they were borne, it would be painful to dwell, his illness terminated in death. He had been for a short time aware that the end was at hand, and, with an unclouded mind, he prepared himself calmly and humbly for the great change; receiving and giving comfort and support from the thankful hope that the close of his suffering life here, was to be the beginning of an endless existence of rest and happiness in another world. He retained to the last, when he knew that his own connection with earthly things was soon to cease, the unselfish interest which he had ever felt in the pursuits and happiness of those he loved.

A few words may be allowed about a character where rare and sterling qualities were combined. His upright, sincere, and honourable nature secured to him general respect. By his intimate friends, he was admired for the extent and variety of his information, always communicated readily, but without a thought of display,—for his refinement and delicacy of taste and feeling,—for his conversational powers and playful wit; and he was beloved by them for his generous, amiable disposition, his active and disinterested kindness, and steady affection. And in this manner his high-toned character acquired a moral influence over his contemporaries and juniors, in a degree remarkable in one so early removed.

To this brief history, little more is to be added; for though it is impossible not to indulge in speculations as to all that Mr Gregory might have done in the cause of science and for his own reputation, had his life been prolonged, yet such speculations are necessarily too vague to find a place here; and even were it not so, it would perhaps be unwise to enter on a subject so full of sources of unavailing regret.

Sixth Letter on Glaciers. Addressed to the Right. Hon. Earl Cathcart.

(Communicated by Professor Forbes.)

Rome, *Feb.* 5. 1844.

My Lord,—In a letter which I addressed to you on the 29th ult., I gave some account of the few new observations which untoward circumstances permitted me to make, last autumn, upon the glaciers of Switzerland and Savoy. I have, however, had leisure to reflect maturely upon the theory of glaciers, which I have been occupied for two years in endeavouring to mature; and, without pretending to find in it a complete solution of every problem which might be proposed respecting these wonderful bodies, I am perfectly satisfied that it is fundamentally conformable to the laws by which they are governed. Some new analogies, to which your Lordship has referred in your last letter, such as that between glaciers and lava streams, may serve to render the subject more popularly intelligible; and in explaining them, I may have an opportunity of removing, in some degree, the difficulties which have arisen in the minds of candid and intelligent persons, who have studied this theory for the first time—difficulties which would probably disappear of themselves by a more prolonged attention.

I have not had the advantage of seeing the eruption of Etna, to which your Lordship alludes, which was indeed over before I arrived at Naples, and of which I did not even hear for a considerable time after; so small is the sensation which such events excite in the country. I have, however, had an opportunity—probably not less favourable, though far less imposing—of studying the mechanism of plastic lava, in the small currents which, during the months of November and December, were very frequently flowing from mouths *within* the crater of Vesuvius. On the 30th November, in particular, I descended to the bottom of the crater, in order to examine a current of very liquid lava, fifteen or twenty feet wide, which issued from a cavity near the foot of the small cone which occupied the centre of the crater, and from whose top (in the shape of an inverted funnel, or of a blast furnace) there issued smoke and flames,* occasionally accompanied by a discharge

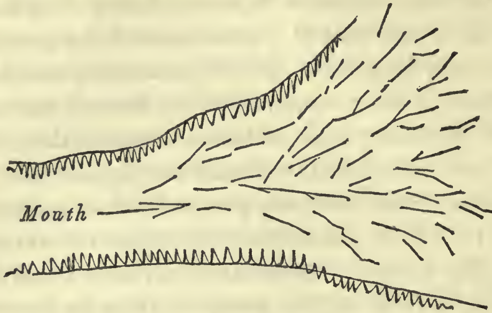
* I am able to add my distinct testimony to that of M. Pilla, as to the emission of *flames* by the crater of Vesuvius. I spent part of the evening of the 1st January on the top, and had not the least doubt that what I saw were actual flames, which issued from time to time from the orifices of the small cone, and which were of a pale colour, often inclining to blue.

of volcanic projectiles. The lava issued in a very steady rapid stream, and spread itself over a gentle declivity with a velocity of not less, I think, than a foot per second.

Admitting the plastic or viscous theory of glaciers, the resemblance to lava fails (1.), In respect of the great liquidity of the lava near its source; (2.), From its very unequal rate of consolidation; a crust being very soon formed upon the surface, which becoming more and more massive, the principle of fluidity is not uniformly distributed throughout the mass, as in the glacier, but a tolerably perfect fluid struggles with the increasing load of its ponderous crust, which it tears and rends by the mighty energy of hydrostatic pressure; and here and there finding a freer exit far removed from its source, tosses high those mighty fragments of the stony arch which confined it into the wild shapes which strike the eye in crossing the wastes of a lava stream, and which seem at first incompatible with the fluid or semifluid principle of motion. This second circumstance, then,—the very unequal and rapid superficial consolidation of the lava near its source,—has no analogy in a glacier, nor even in a river, unless when breaking up a ponderous crust of ice after a sudden thaw. The regulated progression of the glacier, swiftest in its centre, and with a graduated retardation towards the sides, has a much more precise analogy to that of a river than the lava stream has, which is subdivided (when it has any considerable breadth) into many little currents, each rolling past, and being retarded by its more sluggish or already consolidated neighbour; so that its surface resembles that of the bed of many torrents in the Alps, where the more solid matters, the rocks, stones, gravel, sand, and clay, trace out the form of a sluggish mass propelled downwards by gravity, whilst its surface is seamed by the trickling of innumerable rills of water, charged with the more portable materials which have been washed down, or squeezed from the general mass.

