LL71

Loess Letter 71

April 2014

Leicester Quaternary Palaeoenvironments Research Group

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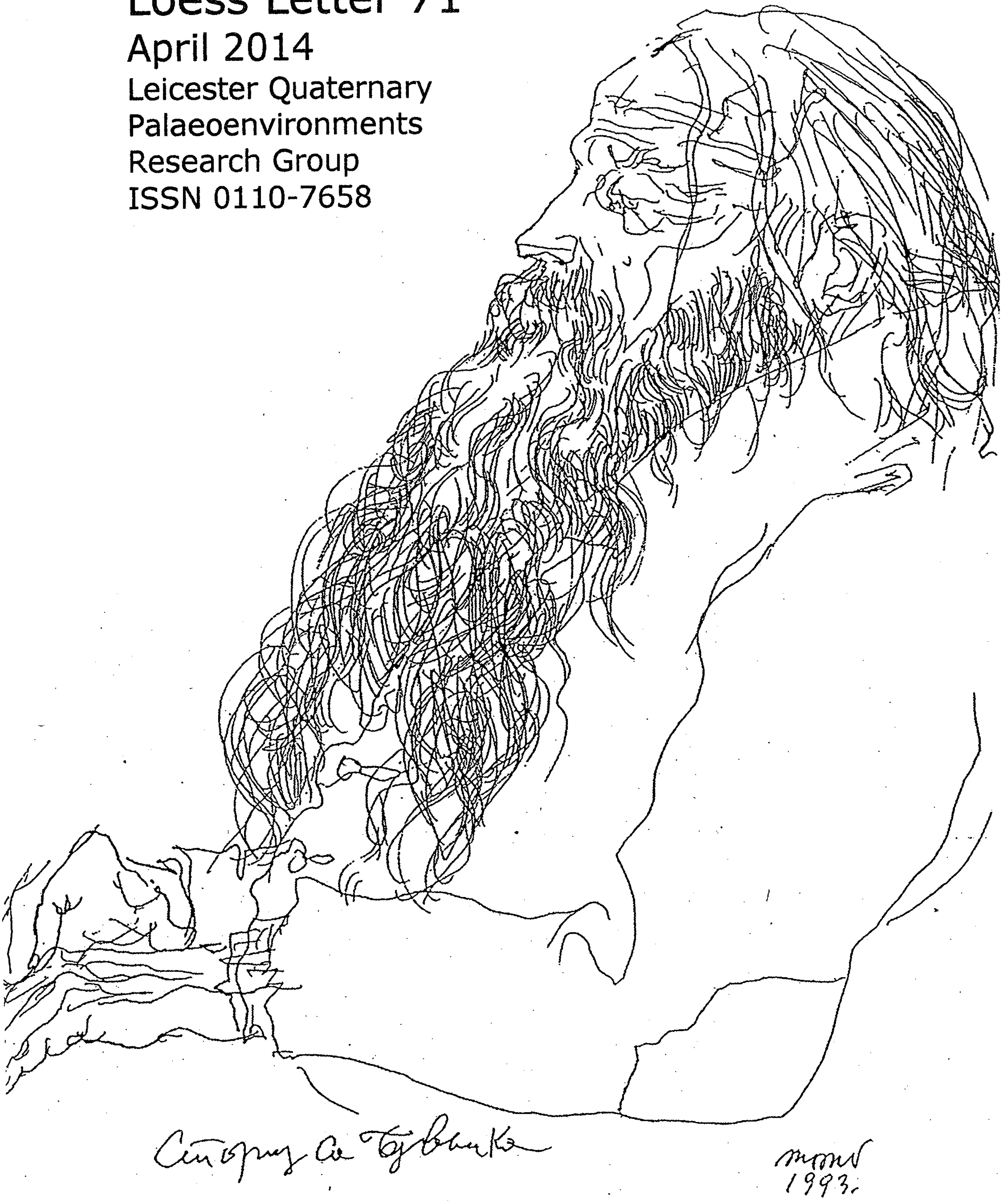

Loess Letter LL71 Pacific
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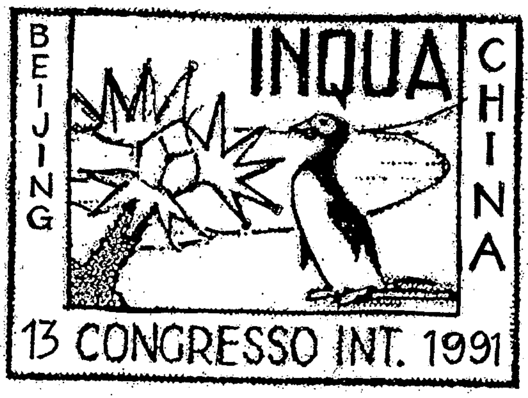
Pacific. In 1977 at the INQUA Congress in Birmingham the Western Pacific Working Group of the Loess Commission was established. Loess research was to be focussed in the Pacific Region; and now INQUA moves back into the Pacific. The 19th INQUA Congress will be in Japan in 2015. The WPWG focussed on China, Australia and New Zealand, and LL71 has a main focus on loess in New Zealand.

LL71. At about the same time as LL71 appears there should be the publication of another Loess Letter Supplement. These tend to appear to coincide roughly with the INQUA Congresses- and the new one will support the 19th Congress in Japan in 2015. LLSns2 is the second in the new series; the first related to the Reno Congress in 2003. LL71 and LLSns2 both relate to John Hardcastle and should be complementary. LL71 reprints his 1889 and 1890 papers on loess- the first publications in loess stratigraphy; and LLSns2 reprints his 1908 booklet on the geology of the loess-rich area of South Canterbury. The plan is that ns2 should be a widely distributed hard-copy and that LL71 should appear initially in an on-line format. LL71 actually reprints LLS23 from 1988- this was the Hardcastle tribute for the 13th Congress in Beijing- a good time to celebrate the invention of loess stratigraphy.

Things are changing in newsletter world and LL is looking for ways to cope. The first 70 issues of LL are available online at www.loessletter.msu.edu this is the new LL reference base.

INQUA Japan. 19th INQUA Congress 27 July – 2 August 2015 Nagoya Japan: 'Quaternary Perspectives on Climate Change, Natural Hazards and Civilization'. Chairperson Yoshiki Saito, Geological Survey of Japan. Queries to: 2015inqua-sec-ml@aist.go.jp. Website: inqua2015.jp.
Loess = Civilization- go to Japan & discuss.



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Loess Letter: the newsletter of the INQUA Loess Focus Group (http://inqua-loess.org) edited by Ian Smalley (ijs4@le.ac.uk) , produced by the Leicester Quaternary Palaeoenvironments Research Group in the Geography Department of Leicester University. Founded at the DSIR New Zealand Soil Bureau in 1979; published twice a year- for anyone interested in loess. Online, at www.loessletter.msu.edu courtesy of Michigan State University.

