) and Nunavut (Tyrrell, 1897), spreading ice-sheets across the Dawsons' glacial seas in the St. Lawrence Lowland and Interior Plains. Bell (1890) synthesized the picture in a paper that reads as modern today as it must have done originally, bringing Canada into the North American glacial summary for Geikie's (1894) book, and overshadowing Dawson's synthesis to the Royal Society in the same year.

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