There are other circumstances, however, in which the analogy of the glacier with the lava stream is more complete; and of these I shall observe—

I. That the *cracks* of the dark-coloured slag on the surface of the liquid lava, as it spreads itself abroad, on issuing from the fiery mouth, are *radiated* exactly as those of a glacier under similar circumstances, and which I have represented in the margin as I saw them on Vesuvius, the lines of fissure



Fissures in the Crust of Lava during Crystallization.

being marked by the liquid fire shining through. A perfect analogy here exists with the phenomena of radiating fissures in ice, which I first described in the glacier of the Rhone, and afterwards in the ice of the Gl. du Talefre, where it joins the Gl. de Lechaud, in the Gl. of Arolla, and very many other instances.

II. That the slags, where solidified, presented *striæ* or *ripple-marks* along their surface, parallel to the direction of the "ribboned structure" of glacier ice, *i. e.*, inclining slightly from the sides towards the centre of the current, in the direction in which the current is moving. These striæ, or ripple-marks, which have a striking analogy in certain cases of the retarded movement of rivers, are carefully to be distinguished, on the one hand, from the *cracks or flaws,* and, on the other, from the *direction of motion* of the fluid particles.*

III. When, at some distance from the source, the lava became viscid and tenacious, and forced itself, in streamlets of a pasty consistence, through the interstices of its slag, thence it became streaky and drawn out, in the direction last mentioned, as molten glass does in the hands of the workman.

* A long accidental delay in the printing of this letter enables me to add, that I have found in the lavas of Etna a yet far more perfect analogy to the veined structure of glaciers than that described in the text. It is, indeed, so completely developed as to leave no doubt as to the identity of origin. Aug. 1844.

IV. But there is a more striking analogy to the ribboned structure of glacier ice, to be found in lava currents at a distance from their origin, and where by any circumstance their surface has been broken up, and their internal structure exposed. In the Fossa della Vetrana, for instance, and other places, I have found the lava divided into thin layers parallel to the interior of the surface of the channel through which it flowed, evidently produced by the adhesion or retardation which the soil exerted upon its adjoining film of lava, and the successive portions of lava upon one another, in proportion as the semifluid mass, rolling upon its own particles (or rather sliding imperfectly over them), produced a solution of continuity and a series of shells, parallel in direction to the bed upon which the whole rests. The thickness of these shells varies from one-third of an inch upwards. I have never, however, observed a structure in the *interior* of the lava except that parallel to the sides and bottom of the canal in which it moves; nothing, in short, corresponding to the *frontal dip* in glaciers. But this is quite natural and conformable to the very different constitution of a glacier; and, in particular, it corresponds to the fact so often urged as a difficulty to the semifluid theory of glaciers, namely, the want of ductility or tenacity of their parts. It is that fragility precisely, which, yielding to the hydrostatic pressure of the unfrozen water contained in the countless capillaries of the glacier, produces the *crushing action* which shoves the ice over its neighbour particles and leaves a *bruise*, within which the infiltrated water finally freezes and forms a blue vein. In the lava, on the other hand, where the tenacity is great, the discontinuity, if produced at all, is soldered up by the plasticity of the parts, whose small crystalline structure farther tends to obliterate the separation. The layers just mentioned, parallel to the bed, are perhaps produced by the successive adhesion of warmer streams of lava to the colder parts already deposited, and, consequently, their analogy to the glacier structure must not be pushed farther than as shewing the directions of the tendency to separation of a very viscid stream, powerfully retarded by its bed. It is the congealing of the lava which makes its adhesion to the sides great enough, and its own fluidity small enough, to bear a comparison with the far less ductile body of a glacier. In the heart of the mass where the same intestinal motions take place (as I have shewn conclusively by using *coloured* layers of plastic matter in the models formerly exhibited to the Royal Society), the displaced particles reunite and consolidate into a homogeneous mass without any trace of dislocation.*

V. The convexity or concavity of a semifluid stream like a current of lava or of a glacier, depends entirely upon the relations or conditions in which it is placed. Upon the same slope, a fluid of one degree of consistence will run off in a concave stream, whilst a more viscid one, which must accumulate in thickness, in order to overcome the resistance in front (just as water which meets a sudden obstacle), rises into a convex curve. This is perfectly seen in the case of a substance like plaster of Paris, mingled with water, whose consistence may be varied at pleasure, and a stream of which may be made either concave or convex, or concave at its origin and convex at its termination, as is the case with a glacier. The evidence on this subject, afforded by the models formerly laid before the Royal Society, is so complete and conclusive, that, however interesting it might be to put into a mathematical form the relations of the *constants* of the effect of gravity, the viscosity of the body, and the retardation of the sides, as affecting the form of the surface, it is sufficient for my present purpose to appeal to facts so familiar, and experiments so easy, that their evidence may well be preferred to the more casual and embarrassed case of lava streams, which, as I have already observed, are seldom or never to be regarded, on a great scale, as *simple* moving masses. I may, however, add, that when the inclination is small the surface is convex, at a certain distance from the origin.

* The following passage from M. Dufrenoy's Account of Vesuvius, is interesting, if it were only as recording his remark, that the variation of velocity in different parts of a stream must produce longitudinal striæ. "La plupart des coulées presentent des bandes longitudinales assez paralléles entre elles ; ces larges striés saillantes sur la surface sont les traces du mouvement de la lave qui ne s'avance pas d'une seule piece, mais par bandes paralléles." Sur les Environs de Naples, p. 324.