Twitter, Facebook, Blog. The 'Aeolian Dust' blog should be appreciated- and so should 'Loess Ground'. There should be more Loess/Dust blogs. There are some dusty regions on Twitter- Tom Gill provides a non-stop dust commentary, recommended by LL. Also go to Sheffield Dust & DrAeolus. Facebook is still under-exploited by Loess/Dust people- please contribute to the Loess Appreciation Group page.

Windy Day. The next Windy Day meeting for aeolian geomorphologists will be in Oxford in October 2014. It's a memorial meeting for Steven Stokes. The first was in Oxford in 1993, there were memorable meetings at Nottingham Trent in 1997 and Leicester in 2012- so back to Oxford for 20th. Contact david.thomas@ouce.ox.ac.uk. Send an abstract 150 words.

ED@80. The hard-copy fruits of the ED@80 meeting are appearing: special issues of Catena and Quaternary International are available now. We hope to give some consideration to these special special issues in LL72.

KuklaFest'14. A loess conference to honour George Kukla. Wroclaw 8-9 September 2014. Field trip to Eastern Poland to follow. Contact: przemyslaw.mroczek@umcs.pl or zdzislaw.jary@gmail.com or www.loess.umcs.lublin.pl/1st.pdf . George Kukla was a major loess scholar; he made an important contribution to inserting loess data into the main body of Quaternary Science; loess scholars will honour him in September.

JOHN HARDCASTLE

1891 - 1991

One Hundred Years of Loess Stratigraphy

Centre for
Loess Research
and Documentation

Thirteenth
INQUA Congress
Beijing 1991

John Hardcastle invented loess stratigraphy in the South Island of New Zealand in 1890. As far as I know he was the first person to relate the material features of a loess deposit to the climate that prevailed at the time that the deposit was formed. This relationship he spelled out at a meeting of the Philosophical Institute of Canterbury on 2 October 1890. The paper was published in May 1891 in the Transactions and Proceedings of the New Zealand Institute.

It is the centenary of publication that we celebrate, 1891-1991. It seems incredible that a schoolteacher from Geraldine, standing on the beach at Timaru, looking at the loess cliffs could have conjured up such a remarkable insight. He deserves to be famous, but is relatively unknown, in fact little is known about him. I hope that the celebration of the centenary of his great discovery will cause a few more facts about him to emerge. The centenary coincides very neatly with the 13th INQUA Congress which is taking place in Beijing in 1991. Another coincidence places this INQUA Congress in north China, the place where Hardcastle's discovery has had its most effective application. Loess stratigraphy will feature prominently in the discussions at the 13th Congress and it is fitting that John Hardcastle should be acknowledged as the 'onlie begetter' of the whole subject.

This supplement reprints two original Hardcastle papers from the Transactions and Proceedings of the New Zealand Institute [Vol.22, 1890, p.406-414 (LPB385) and Vol.23, 1891, p.324-332 (LPB386)] and a piece of commentary from the 'Early Discoverers' series in the Journal of Glaciology, which gives some background to John Hardcastle and his New Zealand setting. The illustrations are from 'Quaternary Dust Mantles of China, New Zealand and Australia' ed. R. J. Wasson, Australian National University 1982.

Ian Smalley
Centre for Loess Research
and Documentation
Leicester 1988

Journal of Glaciology, Vol. 29, No. 103, 1983

EARLY DISCOVERERS
XXXIII

JOHN HARDCASTLE ON GLACIER MOTION AND GLACIAL LOESS

By IAN J. SMALLEY
(Department of Earth Sciences, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada)

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

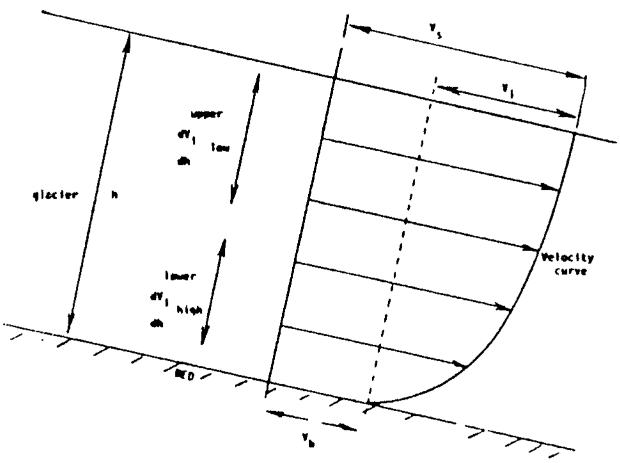

Fig. 1. Glacier velocities after Flint (1971, p. 40, fig. 3–7). The Hardcastle upper and lower regions are shown approximately; in the upper region V_i is nearly constant with change in thickness, but in the lower region changes markedly. V_s—surface velocity; V_i—velocity of internal motions; V_b—base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

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.

ACKNOWLEDGEMENTS

I thank Jewel Davin, librarian at the New Zealand Soil Bureau, Taita, and Max Broadbent of the University of Canterbury library for their generous assistance in the preparation of this paper. Broadbent was able to supply data from the McDonald Dictionary of Canterbury Biographies, and he also pointed out that there does not appear to be any mention of Hardcastle in the records of the Canterbury Branch of the Royal Society of New Zealand, not even an obituary. Someone who made such perceptive observations on the nature and formation of the most important soil material in New Zealand deserves better. I thank Jewel Davin mostly for the opportunity to use her remarkable library, and the chance to work with her on the history of loess investigation in New Zealand.

