would ground, but it is not true of the shallower parts near the shore on which the coast-ice acts and on to which floe-ice and pack-ice is often driven with immense force,—agencies which seem to be quite as capable of carrying with them the masses of partially frozen materials and of pushing them over a floor of solid frozen sand as Land- or Glacier-ice could be.

Mr. Marr refers to a recently-described case where a glacier *traversing a narrow valley* seems to have overfolded certain deposits of stratified sand and clay; thus comparing what may happen in a narrow valley with the phenomena of a district of which he himself says "not only do the contortions occur in the drifts which occupy the valley bottoms, but they are also found in the accumulations which lie on the summits of ridges." Are we to suppose that so able a geologist as Mr. Marr thinks an ice-sheet over-riding a ridge will act in the same way as a glacier pushing itself through a narrow valley?

The sections round Sudbury are exceedingly interesting, and Mr. Marr deserves our thanks for calling further attention to them and for recording new aspects of the changing pit-faces, but in his charge to the jury he has not put all the possible alternatives, and consequently his summing-up is biassed in favour of one explanation.

June 6, 1887. A. J. Jukes-Browne.

THE CAUSES OF GLACIATION.

Sir,—I ask leave for a few remarks on the question of the causes of glaciation, as there are some points connected with it on which I think sufficient stress has not hitherto been laid.

The total amount of direct solar heat received at any place is admittedly nearly constant whatever be the eccentricity of the earth's orbit. The amount indirectly received through the medium of air-currents, clouds, and ocean-currents may vary; but if the variations of this indirect heat are ascribed to the raising or lowering of the temperature, the causes of this raising or lowering must be sought for in the distribution of the direct heat. We come, therefore, to the question, What distribution of direct heat over the various seasons (the total amount being unaltered) is most favourable to glaciation?

In the first place, then, it seems clear that the Glacial period could not have been produced by the freezing of water *in situ*. A snow-cap or ice-cap reaching an elevation of hundreds or thousands of feet over the sea-level could only have resulted from falls of snow. The former question is therefore resolved into the following, What distribution of direct heat is best calculated to increase the annual snow-fall?

In answering this question, two principles must be borne in mind. First, that snow will not fall, or at least will not lie, if the temperature is much above freezing-point. In such cases either rain would take the place of snow, or else the snow would melt at once. Second, that very little snow falls when the temperature is very low. Great cold preserves the snow that has fallen, but it seems necessary for a

heavy fall that the temperature should not be much below freezing-point.

I now distinguish three cases.

1st. Where the mean temperature is above freezing-point. Here, if we could distribute equally throughout the year, no snow would fall. Unequal distribution might, however, produce a considerable snow-fall, though not a permanent snow-cap. In mountainous districts extensive glaciers might be produced in this way.

2nd. Where the mean temperature is below, but not much below, freezing-point. Here an equal distribution of heat throughout the year is most favourable to the formation of a snow-cap. Snow would fall at all seasons of the year, and the melting-point being rarely, if ever, attained, the snow-cap would continue to accumulate.

3rd. Where the temperature is much below freezing-point. Here an unequal distribution of heat is most favourable to glaciation, because we must bring the temperature nearly up to freezing-point at one season of the year in order to obtain the heavy falls of snow which are required to form a snow-cap or ice-cap of considerable thickness.

If these principles are correct, they lead to the following results. A high eccentricity of the earth's orbit when the earth is in aphelion at mid-winter is favourable to glaciation in two regions of the Northern Hemisphere, one immediately round the pole and the other much further south (where, however, the result would be rather extensive detached glaciers than general glaciation). But between these two regions there is an intervening one in which the conditions for glaciation would be unfavourable, the snow-fall being less than if the distribution of heat was equable, while a good deal of this lessened snow-fall would be melted by the increased quantity of heat received during the summer. If the earth was in perihelion at mid-winter, this state of things would be reversed. The polar snow-cap would be diminished, but there would be more glaciation in the southern portion of the Arctic region and the northern portion of the Temperate Zone. As far south as Switzerland, however, the glaciation might perhaps again diminish.

In confirmation of these views, I may add that I do not see how the snow-fall could be increased over the entire region from, say, the fiftieth degree of North Latitude to the Pole at the same time. For high eccentricity would not, I apprehend, increase the difference of temperatures between the Equatorial and Polar Regions. It would produce a summer and winter at the Equator—the former when the earth was in perihelion and the latter when the earth was in aphelion; but when the Equatorial and Polar summers and winters synchronized, the contrast of temperatures would not be greater than at present. During the long cold northern winter, on which Dr. Croll lays so much stress, there would also be winter at the Equator, and if we regard the Equatorial region as the generator of vapour or steam and the Polar region as the condenser, the apparatus as a whole would not be more powerful but less powerful than before. There would be no increase in the quantity of aqueous vapour available for the

production of falls of snow in the higher northern latitudes, and, therefore, an increased snow-fall in one portion of these latitudes must be compensated by diminished snow-fall in another portion.

I have omitted to notice the effects which might be produced when the snow-caps thus formed were set in motion. Moving masses of ice or snow might considerably alter the general phenomena of glaciation. If we take the most southerly portion of our hemisphere in which permanent glaciation is possible, the snow-cap would form most readily if the irruption of northern ice commenced about the same period when the conditions for local glaciation were becoming favourable. These latter conditions would, I apprehend, be most favourable when the earth was in aphelion at midsummer; but the Polar Pack would not attain its full dimensions until some time after the mid-winter aphelion, and in its slow southward motion it might not begin to overrun the northern portion of the Temperate Zone until a still later period. The invasion of Polar ice might nearly coincide with the commencement of the local glaciation produced by very different causes, and a Glacial period would result.

13, Belvidere Place, Dublin,
May 7th, 1887.

W. H. S. Monck.

OBITUARY.

EDWARD TOWNLEY HARDMAN, F.C.S., F.R.G.S.I., ETC.

Born 6th April, 1845; Died 30th April, 1887.

GEOLOGICAL science has suffered a serious loss in the early death, from typhoid fever, of Mr. Hardman, of the Irish branch of the Geological Survey of the United Kingdom.

Descended from an old and respected Drogheda family, Mr. Hardman received his early education at that town. Having by his ability won a Government Exhibition and entered the Royal College of Science, Dublin, in 1867, he obtained a diploma in mining, etc., as well as numerous prizes, and in 1870, he was appointed to the staff of the Geological Survey of Ireland. In 1871 he was elected a Fellow of the Geological Society of Ireland, and in 1874 of the Chemical Society of London.

He examined, and prepared a Memoir upon, the Geology of the Coal-fields of Kilkenny and Tyrone, and prepared a list of papers on the Geology of the North of Ireland. Mr. Hardman was also an active and earnest antiquary, and communicated several papers to the Royal Irish Academy.

In 1883 he was selected by the Colonial Office to examine and report upon the geology and mineral resources of the Kimberley district of the colony of West Australia. Here he was attached to a local surveying expedition, under the direction of the Hon. J. Forrest, C.M.G., Crown Surveyor General to the Colony, and set out for the North-East Territory. Having a camera, he was enabled to photograph numerous points of interest, and also to make sketches of characteristic geological sections. The most important practical