VI. There is a circumstance attendant on the motion of lava streams, which has struck several geologists, before the viscous theory of glaciers had been proposed—I mean the existence of *moraines.* The moraines of lava are best seen in the more defined and united lava streams on rather a small scale,—those, in short, which have the unity and character of a proper stream, moving at once in its various parts. The moraine is composed of stranded masses of lava crust, thrown aside by the liquid fiery stream, and partly, perhaps, of the yielding matter of the bed of the stream pressed outwards and upwards by the hydrostatic pressure of the centre. The former is chiefly, perhaps, the case when streams of tolerably fluid lava flow down a steep inclination, as on the exterior of the cone of Vesuvius; the latter, when the inclination is small and the weight of accumulated lava great. The igneous moraines, though noticed by various geologists, are most emphatically described by M. Elie de Beaumont, in his masterly memoir on Etna, in the following words :—" Une des circonstances que les coulées de lave présentent le plus invariablement toutes les fois qu'elles ont parcouru des talus où elles pouvaient acquérir une certaine vitesse, caractères que j'ai observés sur toutes sortes de pentes depuis 33° jusqu'à 2° et que je n'ai cessé d'observer que là où les coulées se sont arrêtées faute de pente, consiste en ce que chaque coulée est flanquée de part et d'autre par une digue de scories accumulées qui rappelle par sa forme la moraine d' un glacier ; digue qui s'élève constamment à une hauteur supérieure à celle à laquelle la coulée est reduite à la fin du mouvement, et qui marque le maximum de hauteur qu'elle a atteint dans le moment de son plus grand gonflement. Souvent aussi les coulées présentent de pareilles digues vers leur milieu, lorsqu'elles sont partagées en plusieurs courants distincts coulant l'un à côte de l'autre."*

VII. The termination of a lava stream on a level or slightly inclined surface due to its increasing viscidity, presents appearances almost identical with those of a glacier. The same protuberant convexity of surface, the same steeply-inclined

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* E. de Beaumont Recherches sur le Mont Etna, p. 184.

sides and front, and nearly the same ground-plan, all bespeak a similarity in the circumstances of motion. I may add, that in some experiments which I made some years ago upon the flowing of melted iron in narrow channels, and upon small slopes, with a view to illustrate some phenomena of lava streams, before I had commenced a particular study of glaciers, I arrived at similar results, and obtained the same convexity of surface which is produced in the plaster models before cited.

It is very interesting to observe how many intelligent persons have been struck with the similarity between glaciers and lava streams, without, however, pushing the parallel beyond a general resemblance. M. Elie de Beaumont, we have seen, speaks of the moraines of volcanoes; but in various parts of his writings, as well as those of his colleague, M. Dufrenoy, we find the mention of glaciers as continually suggested to his mind when surveying the wastes of Etna and Vesuvius. One of these passages is the following: "L'ecorce superieure d'une coulée separée de l'ecorce inferieure et du sol sousjacent par une certaine epaisseur de lave liquide ou du moins visqueuse, se trouve dans un état comparable à celui d'un glacier, qui, ne pouvant adhérer au sol sousjacent à cause de la fusion continuelle de sa couche inférieure, se trouve contraint à glisser ;"* shewing that the author then adopted the theory of Saussure (since ably defended by Mr Hopkins), in which the fusion of the ice by the heat of the earth, might be said, in some sense, to *float* down the superincumbent solid ; an opinion best controverted by the fact which M. E. de Beaumont has since clearly brought into notice, that under existing circumstances such fusion is perfectly insignificant.†

The writer of a popular Italian guide-book, Mrs Starke, is perhaps one of the first who indicated the striking general resemblance of a stream of lava to a glacier. She describes the former (which she saw during a small eruption of Vesuvius) as "rolling, wave after wave, slowly down the mountain with

* Recherches sur l'Etna, p. 177.

† Annales des Sciences Géologiques par Rivière.

the same noise, (?) and in the same manner, as the melting glaciers roll into the valley of Chamouni; indeed, this awful and extraordinary scene would have brought to mind the base of the Montanvert, had it not been for the crimson glare and excessive heat of the surrounding scoriæ."*

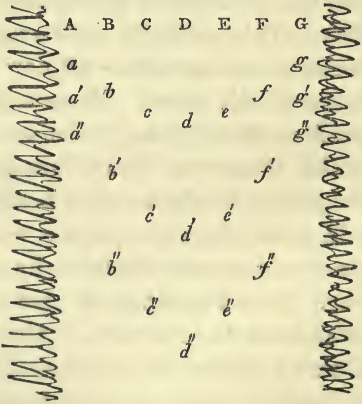
Mr Auldjo, the author of a Narrative of an Ascent of Mount Blanc, and therefore acquainted with the appearance of glaciers, has renewed Mrs Starke's comparison in very similar expressions, in a work more recently published upon Mount Vesuvius. Captain Basil Hall has, if I mistake not, in more than one part of his writings suggested the picturesque analogy of volcanoes and icy mountains, the cradle of glaciers.

We have seen how far there is a real analogy between the mechanism of these two terrible scourges of Almighty power —the ice-flood and the fire-flood, both of which invade the homes and the labours of man, with a force alike irresistible. But to render the analogy more than apparent or poetical, it was required that several difficulties, very obvious, and seemingly insuperable, should be removed; and the chief of these was the texture of ice compared to the texture of lava—the former passing from a brittle solid into limpid fluid by heat, the latter passing like sealing-wax through every intermediate degree of viscidity. This difficulty could only be met by an exact determination of the question—Of how far a glacier is to be regarded as a plastic mass? Were a glacier composed of a solid crystalline cake of ice, fitted or moulded to the mountain bed which it occupies, like a lake tranquilly frozen, it would seem impossible to admit such a flexibility or yielding of parts as should permit any comparison to a fluid or semifluid body, transmitting pressure horizontally, and whose parts might change their mutual position, so that one part should be pushed out whilst another remained behind. But we know, in point of fact, that a glacier is a body very differently constituted. It is clearly proved by the experiments of Agassiz and others, that the glacier is not a mass of ice, but of ice and

* Starke's Travels. French edit., p. 311.

water; the latter percolating freely through the crevices of the former, to all depths of the glacier; and as it is matter of ocular demonstration that these crevices, though very minute, communicate freely with one another to great distances, the water with which they are filled communicates force also to great distances, and exercises a tremendous hydrostatic pressure to move onwards in the direction in which gravity urges it, the vast, porous, crackling mass of seemingly rigid ice, in which it is, as it were, bound up.