MS. received 24 January 1983

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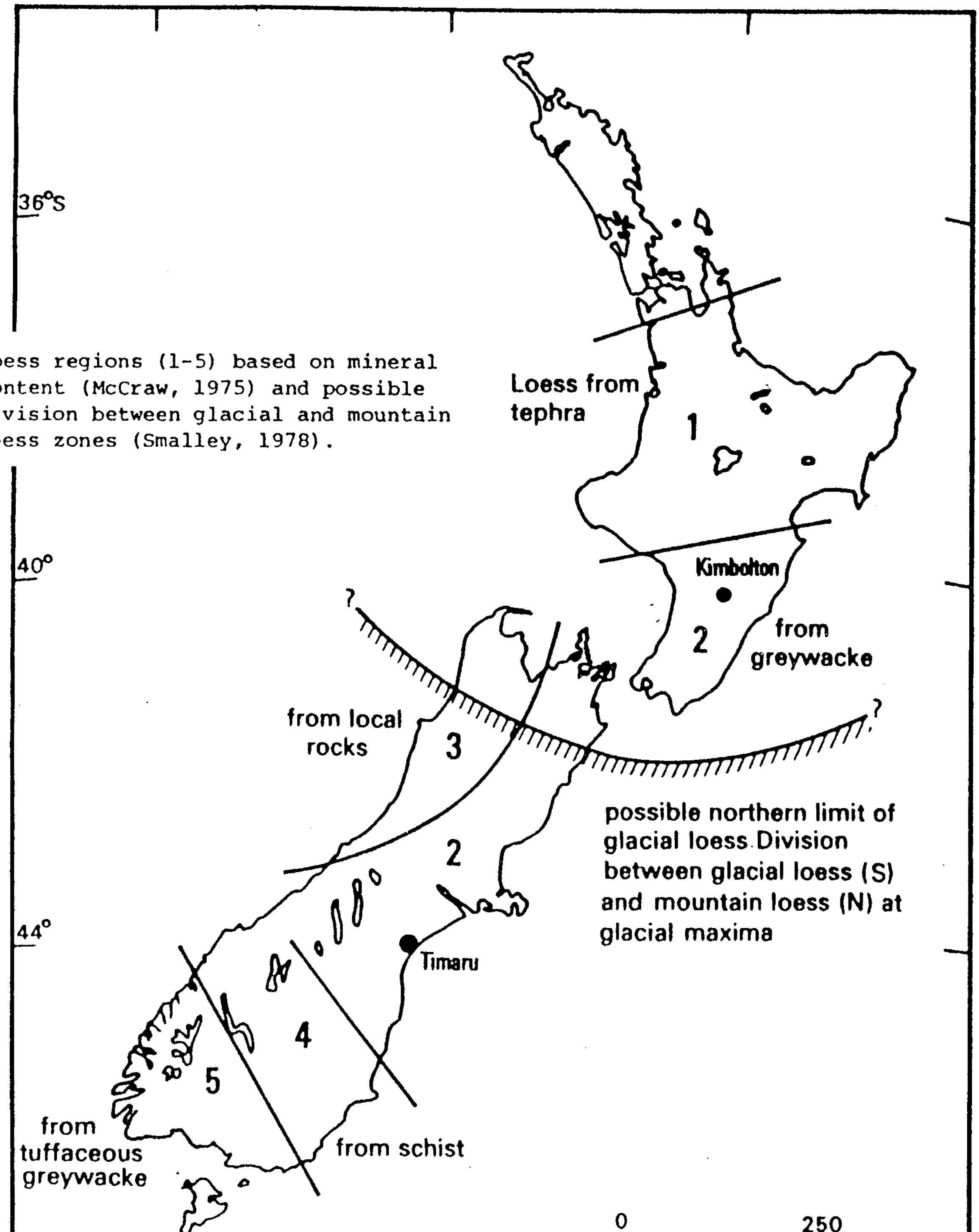

Loess regions (1-5) based on mineral content (McCraw, 1975) and possible division between glacial and mountain loess zones (Smalley, 1978).

Art. XLVIII.—*Origin of the Loess Deposit of the Timaru Plateau.*

By J. Hardcastle.

[*Read before the Philosophical Institute of Canterbury, 5th September, 1889.*]

So far as I am aware, three varying opinions have been published respecting the origin of the clay, silt, or loess which covers the dolerite sheet in the Timaru plateau.

The late Dr. von Haast ("Geology of Canterbury and Westland," p. 367) adopted Richthofen's theory, that it is a subaerial formation, which has grown up under existing conditions, and is still growing.

Professor Hutton raised some strong objections to that explanation, and ("Trans.," xv., 416) concludes (with special reference to an admittedly similar deposit on the flanks of Banks Peninsula) that "the evidence in favour of the marine origin of this deposit preponderates enormously over the evidence in favour of subaerial origin."

Lastly, Mr. J. Goodall ("Trans.," xix., 457) declares the Timaru loess to be a volcanic ash.

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.

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The Material.—The material of the deposit is remarkably homogeneous in character, and is almost wholly fine enough to be easily taken up and transported by winds. The exceptions are a few elements which could not have been wind-borne, and these—except, here and there, at low levels, scattered pebbles and boulders of scoriaceous dolerite of local origin—are among the evidences in support of the dust-heap theory.

A Buried Water-hole.—Among the numerous excavations made in the loess at Timaru, the most instructive as to the origin of the formation is one made to the southward of the railway-station to form a site for the engine-sheds. The section left by the excavation, say 20ft. deep (all numbers in this paper are rough guesses), shows at the surface the remains of a swampy hollow—one of scores, perhaps hundreds, scattered over the Timaru Downs. Some of these hollows contain pools of water after heavy rains in summer, and continuously through the winter; larger ones are never dry, and contain a growth of peaty vegetation. The hollow cut through by the excavation referred to was of the latter class. It once contained a growth of peat, which had been set on fire in the early days of the settlement, or possibly earlier, by aborigines, and the light ashes now form a layer a few inches thick beneath an ordinary black soil. The clay beneath this old pool is distinctly stained blue by phosphate of iron, through the action of the percolating swamp-water upon the iron contained in the clay. This coloration extends downwards for several feet, and gradually fades out. Rather more than halfway down the face of the cutting the section shows the remains of a similar but smaller water-hole, with a little carbonized vegetable matter lying upon the uppermost of several thin layers of silt which were successively deposited in the hollow, and are marked off by lines of peaty stain; and there is a repetition of the blue phosphatic stain in the clay beneath, the stain extending downwards below the base of the section. In this buried water-hole we have proof positive of the existence of a dry-land surface during its formation and existence. Tracing it outwards, the bed merges insensibly into the general homogeneous mass of the formation, but into a layer of it marked by a character to be described in the next paragraph.

Subsoil Iron-ore Granules.—In every railway-cutting and cliff exposed to rainfall there are to be distinctly seen several bands, 1ft. or 2ft. in depth, curving in the spurs so as to be roughly parallel with the present land-surface. These bands project slightly from the general slope of the cuttings, and are also a little darker in colour. Examination shows that the darker colour of these bands, and their relatively greater power of resisting erosion by rain, are due to the presence of numbers of granules of an oxide of iron—precisely such granules as are to be found in the subsoils of damp lands—numerous and large in the subsoil on the margins of the surface peat-pools, and very sparsely scattered through the present subsoil elsewhere. Similar granules are to be found scattered thinly throughout the mass of the loess, but they are distinctly numerous in these bands. These granules must have taken some time to form, and other evidence is forthcoming in proof that the layers in which they occur respectively formed a soil and subsoil for very long periods of time. It is to be inferred, too, that the ore-granules indicate the prevalence of a very wet climate during the whole or some portion of each of these periods, as such granules do not appear to be formed except in wet soils. The climates must have been very wet, as the curvature of the granule-bands is such that the land-surface which each represents was well drained. The buried peat-bed already described is easily traced outwards into one of these granule-bands.

