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JOHN HARDCASTLE ON GLACIER MOTION AND GLACIAL LOESS

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ABSTRACT. In 1890–91 John Hardcastle presented his views on glacier motion and the climatic significance of loess deposits. He should be recognized as a significant pioneer in the study of glacier-flow mechanisms, and more particularly, as the initiator of the study of loess stratigraphy and the multiple-event approach to the formation of loess deposits, especially glacial loess.

RÉSUMÉ. *John Hardcastle, le mouvement des glaciers et les loess glaciaires.* En 1890–91, John Hardcastle présentait ses idées sur les mouvements des glaciers et la signification climatique des dépôts de loess. Il devrait être reconnu comme un pionnier important dans l'étude du mécanisme des écoulements glaciaires, et plus particulièrement, comme le précurseur des études de stratigraphie des loess et des multiples phénomènes que peuvent conduire aux dépôts de loess, spécialement de loess glaciaires.

ZUSAMMENFASSUNG. *John Hardcastle über Gletscherbewegung und glazialen Löss.* 1890–91 veröffentlichte John Hardcastle seine Ansichten über Gletscherbewegung und die klimatische Bedeutung von Lössablagerungen. Man sollte ihn als einen bedeutenden Pionier bei der Erforschung des Mechanismus der Gletscherbewegung anerkennen, speziell als den Initiator des Studiums der Lössstratigraphie und des Mehrfachansatzes für die Bildung von Lössablagerungen, besonders der glazialen.

IN the years 1890–91 John Hardcastle published four papers in the *Transactions and Proceedings of the New Zealand Institute* (Hardcastle, 1890, 1891[a], 1891[b], 1891[c]). They dealt with the loess deposits at Timaru in the South Island, the drift deposits of South Canterbury, and the problems of glacier motion. Contained in these papers, and particularly in 1891[c], is a most perceptive and clearly expressed conception of loess as a recorder of glacial climates, and possibly the earliest recognition of the importance of palaeosols in loess stratigraphy; in fact a truly amazing insight. Hardcastle's observations on glacier motion are interesting, and although apparently of less historical significance than his remarks on the loess, should perhaps be discussed first in this glaciological setting.

Thus Hardcastle, in a paper read before the Philosophical Institute of Canterbury, in Christchurch on 2 October 1890 (Hardcastle, 1891[b]) stated: "The latest authoritative deliverances on the subject of the mode of motion in glaciers of which I am aware state that 'the problem of the cause of glacier-motion cannot yet be considered to be satisfactorily solved,' and 'the solutions accepted are not perfectly satisfactory.' Whilst endeavouring some time ago to work out a particular case of the problem, using as a principal factor a physical property of ice which underlay some interesting experiments of Professor Tyndall's —viz., its plasticity under pressure—I obtained what appeared to me to be a full, clear, and simple solution of the whole problem of ice-motion. When, however, I again referred to articles on the subject I found that my solution did not fit the alleged facts to be explained, in one important particular. It is asserted that 'the top of a glacier moves faster than the bottom.' The conclusion at which I had arrived was generally incompatible with this. There is no ground for impeaching the correctness of the observations from which that generalisation was drawn, yet the generalisation may be erroneous. It may be true of a part or parts only of a glacier that the top moves faster than the bottom; and, if this is so, a true theory, in order to explain those observations, should show to what limited extent, and under what circumstances, the surface of a glacier does move faster than the bottom. . . ." (Hardcastle, 1891[b], p. 332).

That is the essence of Hardcastle's contribution: physics decrees that there shall be more deformation at the bottom of a glacier, but observation indicates a faster flow at the top. Of course these two requirements can be reconciled; we now accept that strain-rate is greater in the lower parts of a glacier and we accept that the upper parts of a glacier are carried by the lower and that there is an additive increase in velocity from the base to the surface. It seems strange that Hardcastle did not make the reconciliation but in 1890 he had never seen a glacier. The Fox and Franz Josef Glaciers were not far away but Hardcastle had not made the journey across the Southern Alps to see them. His physical argument makes good sense: "It appears to me that, taking the glacier as a whole, or any average cross-section of it, the ice at the bottom flows practically under the weight of ice resting upon it. In flowing it will obey, however tardily, the laws of hydrostatics, flowing from a region of greater to one of lesser pressure, and, obeying also the law of gravity, will flow preferably downhill. In other words, the glacier and the névé, or icefield, each consists of two mentally separable portions, moving in distinctly different ways. The lower portion is caused by the weight of ice above it to move as a viscous fluid; the upper portion remains solid, and is borne along by the living stream beneath, just as a mass of drift-ice or of logs is borne along by a river of water ..." (Hardcastle 1891[b], p. 333).