But farther than this, the experiments first announced in the earliest of these letters, shewed, that whatever be the constitution of a glacier, and whatever be the cause of its motion, THE FACT IS, that it does not move like a solid body sliding down a bed or channel, but that the velocity of each part of its breadth is different. It was demonstrated by the most clear and plain geometrical measurements, that whilst the centre of a glacier moves 500 feet, the side of the glacier moves only 300; consequently, the portions of ice which started together soon part company, and the central molecule has completed its course, or arrived in the lower valley, whilst the other, which was its companion, has advanced only three-fifths



of the distance, or remains perhaps several miles behind. Thus it has been shewn from multiplied measurements of the most precise and accordant kind, that a series of stones or marks being supposed to be laid across a glacier in the line ABCDEFG; they will be found, after a certain time, in the position *abcdefg*, after other equal intervals at *a'b'c'd'e'f'g'*, and at *a''b''c''d''e''f''g''*, by which time it will be seen that the neighbour particles have entirely changed their relative positions, and that the mass can have no pretension to be called rigid, but moulds itself after the manner that a fluid or semifluid body does in like circumstances, the centre advancing fastest, and, for some space in the centre, nearly uniformly, whilst the retardation produced by the friction of the banks is most intense in their neighbourhood; which is conformable to what we know of the movement of viscous fluids. It is, therefore, no hypothesis, but a simple statement of a demonstrated fact, *that the manner of movement of the surface of a glacier is not such as is consistent with the continuity of a rigid body, but that it coincides with the manner of motion of a viscous or semifluid body.* Whatever may be the difficulty of conceiving the glacier to be a body thus constituted, the fact admits of no doubt;—the effects of forces applied on a great scale to bodies, are the best and only conclusive proofs of their real constitution, and worth all molecular theories and minute experiments put together.

If a body be really of a *pasty* consistence, ductile and plastic like lava or tar, such transpositions taking place in the interior of the mass are effected without any injury to the texture or continuity of the substance. With a degree less of plasticity, a violent separation of the parts may take place, but they will, by juxtaposition, soon reunite and take a new *set.* With a degree more of rigidity, there must be a permanent *bruising* and *rending* of the parts, in order that a semi-rigid body may assimilate all in its movements to a fluid. It must, therefore, be considered as entirely confirmatory and explanatory of the preceding statements of the seeming plasticity of a body so fragile in its elements as pure ice, that the ice of glaciers is found rent in many parts by the forces tending to dislocation, and that, besides, it contains within itself a testimony to the internal partial movements by which its total motion is effected, in the veined structure already alluded to, occasioned by the varying velocity of the adjacent icy strips A *a a' a''*, B *b b' b''*, &c. This structure is not exactly parallel to the direction of motion of the ice, for reasons which I have elsewhere stated, but which need not now be adverted to. My present object is to shew, that the rigidity of ice, as a physical fact, cannot contradict the mathematical evidence of the manner in which glaciers *do* move, and that the seeming contradiction is reconciled by shewing, that the ice bears permanent traces of the violent strain to which it is subjected, and of the actual bruising and disseverment of its parts, producing a phenomenon otherwise impossible to be explained.

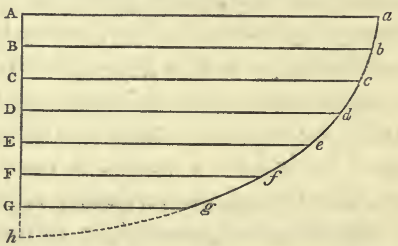
I believe that it is during the progress of the glacier thus subjected to a new and peculiar set of forces depending upon gravity, and which remodel its internal constitution, by substituting hard blue ice, in the form of veins, for its previous snowy texture, that the horizontal stratification observed in the higher part of the glacier or *névé*, is gradually obliterated.

If, as we cannot doubt, the slower motion of the glacier near its sides be owing to the retardation which their excessive friction occasions, there must necessarily be a retardation at the bottom in a similar manner, and the surface of the glacier will move faster than the strata in contact with the ground; to which it is even supposable, that, in some cases, they may be entirely frozen. This retardation may, perhaps, be less than the lateral retardation, because the slope of the valley in which the glacier lies is probably more even, generally speaking, than its breadth is regular. In fact, so great is the irregularity of the ground-plan of any compound valley,—so frequent the interfering ridges or promontories, the bays formed by adjoining tributary valleys,—and so numerous the gorges or contractions,—that we cannot so properly call the lateral resistance to the onward motion of a glacier, *friction*, but rather a direct opposition to the exit of a solid body, which renders its plasticity absolutely essential to its progression. Nevertheless, the inferior slope of the glacier bed being also irregular, and its friction great, must cause a retardation in the lower strata of ice, which must be continually overtaken by the superior ones: and this appears to me to be so plain and necessary a consequence of the combination of facts which we have to consider, that perhaps the direct proof of it would not repay the labour which it would involve, which would be of the most serious kind;—for we must not expect to find the difference of velocity apparent in the superficial strata, even to a considerable depth, since we know that the retardation is a maximum near the sides and bottom, and that, for the same reason, the motion of all the central part of a glacier is nearly uniform, so will the motion of all the part of the ice near the surface be nearly uniform.