Humus-stains.—The vestiges of the successive generations of vegetation have been almost but not wholly obliterated. It would seem that the growth of the deposit was so slow as to nearly allow the rootlets of each generation of plants to suck up the last remnant of the decay of previous ones. Nearly, not quite. Whenever a cutting is newly made, or a fresh face is formed on a sea-cliff, there is observable from top to bottom a brownish stain in the clay, which is intensified a little in certain bands. This stain disappears after a short exposure to the air, the surface soon assuming a bright-yellow "clay" colour. The uppermost of these dark bands, which varies in position from 5ft. to 8ft. or so beneath the present soil (and in some places also the second band, some feet lower down), shows in old "backs," or natural crevices, abundant stains caused by the decay of rootlets, the ramifications of which can be easily traced. This evidence, taken alone, would not be of much value, as recent rootlets—very few in number, however—penetrate these cracks. The obscure brown stains in deeper bands, to which recent rootlets do not extend, are evidently of the same character as the more strongly marked upper ones, and I have no doubt that these darker bands, and the more diffused stain of the spaces between them, are due to a trace of humus remaining in the successive subsoils. The ore-granule bands previously described are the representatives in a weathered face of the bands of darker stain in a fresh face of the clay. Such granules of ore are frequently formed in the present subsoil in the shape of pipes around decaying roots. I have found in the granule-bands specimens which bore on a concave surface plain imprints of vegetable form. At a low level in the deposit there is to be seen here and there a stratum of fine, dense, somewhat plastic clay (as Sir J. von Haast well described it in one of his reports), which, from the positions in which it occurs, can be nothing else than a fine mud settled from pools of storm-water. This low-lying, exceedingly tough and impervious material has in some places retained stain-impressions of roots.

Worm-borings.—Very satisfactory proof that the loess is a dry-land formation is afforded by the fact that worm-borings are to be found in it plentifully, in the dark bands, from top to bottom. Most of them have been filled up by the worms, as are recent borings; but some are partly open, and the upper part of the filling consists of loose distinguishable "casts." It cannot be asserted that the lower borings were made by worms working down from the present surface. The borings are unmistakably more numerous in and just beneath each brown-stain band than in the spaces just above these bands, and they are in some places to be found beneath, and terminating abruptly at, the mud-beds just described, which have not been bored through at all. There are also to be found in the stratum beneath it worm-holes plugged with this mud, the plugs preserving the characteristic irregularity, the departures from cylindrical form, in the shape of the borings. The "capillary texture" of the loess, mentioned by Sir J. von Haast, is evidently due more to the multitude of worm-borings than to the decay of roots, though this, no doubt, had some influence in producing it.

Evaporation-veins.—Another evidence of the dry-land origin of the loess, and of long pauses in its growth, is the existence, beneath some of the lower granule-bands, of what, for want of a known name, I must call "evaporation-veins." Most clay-formations contain what excavators call "backs"—natural vertical cracks—and these are usually lined with a film of greater or less thickness of finer, whiter, and denser material than the clay between them. In many roadside cuttings these vertical veins are seen to streak the clay quite thickly. If the vegetable soil be cleared away these veins are seen to divide the subsoil into irregular figures, rude pentagons being the most common form. In size the figures vary from a few inches up to 2ft. in longest diameter. A small number may be larger.

I have never met with an explanation of these veinings, and must attempt one. Whenever a soil cracks through drought the cracks extend into the subsoil. The cracks in the subsoil must be fine, as one never finds on digging into it streaks of dark vegetable soil fallen into them. As the drying of the ground in a drought proceeds, the moisture at the surface of the fissures will evaporate; and that remaining in each prism of clay will constantly endeavour, so to speak, to maintain its capillary level, and will keep up the supply for evaporation at the fissures. In thus moving towards the fissures, I conceive that the water drags with it such fine particles of earth as can be moved between the coarser particles of the mass, and these fine particles are of course deposited on the sides of the fissures when the water evaporates. The fissures, once formed, remain planes of weakness, the ground cracks in the same lines year after year, and in course of time a considerable thickness of fine material may be thus separated from the mass and collected upon the sides of each clay prism. (Is the whiteness of the veins due, wholly or in part, to a bleaching-power in the water which filters into them from the soil when a rain occurs?) In the present subsoil at Timaru these white veins range up to 1½in. in width, between prisms of clay not exceeding 2ft. in longest diameter, and they extend downwards as much as 8ft. or 10ft. in some places. In the lower portion of the loess there are two or more series of these veins, the highest terminating above in a granule-band about 10ft. above the rock. There is another terminated by the second well-marked band from the surface. There may be other series: the cuttings are too much hidden by rain-wash to allow one to see. If there were any possibility of mistaking the veins in vertical sections, there can be no mistaking the characteristic pentagonal forms seen in horizontal sections. The existence of these veins supports the testimony of the granule-bands as to the occurrence of long pauses in the deposition of the loess. But, while the granule-bands seem to indicate a wet climate, the evaporation-veins indicate a dry one, and to accept the contradiction and explain it we must suppose the pause was sufficiently prolonged to permit of a complete change of climate, either from wet to dry, or from dry to wet.

"*Bird-stones.*"—It would be reasonable to suppose that the surface peat-pool cut into by the engine-shed excavation was formerly more or less frequented by water-fowl, and that they would leave lasting vestiges of their visits or sojourn there in the shape of ejected gizzard-stones. As a matter of fact, they have done so. Many small stones, well worn—unquestionable "bird-stones"—can be picked out of the clay immediately beneath the ashes of the burned peat-bed. The same expectation might be formed regarding the buried peat-pool; and it would be fully justified, for these vestiges of the water-fowl of the period are immeasurably more numerous there than similar ones in the surface-hollow. The majority of the stones are small, though larger than those in the upper bed, but among them are some the size of common marbles. Large and small, there must be a bushel or two of gizzard-stones buried with this old water-hole, the section of which is only about 20 yards long, and the stratum representing the pool only 12in. or 15in. thick. The same proofs of the existence of bird-life are to be found throughout the deposit, from the clay which fills the larger crevices in the dolerite to the top, very thinly scattered through the mass generally, but in astonishing numbers in the granule-bands. In each of at least three of these bands superposed at one spot bird-stones exist in such quantities that one may well speak of them as "so many bushels to the acre." Certainly no farmer could afford to sow grain so thickly. The buried peat-pool runs out into the uppermost and most prolific of these. The majority of stones found in the buried pool are of quartz or of other mineral whose whiteness deceived the birds; those found in the granule-bands, while containing a not-inconsiderable proportion of white stones, are of all colours, but for the most part of hard materials. Water-fowl usually possess considerable powers of flight, and from frequenting watercourses they have a better chance of obtaining quartz or other white or whitish pebbles. This would account for the larger proportion of such pebbles in the buried pool. Land-birds, whether of powerful flight or not, have not the same opportunities for selection; hence the mixed character of the pebbles found in the granule-bands — the old land-surfaces. The whole of the pebbles can, I believe, be matched as to mineral character from the drift-deposit overlain by the dolerite.