If we use the symbols of Flint ([c1971], p. 40) we can say that V_i—the velocity of internal motion—does vary as Hardcastle stated it should (see Fig. 1 for Flint's diagram). V_i is a measure of strain and it varies little near the surface (Hardcastle's upper portion) but increases rapidly near the bed (the lower portion). V_s—the surface velocity—is inevitably greater than V_b—the base velocity, but Hardcastle did not realize this:

"According to this view it cannot be generally true that the surface of the glacier moves faster than the bottom. Nevertheless it must be true of a certain part or parts of each glacier. . . . No theory of ice-motion which assumes greater mobility of the surface as a normal condition will explain the scooping-out of rock-basins or fiords. The theory here offered explains it readily, as it transfers the scene of greatest activity to the base of the glacier, and the deeper the ice the more energetic will be its action on the rock beneath." (Hardcastle 1891[b], p. 333–334).

"So far as I can judge, this theory 'fits all the facts.' It may be summarized thus: Glaciers and icefields flow through the lower portions, being reduced to plasticity or quasi-fluidity by the weight of the upper portions, and the former in flowing away bear the latter with them. The pressure necessary to effect such reduction at any point, and therefore the critical depth of the ice at that point, depends upon the sum of resistances to hydrostatic movement at the base—chiefly upon distances to a point of no resistance, gradient of bed, and amount of obstruction presented by the form of the channel or course of flow." (Hardcastle 1891[b], p. 334).

Leaving aside his aberration about the velocity distribution within the glacier the Hardcastle view of glacier flow is surprisingly modern, and he identifies some critical factors affecting flow velocity. He was even more perceptive when he was closer to home and looking at the Timaru loess. He lived in Timaru for many years and died there in 1927 at his house, 11 Heaton Street. He was born in 1847; he passed his qualifying examination as a schoolmaster and applied for the vacant mastership at Geraldine, a small town in the South Island about 40 km north of Timaru and about 150 km south-west of Christchurch, in the Canterbury region. There were 81 pupils in 1873. He edited the *South Canterbury Times*, and he worked

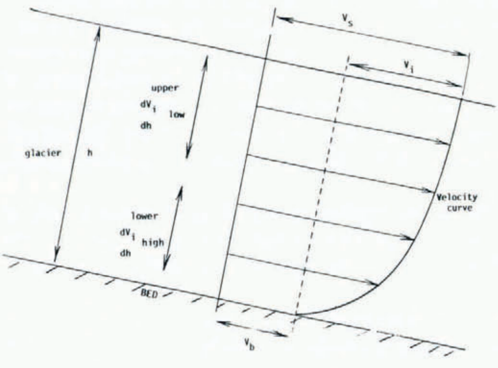

Fig. 1. Glacier velocities after Flint (1971. p. 40, fig. 3–7). The Hardcastle upper and lower regions are shown approximately; in the upper region V_i is nearly constant with change in thickness, but in the lower region changes markedly. V_s—surface velocity; V_i—velocity of internal motions; V_b—base velocity (sliding); h thickness.

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for a while as a journalist in Napier. He probably first joined a branch of the New Zealand Institute (the precursor of the Royal Society of New Zealand) in 1885 while he was working in Napier. He is on the Hawkes Bay branch membership list for the years 1885 to 1888. He only spent a few years in the North Island and then returned south. He is listed as a member of the Canterbury branch in 1889, and stays a member until 1898; this was the time when he made his major scientific contributions, and possibly invented loess stratigraphy. His major paper (Hardcastle 1891[c]) was presented at the Philosophical Institute in Christchurch on the same day as the contribution on glacier flow; it concerned the Timaru loess as a climate register. A year earlier, on 5 September 1889, Hardcastle presented his first loess paper—on the origin of the Timaru loess:

"The object of this paper is to state some evidence which proves that the Timaru loess, and presumably also the similar formation on Banks Peninsula, and others elsewhere, is of subaerial origin; that it is a formation of wind-borne dust, entrapped by successive generations of dry-land vegetation; that the whole deposit from base to summit, inch by inch, line by line, film by film, has successively been a dry-land surface; that it accumulated not only slowly, but intermittently, with prolonged periods of pause; and that its growth was dependent upon a set of climatic conditions which no longer prevail in the neighbourhood.