These considerations suggest the explanation of a difficulty, kindly suggested to me by a most competent judge, who expressed himself at the same time persuaded of the truth of the viscous theory of glaciers. "How comes it, that, if the motion of the different parts of a glacier diminishes from the surface to the bottom, the 'trou de sonde' or *bore*, 140 feet deep, made by M. Agassiz in the glacier of the Aar, is stated to have remained vertical for a period of many weeks?" In the first place, the *fact* of the verticality requires confirmation; for it is difficult to understand how, by means of a plummet, a hole 140 feet deep, and only 3 or 4 inches in diameter, could have its verticality tested. Such bores, so far as I have seen them, are more or less twisted, owing to the softness of the material, and the method of working; and it seems beyond all probability, that a hole of such a depth constructed in the ordinary way, should be either mathematically straight or vertical. I apprehend that the verticality alluded to by M. Agassiz, or his coadjutors, is merely that of popular language, indicated by the boring rods standing vertically outwards when plunged into the hole, which, on account of their flexibility, would not be an indication of the verticality of more than the upper twenty or thirty feet of the bore at the most.*

* Since this passage was written, I have had an opportunity of referring to the description of the experiments of Agassiz in the *Bibliothèque Univèrselle*; and I find that there is no evidence whatever of the continued verticality of the bore of 140 feet, which existed (to that depth), I believe, but a few days: the observations of continued verticality, such as they are, applied to small bores only, not exceeding 25 or 30 feet, which, of course, greatly increases the force of the reasoning in the text. Aug. 1844.

But, even setting aside this important consideration, the principle of the variation of velocity being chiefly confined to the neighbourhood of the sides and bottom, and the comparatively quiescent and passive state of the central and superficial part, seem sufficient to explain the facts within the reasonable limits of error. The depth of 140 feet appears, from M. Agassiz's own observations, not to exceed ONE SIXTH, at most, of the depth of the glacier of the Aar in that part. Now, let A B C, &c., represent points in the vertical section of the glacier; then, from all that we know of the superficial



motion of glaciers, or of the parallel case of rivers whose velocity has been ascertained at different depths, the velocities will vary in some such manner as A *a*, B *b*, C *c*, &c.,—the variation being scarcely sensible at first, and very rapid at the bottom, where the velocity may even be zero, if the curve be prolonged to the point *h*. But, supposing G to be the bottom of the glacier, it will be seen how insignificant may be expected to be the variation of velocity between A, the surface, and B, one-sixth of the depth, during the short period of a few weeks, or even months. I have the honour to be, &c.

Seventh Letter on Glaciers.—On the Veined Structure of the Ice. Addressed to the Rev. Dr WHEWELL, Master of Trinity College, Cambridge. By Professor FORBES.

SALERNO, *May* 18. 1844.

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You object that the shells produced by the rupture of the parts of the ice caused by excessive friction, should be all parallel to the sides and bottom of the trough of the glacier, instead of being inclined from the sides inwards and forwards towards the centre, as in Fig. 1,

Fig. 1.

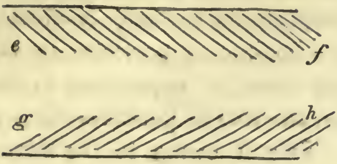


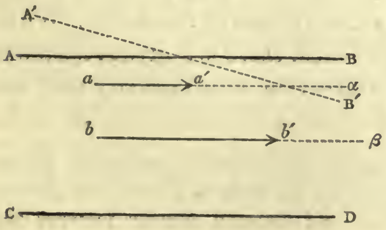
Fig. 2.

and from the bottom upwards and forwards, as in Fig. 2. You will find that I have endeavoured to explain this in the last chapter of my book of Travels; but not having it by me, I cannot refer you to the particular passages. The point in question is undoubtedly the least obvious and most difficult part of the theory; but as I have no doubt of its exactness, it will have a proportionate weight in deciding in its favour the opinion of persons accustomed to mechanical theories. It would be difficult to bring it home to the apprehension of ordinary readers; and, for this reason, I have dwelt upon it, perhaps, too shortly in the chapter alluded to.

You will readily admit, that if I shall demonstrate separate reasons for the existence of each of the structures figured above, (the first a plan, the second a section), the result will be the spoon-shaped structure which I have shewn to exist in glaciers.

(1.) The tearing asunder of the particles of the glacier, owing to the friction of the sides is, *nearly*, but *not quite*, parallel to the sides; for this reason, that the lines of greatest strain are determined, not merely by the force of gravitation which urges the particles forwards, but there is a *drag* towards the centre of the stream, in consequence of the greater velocity there.

Fig. 3.



Let A B be the side of the glacier, whilst the particle *a* moves to *a*′, the central particle *b* moves to *b*′, which, owing to the cohesive bond between *a* and *b* must produce a strain oblique to the axis of the glacier.

Or view the matter thus—the movement of the ice stream (considered just now solely as respects its surface), is effected against a varying resistance. The line of particles in the direction $a\,\alpha$ presents a greater force of opposition to the movement of the particle *a*, than the line of particles $b\,\beta$ presents to the movement of *b*. This is owing to the lateral friction acting more powerfully in retarding the first than the second; consequently the *virtual* wall of the glacier, or plane of complete resistance, will be no longer A B, but inclined (for the particle *a*) in the direction A′ B′.