Bird-stones are to be found in the present soil and subsoil, but they are so rare that the search for them is disheartening work. This refers to the dry-land surface. In the old peat-pool at the engine-shed very small stones are somewhat numerous, and beneath the mud in the bed of the Waimataitai Lagoon, now being cut back by the sea, white stones, of such size that they must have been used by some of the moa tribe, are not uncommon. In two places—one near the base of the deposit, the other in the lowest granule-band—I obtained a few large, mostly well-rounded pebbles of brown sandstone, such as could only have been used by gigantic birds.*

Moa-bones.—Moa-bones have been obtained from the formation. Some were dug out in making the excavation for the passenger-station, but I cannot say from what position. In the somewhat low sea-cliff of clay at Dashing Rocks moa-bones are occasionally weathered out, about one-third of the way down the face. These have no relation whatever to the remains of a moa-hunters' encampment near that spot, these remains being wholly contained in black soil.

Exceptional Bedding.—The loess generally is quite devoid of stratification in the ordinary sense, but there are small portions here and there which show a perfect bedding. Sir

* This section will suggest a solution of the "very puzzling geological problem" stated by Mr. J. C. Crawford in "Trans.," xvii., p. 341.

J. von Haast mentions one of these in a report on the water-supply of Timaru. A much larger patch was cut into in "stripping" off the clay at the North Mole Quarry, on the bank of the Wai-iti Creek. This patch rises upwards from the creek as though laid down upon a sloping bank; the bank of clay it overlies is well veined and worm-bored. During the formation of a mass such as this from wind-borne dust, it could not but happen that now and then storm-waters would scour away from one place, and deposit in stratified form in another, some of the surface-soil. These rearrangements of material would naturally be made most frequently near the large watercourses, and it is in such positions that the only two cases I am aware of are found. The one mentioned by Sir J. von Haast is in the cliff bounding the Waimataitai Valley, on the south side. It consists of a small patch, as seen in section in the sea-cliff, 10ft. or 12ft. wide, 4ft. or 5ft. deep, and situated about midway up the cliff. The other case, as already stated, is beside the Wai-iti Creek. Granting that this bedded layer was laid down by a flood in the creek, it must appear that the stream had not then cut through the 50ft. of dolerite rock as it has done, and through some 150ft. of the underlying drift-formation besides. The Waimataitai Creek has similarly, but in less degree, cut down its channel since the patch of stratified loess was laid down.*

In dealing with the vestiges of vegetation mention was made of a fine, somewhat plastic clay which occurs here and there, and regarding which it was suggested that it must be a mud deposited by pools of storm-water. This view is suggested by the fact that the best specimens of it are found in hollows in the rock-surface. In the North Mole Quarry a depression in the rock-surface was evidently almost filled by it, the deposit exceeding 2ft. in depth in the centre, and thinning out towards the margin of the hollow. In many places the mud-bed is formed, not at the base, but at some higher and apparently not constant level, yet never far from the base. A hint is supplied by the case of Wai-iti Creek, and the stratified silt at Waimataitai (which rests upon a similar mud), that the cutting-down of the channels after a time prevented the overflowing of storm-waters, and the production of more mud-beds and bedded rearrangements of the silt.

Summary of Evidence.—I think it will be conceded that the evidence herein adduced is sufficient to prove the growth of the Timaru loess as a strictly dry-land—an Æolian—deposit. There are good evidences of several old land-surfaces in

* Since this paper was written it has occurred to me that the Wai-iti Creek patch was more probably a wind-drift. Unfortunately this idea did not occur to me soon enough, for on going to the quarry to re-examine it I found it had been nearly all carted away.

(1) bands of soil and subsoil ore-granules, (2) humus-stains, (3) worm-borings, (4) bird-stones—all in the same bands; (5) a buried water-hole in connection with one of them, (6) series of "evaporation-veins" in connection with more than one, (7) and, lastly, the exceptional occurrence of current-bedding, in silt and mud-beds near watercourses. All these evidences are mutually corroborated, and point to but one conclusion—the conclusion above stated.

Marine, lacustrine, or fluviatile agencies are entirely out of the question. The Timaru plateau stands above all the surrounding country, and on the summit of Mount Horrible the loess rises to over 1,000ft. above the sea. Neither lake nor river could have lain or flowed over this region. Nor can submergence beneath the sea be invoked in explanation. The bands containing the several characters above described are all flat or curved with definite relation to the present drainage-lines. This relation would be impossible were the loess a marine deposit. Not a single shell or other mark of the sea has presented itself to me in the original deposit. I am informed that Mr. McKay found a marine shell in the loess. I am compelled to conclude that it must have been obtained from a slope-deposit or other rearrangement of the original formation; in such cases they are not uncommon. The Timaru region has not been beneath the sea for long ages. The dolerite buries an older land-surface, with distinguishable soil, impressions of plants, worm-borings, and moa-bones; this soil being formed upon the surface of a considerable thickness—some hundreds of feet—of river-gravels, sands, and clays.

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. Under the action of running water it tends to separate into darker- and lighter-coloured layers, the darker being the more oxidized particles. Sir J. von Haast remarked the resemblance of the stratified silt he saw to glacier-silt, and quite recent rearrangements by rains of the material of the cliff present precisely the same appearance. No other agent than ice could have produced so great a quantity of such fine material.