For the production of a massive subaerial formation of dust four factors are required—(1) a source of wind-borne dust, (2) winds to transport the dust, (3) vegetation to entrap it, and (4) sufficient time for its accumulation. In respect of this formation, the first of these factors must be indicated, but need not be located. The second will be granted; also the fourth. The third will be admitted if it is proved that the deposit was formed on dry land. I leave the indicating of the source of dust for the present, proceeding first to prove that the loess is a dry-land formation." (Hardcastle, 1890, p. 406).

This must be the earliest, and the most clearly expressed, statement of the need to identify all the critical events in the process of loess deposit formation. This requirement has been restated more recently (e.g. Smalley, 1966, 1972) but had been neglected for many years. If Hardcastle's requirements for loess formation had been kept in mind by all the protagonists, much heated debate might have been avoided. He touches on one very critical problem; the mechanism of formation of the loess particles themselves. Mechanisms are still being suggested (e.g. Nahon and Trompette, 1982, Whalley and others, 1982) but Hardcastle not only detected the problem, he provided an elegantly worked-out solution:

"Having found the loess to be a dry-land deposit, we must find the still-missing factor in the dust-heap theory.

The Source of the Dust. – There was only one source possible in these latitudes for such a quantity of dust; and a mere hint as to its nature will suffice. If we consider the loess to belong to the great Ice Age there is no difficulty. The dust was 'rock-meal', produced by the great ice mill, and spread out by rivers of sludge for the winds to dry, and pick up, and bear away, losing more or less of their load whenever they passed over a vegetated region. The material itself to-day bears testimony that such was its origin. . . . No other agent than ice could have produced so great a quantity of such fine material." (Hardcastle 1890, p. 413).

This is probably the first statement to the effect that glacial grinding produces loess material. Hardcastle proposed that his idea might also apply to loess in Europe and North America, which have in fact turned out to be the regions where 'ice-sheet' loess (Smalley, 1978[a]) predominates. Having developed his glacial mechanism Hardcastle was in a position to make the climatic connection:

"As described in my paper of last year, the loess contains marks of several pauses in its deposition, in bands containing (a) drought veins, the product of a dry climate; (b) rust-granules, the product of a wet climate; (c) multitudes of birds' crop stones, which I shall presently suggest have an interesting significance as an index of climate; and (d) at one level certain alterations of texture produced by extreme severity of climate. Deposited upon areas elevated above the reach of rivers, this growing dust-heap played the part of an observant bystander, taking notes of certain climatic phenomena as they successively arose. The record of the lowest separable layer, marked off by a band in which both drought-veins and rust-granules occur, may, I would suggest, be read as follows:

1. A phase of cold, producing great icefields and glaciers in the highlands, which send down floods of sludgy waters, inundating the lowlands, and creating fields of dust, from which the winds picked up and deposited here a bed of loess up to 10 ft [3 m] thick where the contemporary denudation was slight. (This is the thickest of the layers.)
2. A phase of improving climate, during which the glaciers diminished and the supply of dust ceased, probably in part through the trapping of the glacier silt in lakes or pools, occupying basins scooped out

by the previously extended glaciers. The climate here continued wet, however, for even where the slope of the surface afforded good drainage the rust-granules characteristic of wet soils were formed.
3. The climate further improved, becoming dry enough in summer to crack the ground to a depth of a few feet, and drought veins were formed.
4. The moist climate returned, the formation of drought veins ceased, and that of rust-granules was resumed.
5. With increasing cold the glaciers again advanced, and the supply of dust was resumed, this recommencing the series." (Hardcastle 1891[c], p. 327).

Hardcastle pointed out the connections between loess formation and glacial action almost ten years before Tutkovskiy (1899), for different reasons, proposed a similar connection. The reasons for the neglect of Tutkovskiy's work have already been explored (Smalley, 1978[b]); Hardcastle's obscurity stems from different causes. His work was well known in New Zealand at the end of the nineteenth century and was part of an animated discussion on the problems of loess origins which was underway at the time (see Smalley and Davin, 1980). But it was published only in a New Zealand journal and was never incorporated into the main-stream of loess knowledge. Had Hardcastle been a professional scientist there would doubtless have been follow-up papers which would have provided the new ideas with the necessary multiple exposure. It seems likely that pressure of other interests caused Hardcastle to leave the Canterbury Institute in 1898; he is not on the list of members for 1899. However he rejoined in 1924, when he was 77, and stayed a member until his death in 1927.

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