If this reasoning require support from experiment, it is easily had. I have described, in a foot-note to my last chapter, the experiment of dusting powder upon a moving viscous stream; and our friend Heath has now a specimen of the result, shewing the lines of separation in the direction I have stated. The same is remarkably shewn in the case of a stream of water; for instance, a mill-race. Although the movement of the water, as shewn by floating bodies, is exceedingly nearly (for small velocities, sensibly) parallel to the sides; yet the variation of speed from the side to the centre of the stream occasions a *ripple* or molecular discontinuity, which inclines forward from the sides to the centre of the stream at an angle with the axis, depending on the ratio of the central and lateral velocities. The veined structure of the ice corresponds to the ripple of the water, a molecular discontinuity whose measure is not comparable to the actual velocity of the ice; and, therefore, the general movement of the glacier, as indicated by the moraines, remains sensibly parallel to the sides.*

(2.) If I have explained myself distinctly as respects the fissures produced by lateral friction, there will be little difficulty in applying the same reasoning to the resistance of the frontal dip, exhibited in the second figure of this letter. When a fluid, or semi-fluid, is very viscous, there is a great resistance to its onward motion in the direction which gravity and the

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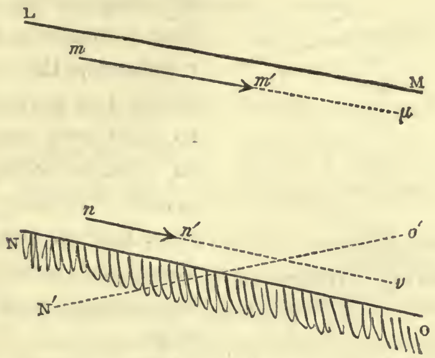
* have lately identified completely the planes of separation in the lava streams of Etna, which correspond perfectly to those of the glacier, being nearly vertical at the sides, and directed slightly towards the centre of the stream.

fall of the bed prescribes. Let L M be the surface, N O the bed of a glacier; then the resolved force is usually con-

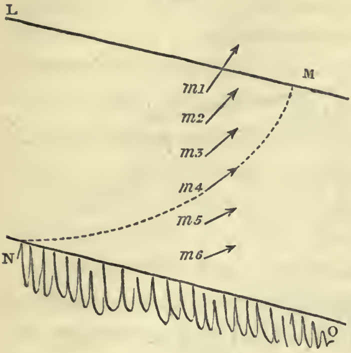
Fig. 1.



sidered as acting on the particles *m n*, in the directions *m m′*, *n n′*, parallel to the bed. But if we reflect that, owing to the length of the glacier, and the toughness or consistency in its mass, the resistance of the line of particles *n v* is enormous, the plane of complete resistance N O will virtually be twisted in the direction N′ O′, and the particle tends to be thrust *forwards* and *upwards*, which will evidently produce the frontal dip.

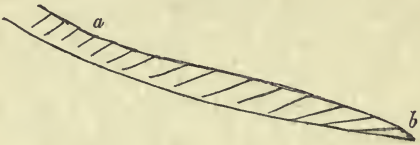
(3.) But there is a peculiarity in the vertical plane which did not exist in the horizontal one. In the case we first considered, the veined structure exists almost entirely in the neighbourhood of the sides of the glacier, and is lost towards its centre, being due to the influence of friction, which varies with the distance from the side; the central part, *e f g h* (Fig. 1.), moving nearly uniformly, would cease to exhibit a linear arrangement. The completion of the curve is due to the influence of the curvilinear bottom, combined with the opposing mass of the glacier in front; and this influence will extend to the very surface, as a little consideration will shew. For, resuming the construction of Fig. 4, since a vertical series of particles, $m_1 \,.\,.\, m_6$ (Fig. 5) are supposed to be acted on by a force partaking of the nature of hydrostatic pressure, derived from a great elevation, each particle is ready to move onward in the direction in which the effective pressure is greatest; and it is plain, that, owing to the diminishing relation between the weight of the superincumbent particles and the frontal resistance, the direction in which the particles will tend to slide over one another, or to produce rents, will approach verticality at the surface, and on the whole will, therefore, tend to produce lines of discontinuity, such as N M.

Fig. 5.



(4.) Considering the glacier at different points of its length,

Fig. 6.



it is evident, by similar reasoning, that near the region of the nevé *a* the frontal dip will be all but vertical, because there the horizontal resistance is enormous; whilst at the lower end *b*, where it tends to vanish, the shells will tend to parallelism with the bed. It is needless to add, that the relative movements of the particles over one another, producing discontinuity, are not to be confounded with their absolute motions in the glacier, exactly as under head (1.) I must however, observe, that as the tendency of any particle due to the hydrostatic pressure will be to describe ultimately the whole curve N m_4 M within the glacier, this may account for some of the facts, or supposed facts, which indicate a tendency in the ice to expel bodies engaged in it, as well as the convexity of the glacier at all times, and its remarkable rise of surface during winter.

Lastly, The ablation of the surface of the glacier during its descent from *a* to *b*, (Fig. 6.) will tend continually to give the observed elongated forms of the superficial bands, by cutting the shells of structure obliquely.

I remain, my Dear Sir, yours sincerely,

JAMES D. FORBES.

To the Rev. Dr WHEWELL.

On the Ancient Peruvians. By Dr J. J. de TSCHUDI.*

Communicated by the Ethnological Society.

During a stay of five years in Peru, spent for the most part in the interior of that remarkable country, I devoted as much of my time as I could spare from my studies in Natural History to the investigation of the condition, past and present, of the aboriginal inhabitants. In the course of these researches I collected many facts connected with their history and manners. I have thoroughly examined more than eighty ruins of Indian villages, with, perhaps, half that number of tombs. I have seen and described many of their relics, and have brought to Europe ten mummies of different ages and sexes (six others are still expected); and more than thirty skulls of Indians are lying before me, the most beautiful collection that has ever been obtained from that part of America.

