but only that, by utilising and developing the experience of their predecessors, many amateurs now approach much more nearly to the high-class guides' standard, seeing that the latter remains where it was in the early days. If this were not so, to my mind the Alpine Club would not have justified its *raison d'être* and would have but a poor apology for its own existence. The improvement on the part of the amateurs has been gradual though slow. It is only by comparing the standard of mountaineering in the present day, and the relative efficiency of guides and amateurs with those of ten years ago or so, that the distinct advance can be recognised.

Dr. Heim on Glaciers and Glacier Theories.*

By F. F. TUCKETT.

PART II.

SECTION VII.—'Glacier Débris' occupies 77 of Professor Heim's pages, but our references to it must be confined to a quotation of the author's views on the erosive power of ice in the formation and modification of valleys, lake basins, etc.—a subject which has been much discussed by geologists, and is still a matter of controversy. His general attitude may be inferred from the remark that 'it is evident that in the course of time, through the lively interest in the phenomena of the glacial period, the influence of glaciers has been over-estimated by many geologists, especially those who occupied themselves with the subject of glaciers in the past, without sufficiently studying those now existing. Many a one-sided exaggeration and too speculative conception would have been avoided, and observations in many respects valuable and good would have largely gained in precision and significance, if more regard had been had to the glacier phenomena of the present day' (pp. 340–1).

It results from observations in Greenland, the Alps, etc., that 'as a whole, glaciers derive their moraines not from their beds, but from the sides of the valleys which bound them' (p. 359), or, it may be added, in the case of Greenland, from the detached islets of rock ('Nunataker') which rise in

* Handbuch der Gletscherkunde, von Dr. Albert Heim, Professor der Geologie am Schweizerischen Polytechnikum und der Universität in Zürich. Mit zwei Tafeln und einer Karte. 560 pages. (Stuttgart: Verlag von J. Engelhorn, 1885. 18 francs.)

their midst. Careful comparison of the percentage of mud and sand in glacier, as contrasted with ordinary streams, clearly shows that in the former it is very much less, even indeed to an almost vanishing extent, and hence Professor Heim concludes that 'glacier erosion is almost infinitely insignificant in its effects in comparison with that caused by water' (p. 366). As a popular corroboration of this result of accurate scientific determination, he cites the common saying of the inhabitants of mountain districts, who contrast the glacier stream as 'zahm' (tame) with the 'Wildbach,' or 'savage' torrent. Superficial observation might easily exaggerate the amount of matter brought down by the glacier stream, for, owing to the fine state of division of the particles, their apparent amount is enormously in excess of the reality. Dolfuss' observations in July and August, 1841–45, on the water of the Aar at the point where it issues from the glacier give 142 gr. of sediment per cubic mètre, or $\frac{1}{7040}$ of the weight of the water, but for the whole year this must be reduced to about $\frac{1}{20000}$, or ·00005 per cent. At the Hufi glacier, Professor Heim found the proportion in June during the middle of the day $\frac{1}{6000}$, in September $\frac{1}{10000}$, and at the Forno glacier $\frac{1}{25000}$. The mean result of similar observations in the case of seven Greenland and ten Norwegian glaciers during the summer months is 147·9 gr., thus agreeing very closely with Dolfuss' determination. Helland calculates the total daily yield of detritus during July from the entire Justedalsbräen as 2,000,000 kilogrammes, and for the entire year, 180,000,000 kilogrammes = 69,000 m³ of rock, or a mass of 41 mètres cube.

Now there is abundant evidence to show that ordinary mountain streams whose collecting basin is only one-tenth of the area of that of the Unteraar glacier will, when swollen by rain, bring down in the course of a day or two 10,000 to 100,000 m³, and instances are not rare in which, in the course of a few days, such 'Wildbäche' have transported 1, 2, and even 3 millions of cubic mètres of debris into the main rivers or lakes. If now we deduct from the sum of the glacier detritus contained in its torrent that large portion due to the mere friction of its moraine materials derived from weathering, or other sources independent of itself, the residue to be credited to the actual eroding work of the 'ice-tool' of our day becomes, as above stated, 'almost infinitely insignificant.'