Other Loess Deposits.—The small dolerite sheet of the

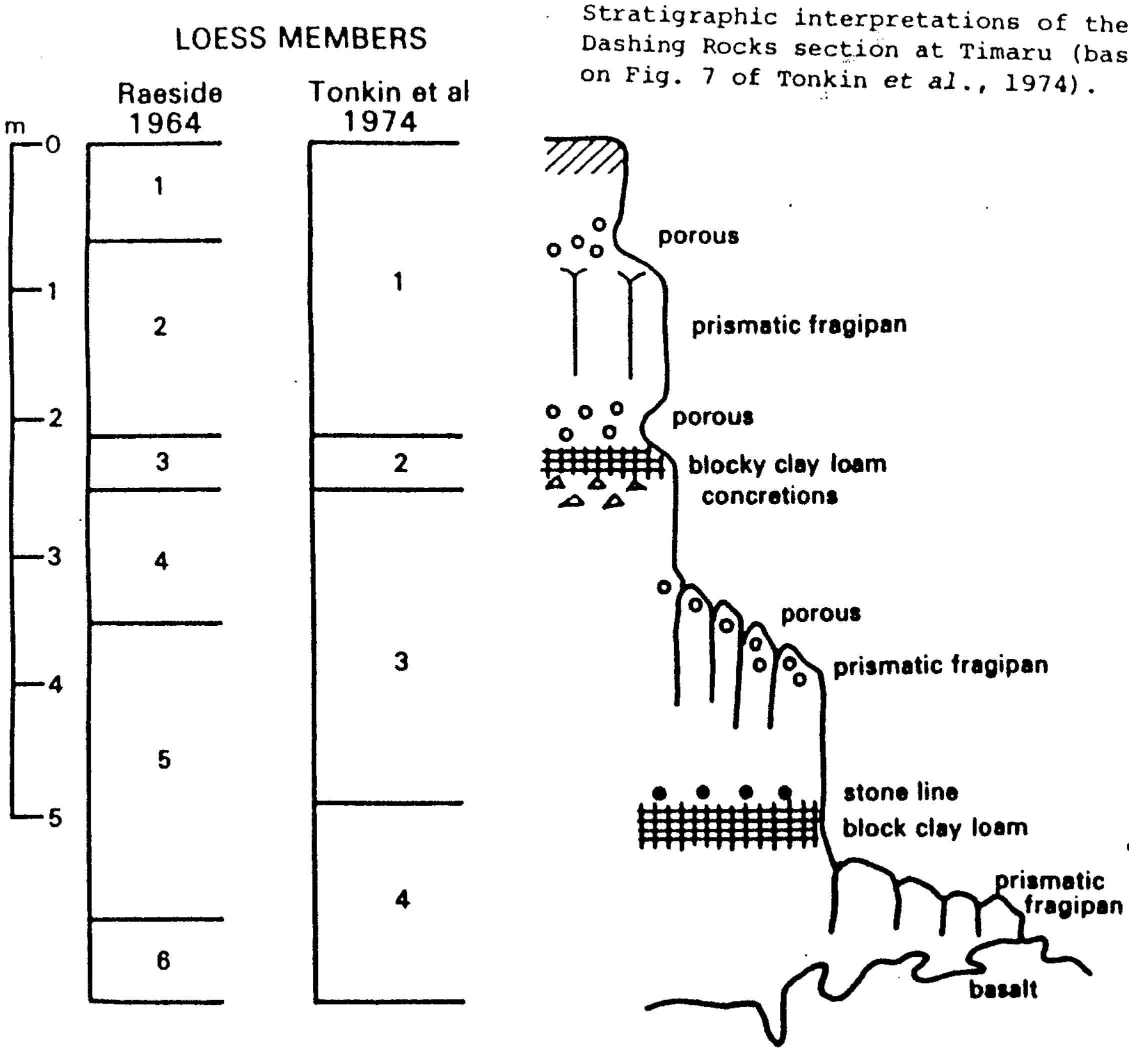
Geraldine Downs—which in all probability was emitted simultaneously with the Timaru dolerite—is covered by a bed of clay several feet in depth. I have not examined this with instructed eye, but, as it could have been deposited in no other way, its origin may safely be declared to have been similar to that of the Timaru loess. It is a stiffer, "colder" clay than this of Timaru, and this fact may be accounted for by difference in the character of the dust supplied to the winds which formed it. I cannot doubt that examination of the loess on Banks Peninsula (described by Professor Hutton as aqueous) would result in like proofs of its subaerial origin being obtained. Other loess-fields in Canterbury would doubtless furnish similar evidence.

The descriptions I have read of the great loess-formations of the Rhine and of the "terrace" formations of North America, the origin of which, I understand, still puzzles European and American geologists, suggest to me in every detail that the dust-heap theory which explains the Timaru loess will also perfectly explain them.

In a small volume on the "Geology and Physical Geography of Brazil," by C. F. Hartt (Trübner, 1870) (which appears to be one of a series published under the title "Scientific Results of a Journey in Brazil; by Louis Agassiz and his Travelling Companions"), the author describes a "sheet" of arenaceous clay, very uniform in composition, "absolutely structureless," "totally devoid of stratification," usually quite free from pebbles or boulders. This sheet covers the coast provinces of Brazil from the level of recent estuarine formations—even extending beneath these—to the tops of the highest hills Mr. Hartt ascended. From his numerous topographical observations and his summary description of this superficial formation, which varies in thickness from a few feet to 100ft., I gather that it is a loess, and that it is probably of similar origin to the Timaru loess. The author and Agassiz could find no mode of deposition competent to account for all its features save a general glaciation of the country. It was a boulder-clay without boulders. The agency of dust-bearing winds, however, was not one of those taken into consideration by them.

A superficial deposit in Lower La Plata, described by Darwin ("Voyage of the 'Beagle'") as estuarine, "with concretions and bones," may also well be a wind-drifted dust formation.

Stratigraphic interpretations of the Dashing Rocks section at Timaru (based on Fig. 7 of Tonkin *et al.*, 1974).



Art. XXXI.—*On the Timaru Loess as a Climate Register.*

By J. Hardcastle.

[*Read before the Philosophical Institute of Canterbury, 2nd October, 1890.*]

In a paper submitted to this Society a few months ago I had the honour to offer what I hoped would prove a useful provisional reading of the earlier of the recent geological formations of South Canterbury, viewed as records of climatic changes. The point then reached was the close of the interglacial period. I now propose to continue the reading, from materials provided by the second great cold age, the chief among them for its instructiveness being the loess of Timaru.

In a paper read last session, and published in the Transactions,* the conclusion was stated that the loess is an Æolian deposit, a heap of wind-borne dust, the dust being rock-meal wind-swept from areas of lowlands overflowed by rivers charged with glacier silt. This conclusion, I learn, has been adversely criticized by those well able to judge of the value of the facts and arguments stated in support of it, and, as the value of any reading of the characters contained in the loess depends upon the origin of the formation being correctly ascertained and admitted, I have looked over my paper to see where lies the error or weakness of my presentment of facts which in nature permit of no doubt that the loess is Æolian. I find that of the several characters described there is one, and it may be only one, which as far as I can see is quite inconsistent with any other theory, and unfortunately very little stress was laid upon this character. It is, however, twice briefly mentioned. It is stated in that paper † that the bands marking pauses in the process of deposition "curve in the spurs so as to be roughly parallel with the present land-surface;" and, further,‡ that these bands "are all flat or curved with definite relation to the present drainage-lines."§ I cannot but think that, had special attention been drawn to this feature, the result must have been to disarm adverse criticism of the "dust-heap theory." Not having done this before, I must take this opportunity of remedying the defect.