I shall, probably, at some other time have the pleasure of bringing before the Ethnological Society my researches on the great migrations of the nations of the northern division of the New World, together with my views on the different tribes and races: for the present I shall communicate a few general remarks only.

The greater part of the old Indian villages in the Sierras of Peru, are situated on steril heights, conical turreted hills, summits of mountains or narrow ridges, and on an eastern exposure. The choice of this latter situation was determined by their religion. It was, in fact, natural that the Indians, who considered their kings to be the offspring of the sun, which they adored as their primary divinity, should have chosen, for the sites of their towns and villages, positions from which they

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* Read before the Society, 1844.

could see and adore the god at his first appearance above the horizon. To this practice, which in some provinces was very rigidly followed, they sacrificed much of their comfort, as they were not only exposed to violent and icy winds, but also found themselves on points totally deprived of water, which, in some cases, had therefore to be brought from a distance of two or three miles. This explains why we find in certain ruins of Indian villages, especially such as are situated at a distance from springs or brooks, so great a number of water-pots of all sizes, forms, and materials. In these pots the indispensable fluid was fetched from a distance on the backs of Llamas. I found the same custom still subsisting among the Indians.

In all large villages, where the ground permitted, a great central square was formed, from which very regular streets frequently branched off in all directions. The structure of the houses is extremely varied. Close to the largest palaces, having from twenty to twenty-five windows in front, are the smallest, narrowest, and poorest cottages. Stones and cement are almost everywhere the usual building material; but near the coast, on the western side of the Cordilleras, larger edifices of bricks are found, and called by the Indians Ticacuna.

In the districts of Tunin and Ayacucho, I have seen large villages consisting of tower-like buildings of a very peculiar structure. Every house is round or quadrangular, the inner diameter being about 6 feet. The walls are from 18 inches to 2 feet thick, and the height of the whole building seldom exceeds 20 feet. The entrance opens towards the east or the south, and is, at the utmost, 2 feet high. Having crawled in, we find ourselves in a space of about 6 feet across, and of equal height. The walls are rude and bare, but in them are deep holes, which must once have served as cupboards, as we still find in them very frequently maize, corn, small pots, &c. No window enlightens the space. The roofs of these rooms consist of several horizontal immured flagstones, which, in the middle, do not touch each other, but leave an open space about one foot and a half broad. By this opening we may ascend, and arrive, not without difficulty, at the second story, which is built in the same manner, but has generally some openings instead of windows. The roof is the same as the lower one, and through it we come to the upper story, the roof of which forms that of the whole house, and consists of very solid masonry. The upper story is generally lower than the other, and probably served as a store-room. I once, however, found in it the well-preserved mummy of a child. The family lived on the ground-floor. We can distinguish very clearly the place where they used to cook. The one immediately above was the sleeping-room ; a great flagstone is often found in it, which served to cover the opening. The old Indian fortification Hinckay is of entirely similar structure, though on a grander scale. I have felt very comfortable in these small and narrow dwellings ; they frequently protected me for hours from violent rain, after I had expelled a fox or a zorillo from them.

I have often found in these houses the best preserved mummies and other antiquities. Only a small part of the dead were buried in tombs of masonry, in the so-called Huaca, or more correctly Aya-huaci (Dead house). Near the coast the bodies were laid, many together, in certain places in the sand ; in the mountains, however, in caves, in fissures of the rocks, or in their own houses. When the last was the case, I observed the following arrangement. Immediately below the surface, and only covered with a thin stratum of earth, the bodies are placed, more or less preserved, mostly, but not always, in a sitting posture. The head, in this case, is supported by the hands, the elbows by the thighs, and all the fingers of each hand are tied together with a string, which, running across the neck, connects both hands.

If we remove the bodies and clear away the second stratum of earth, we arrive at the domestic implements of the Indians, cooking and water-pots of clay, calabayos, huallcas, implements of war and hunting. Below this stratum there followed the third and last, which contain the gods ; they are mostly made of clay, but sometimes also of silver and gold ; such idols have been found in different places, which contained from twenty-five to thirty pounds of the finest gold.

On the eastern side of the Cordilleras, large huacas are very scarce ; but they are frequently met with in the coast districts of Peru. The mummies deposited in the fissures of rocks cannot often be removed without extraordinary difficulty; and it appears incomprehensible how the dead bodies, with all their muscles attached, could be forced into them. Most curious groups of mummies are found, which strongly excite our curiosity. One of the most interesting was discovered in the fortification Huickay mentioned above:—A woman in the act of delivery, in a sitting posture, presses with her knees forcibly against the back of a man, who is squatting before her, and keeps hold of his shoulders with her hands spasmodically contracted; the head of the child is already born, but the trunk and extremities are still in the genitation of the mother. I intended to have sent this peculiar group to Europe, but in my absence it was destroyed by the brutality of a European. I found another group in which a child kept firmly hold of the nipple of the mother. Together with the mummies are frequently discovered skulls and skeletons of animals, especially of the mammiferous genera, canis,* felis (Felis onca, and concolor), lutra, mephitis, lagidium, anchenia; of birds, condors, owls, ramphastidæ, prittaciæ. With the mummies of children, which I dug out in the Palace of Tarmotambo, I found the specimens of a species of Arara, not natives of Peru, but only of the northern parts of South America. Of reptiles, the tortoise is the only one which was buried with the dead. I have never observed any remains either of Saurians or Ophidians.

Regarding the skulls, I will here only mention one very singular peculiarity. In the children of that part of the primitive inhabitants of Western South America, who were distinguished by a flattened occiput, a bone is found between the two parietal bones, below the lambdoidal suture, separating the latter from the inferior margin of the squamous part of the occiput. This bone is of a triangular shape—its upper angle lies between the ossa parietalia, and its horizontal diameter is twice that of its vertical. It coalesces at very different periods with the occipital bones, sometimes in the first month after birth, and sometimes not until after six or seven

* I hope to shew in the second number of my Fauna Peruviana, that the dog, Canis familiaris, was indigenous to Peru, and not introduced by the Spaniards.

years. In one skull belonging to a child about seven years old, with a very flat occiput, this line is separated by the most perfect suture from the squamous part of the occiput, and is 4 inches broad and 2 inches high. In a more advanced age, it probably completely integrates with the rest of the skull. I have, however, perceived it in all the skulls of this class which I have examined. On a close scrutiny, we generally find traces of it in the linea semicircularis superior.

This bone, which, in remembrance of the nation in which it is found, I call *Os Incæ*, corresponds entirely to the Os interparietalia of the Rodentia and Marsupialia. We know that it exists in these classes of mammalia through life—that it also occurs in the fœtal state of several pachydermata, ruminantia, carnivora, &c. In the ordinary embryos of man, there are barely some traces in the first months, which, however, soon disappear. I think it, therefore, very curious that we should find so retarded a formation in a whole race of men, who have exhibited a very inferior degree of the intellectual faculties.

I have just heard that Mr Bellamy, in a paper on Peruvian Mummies, read before the British Association on the 3d of August 1841, and printed in the Annals and Magazine of Natural History, October 1842, has already pointed out this peculiarity in the osseous structure, and I am much pleased to confirm his observations by the examination of more than a hundred of such skulls.

I may, however, observe, that Mr Bellamy certainly did not obtain his mummy from the high plains of Peru, as in those districts there occurs no drift sand strongly impregnated with salt. In those plains the mummies are not found in any quantity at a short distance below the surface; and, lastly, Captain Banckley, who could obtain any quantity of mummies at Arica, or some other seaport town, would certainly not have taken the trouble of fetching them from the high plains. Dr Bellamy is also too hasty in determining the race of the nation to which these skulls belonged, especially if he ascribe them to that nation, which is said to descend from Asiatics, who emigrated with Manco Capac.

I transmit to the Society the drawing of a skull, which I dug out of the old Indian fortification Thrickay. It belongs to one of the three typical races of the former inhabitants of Peru, and is not to be confounded with those figured by D'Orbigny under the denomination of Aymara.

In the hope of throwing some new light on the question in dispute between Dr de Tschudi and Mr Bellamy, Dr King entered into correspondence with the latter gentleman, which drew forth this reply. "In the very rough communication which I had the honour of making to the British Association, I confined myself as much as possible to facts, just venturing enough, in the way of opinion, to draw on discussion. I am delighted that the time is at length arrived, for something favourable to science must be the result. My knowledge, however, is far too limited to permit of my joining in any argument that may be advanced; all I can do, is to take care that no misstatement is made of what I have made public.

"It has been, and I fear always will be, my misfortune to write from my own fireside, for my avocations have, and probably ever will, keep me at home. I have little or no geographical knowledge of Peru, and of its minute physical characters I know less. Dr de Tschudi, I presume, from the boldness of his assertions, is a traveller, and that he has visited the part of the world in question. Hence, doubtless, he is correct, when he says that the mummy was not brought from the high plains of Peru, for the reasons he gives appear to be too forcible to admit of any doubt. We have, in fact, from him what looks very much like personal observation, for he says, 'in those districts there occurs no drift-sand,' &c.

"Captain Blanckley, from whom the mummies were procured, some little time after they fell under my notice, went abroad, and I have in vain several times since endeavoured to communicate with him. In my paper I have said, after regretting my inability to furnish information of a more correct character, that he 'stated to me in conversation, that he exhumed them himself from an elevated part of land in the mountainous district of Peru, but at a considerable distance from the lake Titicaca.' Now, all one can remark upon the different statements of the Doctor and Captain Blanckley is simply this, that the 'elevated tract of land' of the latter is not included geographically in 'the high plains' of the former;

and as Captain Blanckley has added, that the spot where he exhumed them is at a considerable distance from the lake Titicaca, it is fair to presume that his discovery refers to some locality nearer the sea ; an opinion which I should consider to be correct, as he was only a casual explorer, not able to venture far from the ship of which he had the command.

" Dr de Tschudi considers that I have been 'too hasty in determining the race of the nation to which the skull belonged.' All I have said upon that question is as follows :—'This peculiar race were in all probability the aborigines of the country, and it is probable that these mummies may be the relics of some of the last of the Titicacans ;' so that it must be observed that I have not determined—I have but suggested, and the question is left entirely open for the more competent to argue.

" In the last place, Dr de Tschudi alludes to the mixed race, recently from the intermixture of the aborigines with the followers of Manco Capac, as if I had referred the mummies to them or their descendants. In this he has completely misunderstood me, as will be apparent from what I have just stated, and from this which I now quote from my original papers :—'I would suggest that the adult skulls of Titicacans, in the Museum of the Royal College of Surgeons, are of this kind, the one possessing all the peculiarities of the race in its unalloyed form—the true Titicacan ; and the other being of a spurious character, resulting from the union of the indigeæ with the settlers of Asiatic origin, the companions of Manco Capac of traditionary fame.' "

The Mongols. By Bayle St John, Esq.*

(Communicated by the Ethnological Society.)

The Mongols belong to that vast family of nations which inhabits the eastern, central, and perhaps northern, divisions of Asia. But they are most intimately connected with the Tatars—so intimately, indeed, that it would often be difficult to distinguish the descriptions given by travellers of the two

* Read before the Ethnological Society, 24th January 1844.