Every detail of the loess of Timaru emphatically denies that it is of marine origin. But if it existed under different topographical conditions most of the details might be held to be consistent with the "inundation" theories which have been proposed to account for loess deposits in Europe. By no exercise of the imagination, however, after as full an appeal to nature for inspiration as possible, can I conceive how, by any form of aqueous agency, each distinguishable layer could have been deposited upon the previous one in such a manner as to preserve the drainage-lines. Here the lines of surface-drainage, small and great, have been preserved throughout the process of deposition. Where there are rounded ridges or flattened ridges between gullies and hollows now, there have been rounded ridges and flattened ridges from the first. The hollows have not been carved out of a level continuous sheet of material. Every form of deposit of fine material by aqueous agency tends to level and smooth over the area of deposit.

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* Trans. N.Z. Inst., vol. xxii., art. xlviii.

† *Loc. cit.*, p. 407.

‡ *Loc. cit.*, p. 413.

§ Mr. T. Goodall, in a paper on the loess (Trans., vol. xix., art. lx.), also says, "These beds curve with the hill, and do not occur in flat beds as in marine deposits." He also gives a diagram showing the curvature.

This was not the tendency with the agent which built up the Timaru loess; on the contrary, the effect was to increase the unevenness. The bands of stratification curve with definite relation to the drainage-lines. It is easy to understand how such curves were produced, on the dust-heap theory. They are the resultants of the conflicting forces of equable deposition, and inequable denudation by contemporary rains, the latter having greater power on the slopes and surfaces near the drainage-lines. It appears to me that this curved stratification, the formation being superficial, undisturbed, and resting upon a level base, is a crucial test, and settles the question.

The loess being of Æolian origin, it necessarily follows that it belongs to a glacial age, for no other agent than ice could, in this latitude, produce material of this kind, and under such related conditions that the material could be spread out for winds to lift and bear it away to new fields of deposit. As we saw from an examination of the products of the first cold age, the Canterbury Plains were principally built up long before the loess period, but the seismic disturbances during the interval produced alterations in levels which we have few, if any, means of fairly estimating; and where those dust-fields were chiefly situated is a question it would be difficult to answer. The building-up of shingle-fans implies the overflowing of their banks by the fan-building rivers, and perhaps we should look to such action for the spreading-out of the dust which was swept over the higher lands by the breezes. In that case we should have the whole of the Canterbury Plains, and any contemporary extension of them eastward, by changing positions, as the immediate source of the dust. Against this idea, however, is the fact that the shingle of the fans appears to be free from glacier silt, and also the fact that the fans are traceable to, and appear on the whole to be contemporary with, the moraine-dams of the mountain lakes, while the loess must be older. It appears to belong to the whole of the second glacial period, and principally to the earlier stages and the culmination of its severity, rather than to the latest, the moraine and fan-building stage.

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

* Previously described under the name "evaporation veins."

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 10ft. 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 the 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.

If right in the main, this reading may be wrong by containing a redundant clause. There may have been but one phase, not two, of wet climate, giving rise to the production of rust-granules. If but one, there is some reason to suppose that it was related to the return of the cold phase rather than to the retreat of that phase. A ground for this supposition will be stated later on, in the suddenness of considerable improvements in climate.

The series of variations of climate registered in the first layer of loess appears to have been fully repeated but once. There are only two of the buried subsoils, so far as my observations show, that contain the drought-veins produced by dry climate cracking the ground, the second of these being near the top of the deposit. I have not been able to determine the exact number of marks of pauses in the deposition, but there are in one good section five or six distinct and a few indistinct ones. As the faces of the cuttings are coated with rain-wash it is not easy to count these soil-bands with certainty. As each of them indicates a long period when the supply of dust ceased, and as we trace the dust to an origin dependent upon a certain condition of climate, each of these bands registers an absence of that condition—in other words, an important alteration in the climate.

Towards the close of the loess record two new characters are introduced, the interpretation of which for a long time puzzled me completely. From 2ft. to 4ft. beneath the summits of the ridges the loess shows in weathered road- and railway-cuttings a projecting band 1ft. to 3ft. thick, the material in which differs from that above and beneath it only in being more compact, and thus resisting the weather better. The presence of drought-cracks nearly everywhere has enabled the rain to carve this band into elongated bosses. On the slopes of the spurs this character gradually gives place to another, which is quite unique in the formation. Where well developed, as on the slopes of the larger gullies, this consists of hard flaky layers, some rusty, some not so, some even whiter than the loess generally; the whole generally but a few inches, but in some places a few feet, in thickness, and frequently, or rather generally, separated into small roughly cubical fragments. The whiter portions look just like the "pugged" clay formed beneath landslips and seen where such slips have been sectioned in roadwork. The two related characters show more or less clearly in every spur in cliff and cutting at the coast, and the pugged layer in most of the sidling road-cuttings on the slopes of the gullies all over the plateau. The only explanation I can find to account for these characters is that they register the phase of greatest severity of the ice age to which the loess belongs—the second glacial period; that they show that the summits of the ridges at that time were compacted by a heavy load of ice, while the surfaces of the slopes were "pugged" by the ice creeping over them to form ice-streams in the gullies. Adopting this explanation, the extensive denudation of the dolerite and underlying gravels seen in the larger gullies and their branches becomes comprehensible; whilst it must be simply a cause of utter bewilderment at the time required, if we must believe this denudation was effected by the trifling surface-drainage now at work.

Knowing that in the discussions which took place some years ago upon the glaciation of New Zealand the view was strongly combatted that there had ever occurred such a degree of glaciation as to involve the lowlands of Canterbury, I have been the more cautious in adopting it. It is, however, well supported by plainer evidence in the immediate neighbourhood.

The map and descriptions of the icefields and glaciers of the great glacier period, in Haast's "Geology of Canterbury and Westland," can by no means show the full extent of the glaciation of Canterbury. The map shows, the text describes, only the larger glaciers originating in the Southern Alps. Besides these there must have been many minor snow-fields with their glaciers. One of these minor fields evidently existed on the north side of Mount Misery (otherwise Cave

Hill), immediately west of the Timaru plateau. This snow-field gave rise to a small glacier which, gathering towards the north, swept by east and south to the Pareora, along the western side of Mount Horrible (the summit of the Timaru plateau, 1,100ft.), and gouged away the mountain on that side, with its thick cap of dolorite upon soft marine-beds, into a precipitous face 800ft. or 900ft. high. This stream, joining another flowing from the upper Pareora country by the south of Mount Misery—rather a broad sheet of land-ice, perhaps, than a mere glacier-stream—gouged away the southern side of Mount Horrible and lower portions of the plateau in a similar manner. Moreover, the summit of Mount Horrible, though of no great area, yielded a glacier which, flowing down a slight slope northwards, scooped out on that side a wide yet ravine-like gully, this stream then joining that from Mount Misery. Mount Horrible is thus blocked out by precipitous faces on three sides, in a manner giving a western aspect justifying its name. No other agent competent to do the work could have operated here; no other agent operates in such a way; and, besides the general character of the denudation, there are a few other marks of glacier-work on the mountain, in perched blocks, and a small lateral moraine piled against the remnant of an enormous slip from the precipitous southern face. Having studied the enormous gouging of Mount Horrible, evidently the work of ice, I have no hesitation in attributing the two peculiar characters in the upper loess to the glaciation of this deposit. These marks, then, show that the severest phase of the second ice age occurred near its close. Another layer of loess was afterwards added, but it is of less thickness than earlier ones, and should, I think, be referred to the earlier stages of the retreat of the ice, as in later stages the glacier silt would scarcely escape being trapped by rock-basin lakes, which later on were filled with shingle.

Among the accidental constituents of the Timaru loess, the multitudes of bird-stones in most of the bands marking long-persistent land-surfaces are surely the most remarkable. Their distribution also is remarkable. According to my observations they are decidedly much more numerous at the coast than a couple of miles inland, and also more numerous at the north end of the coast cliffs than a few miles further south. So far the only good section of the whole deposit that has been made inland is the "stripping" at the Harbour Quarry, and here the bird-stones are few, certainly much less numerous than at the coast. The number and the partial distribution of the pebbles may be accounted for by the supposition (besides that of an arctic climate, otherwise found necessary) that the Timaru plateau never extended much further eastward than it does at present. We may then see in this well-drained north-eastern angle of the dolerite and loess plateau the mustering and alighting-ground of swarms of birds migrating to and from less frigid regions with each recurring year. I cannot see how the partial distribution is to be otherwise accounted for. But there is another difficulty. Sea-birds do not use gizzard-stones, their use is confined to granivorous birds, and these seldom or never discharge them. Are these multitudes of stones, then, a mortuary talus? If so, why their markedly greater number near the coast? I have never met with any statement on the subject, but I think it more than probable that birds about to take a long migratory flight will unburden themselves as much as possible before starting, including the discharge of their gizzard-stones. It is worthy of note that bird-stones are numerous in some places in the clefts in the dolerite, deposited there before the loess began to fall; and also that the loess in the upper portion, including the compressed and pugged layer and a few feet beneath it, is barren of them. From the last fact it is to be inferred, if the general explanation is correct, that the climate became too severe to allow the birds to visit this region.

In this connection must be mentioned that in the lowest layer of the deposit stones are to be found which could only have been used by large birds of the moa family. I have found an odd one or two higher up, and also fragments of bones; but in the lowest layer I have seen two nests, so to speak, of large stones. In my last paper on the red gravels, it was stated that bones of large birds have been found beneath the dolerite; therefore there is nothing to be wondered at in finding relics of such birds in the later formation. There is this curious fact, however, in connection with the majority of the pebbles in one of the nests referred to: that they were unquestionably picked up by the bird or birds from an exposed sea-beach. They are of the same or very similar rock material as those forming the bulk of the present sea-beach, *i.e.*, Waitaki shingle, and they have the discoid shape produced by the action of the waves on the beach. I have been very careful to make sure that these pebbles are really imbedded in the original deposit, and not merely surf-washed and mingled with slip stuff, cases of which can be seen all along the cliffs. A vague and unsatisfactory inference might be suggested from the fact stated, that the beach from which the pebbles were obtained was not far away, and, from this, the further inference that the land in that case could not have been at a much greater elevation than at present. In the second nest referred to, the pebbles were all well-rounded.

Before leaving the loess, I would suggest that the upward range of the loess on Banks Peninsula may be a peculiar evidence of the contemporary climate. I read that it extends only some 800ft. up the hill-sides. Why so? It cannot be that was the limit—*plus* the amount of any subsidence since—to which winds could lift the loess-forming dust. Does not this limit of height mark what was practically the limit of vegetation capable of entrapping and retaining dust—in other words, the snow-line?

If we suppose the ice retreated from the field of its greatest extension to the limits marked by the great lake-dams, we have to deal with a great amelioration of climate, and the change appears to have been as sudden as it was great. There is an absence of marks of gradual retreat over the country generally, and the great moraines have almost as definite a limit of commencement as of termination. The second great thaw, under the influence of which the glaciers retreated to something like their present dimensions (or it may have been further back), also appears to have been a sudden thaw. It was certainly very rapid, compared with the length of time occupied in building up the great terminal moraines. The fans, which originate from those moraines, also appear to have been completed by an extraordinary, one might say a cataclysmic, rush of water, not by ordinary river-action. The small terraces and gutters which make old river-beds rough travelling are absent from the surfaces of the fans, where these have not been smoothed over by a surface of soil. A sweeping rush of water would account for this. Probably, in some cases such a rush of water might be attributable to breaches in lake-dams, but scarcely in all cases. One of the most remarkable instances of the smoothing of the surface of a fan is that of the small fan of the Waihi (Woodbury), of which the material is, at the gorge, very coarse and bouldery. The river at its highest now is but a small stream, that could scarcely cover the levelled upper portion of the fan. It seems to me that this fan could only have been levelled in the manner it was (before subsequent terracing on one side) by a powerful rush of water. And there is no lake on any of its branches, but it drains a bulky mountain, which at the time glaciers filled the great lakes probably carried a heavy load of snow.

Much has been written about the great glacier period, but I do not remember having seen attention drawn to the sudden termination of the work of building the moraine dams. The compactness of those great terminal moraines, their small breadth in proportion to the length of the glaciers which piled them, suggests a corresponding steadiness of climate. This, however, may be misleading; the moraines may be the record not of a continuous and equable period of cold, but of a series of maxima of nearly equal intensity. If such was the case, evidence of the fact might be found in excavated moraines, such as has been described in the Nelson Province. Be this as it may, the cessation of the work of piling up the terminal moraines clearly points to the occurrence of marvellously sudden ameliorations of climate. The absence of marks of slow retreat—in morainic matter—of the ice from the low-lands appears to tell a similar tale of an earlier age. How such sudden changes were brought about is a question on which I can offer no opinion; but I think the condition of the alpine lakes, with their high and steep moraines, clearly proves that the ice retreated from them with great suddenness. If this were so, as it appears, the lesser changes registered by the loess may likewise have been sudden changes—that is, occupying but a brief time compared with the duration of each fixed phase.

LOESS STRATIGRAPHY CENTENARY 1891-1991

HARDCASTLE

Postscript

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