Another fact bearing on the notion of the high erosive power of ice is the frequently undisturbed condition of beds

of loose debris over which an advancing glacier is moving, so that, in some cases, when an ice-stream has again retreated after an interval of three or four years, the roots of plants have been found undisturbed and still living, whilst in no instance, it is believed, have any basin-like cavities been detected either in the debris or the rock on which the glacier has rested. There is a large amount of evidence given on these points to which it is impossible here to refer in detail. To take a single case. The Forno glacier, near the Maloja, after leaving behind in its retreat fragments of itself covered with moraine material, was, in June 1884, 'pushing vigorously forward once more over the *disjecta membra* and their load of debris without, in most places, in the slightest degree disturbing either the latter or the entire surface of the old ground moraines' (p. 376). In fact, very often the advancing glacier melts away around an opposing block in its bed rather than removes it. Again, 'the extrusion of an ancient alluvial deposit and the conversion of its area into a lake basin, has, as yet, never been witnessed in connection with existing glaciers, much less the gouging or ploughing out of such in rock *in situ*. Only the loose masses standing directly in the way are thrust along by the glacier. When we are told that the glacial origin of lake basins is explained by a scooping out ("ausfegen") of old detritus (De Mortillet), or by the erosion of the rock (Ramsay), and that they are the evidence of the scouring action of ice (Penck), we have to deal not with directly observable facts, but with hypotheses which from their very nature, even if we held them to be true, do not properly belong to the construction of a chain of evidence ("Beobachtungsketten")' (p. 381).

On the question whether 'ground moraines' are practically the product of the action of glaciers on rock *in situ* occurring in their bed Professor Heim, after quoting a mass of opposing opinion, concludes as follows: 'We consider it probable that, when a glacier advances over ground not previously so invaded, it will come in contact with many obstacles which will break or yield rather than submit to be planed down. Later, too, this may recur exceptionally. Glaciers of the glacial period have left us evidence of such direct shattering and disturbance of obstacles. But the plasticity of glacier ice is so great that, if a block or salient angle of rock offers much resistance to the thrust, it remains stationary and engraves a furrow on the surface of the ice. The greater the mass of the glacier, the greater the ductility (?) and plasticity of the ice in contact with its bed,

though its pressure is not proportional to its thickness, but approaches a certain maximum, beyond which all increase of weight is devoted to the more rapid plastic transformation of the ice, and is no more crushing to the fragments of the "ground moraine" than deep water is to the pebbles on the bottom of a lake or ocean' (pp. 384–5). In some cases it is conceded that the long continued action of glaciers has worked considerable changes in the removal of detritus and the consequent widening, and perhaps *slight* deepening, of valleys, but 'in the harder rocks of the Alps and other regions the influence of glaciers on valley forms is, for the most part, absolutely indistinguishable' (p. 386).

Were we to go as far as Lyell and admit that, even in harder rock formations glaciers may conceivably scoop out superficial cavities so that shallow pools may be formed, 'we are not in a position to cite a single proved instance of this, and it has never been practically demonstrated even when the bed of a glacier has been laid bare for a distance of 500, or even 1,500 mètres, by the retreat of the ice. We are of opinion that the notion is a theoretical possibility and, as such, is not to be dismissed altogether, since even so wide a degree of difference from anything yet observed cannot be held to be *à priori* impossible under conditions of increased scale and duration of glaciation' (p. 386).

After a careful comparison of the eroding effects of water and ice, Professor Heim continues: 'It is not maintained that certain results which streams do not effect are impossible to a glacier, but that among all the valley-forming agents glaciers necessarily play a very subordinate part in comparison with flowing water; so that *glaciation is equivalent to relative cessation of valley formation.* Polished surfaces ("roches moutonnées") are the remains of original irregularities of the ground, and glaciers have never completely succeeded in erasing or ploughing out the existing relatively smaller inequalities and hollows whose rough, unpolished contours show that the comparatively rigid ice has been unable to penetrate to or affect them. The careful examination of glacier beds left bare by the retreat of the ice forces on us the conclusion that glacier work is small in amount, and that it is incapable of planing away even a small shelf of rock. Its force is expended on the jutting prominences in its path, so that it is unable to attack the depressions. The characteristic glacier action which we can actually observe is only subordinate, detailed work, wearing down indeed salient angles but not such as materially modi-

fies valleys. Glaciers do not stamp on mountain or valley their actual form; they merely smooth, and very slightly wear, the rough surface of that which previously existed. Every examination of a region of glacier polish leads us afresh to recognise the insignificance of glacier agency in the formation of valleys. A large amount of evidence conclusively shows to an unprejudiced observer that glaciers only to a certain extent round off projections, but that streams and subaerial weathering have given to valleys their forms, and always far surpass glaciers in their effects' (pp. 389–392).

After this clear, definite, and to my thinking accurate statement, we naturally find that Professor Heim 'holds the excavation by glaciers of large lake basins in rock (Ramsay) as unproved, and not supported by direct observation of their existing action, though deserving of further investigation' (p. 400). The *cirque*, valley, and *fjord* formation by the same agency (Tyndall and Helland), on the other hand, he considers as 'altogether a wide misconception of the facts in connection with the action of various agents—erosion, weathering, glaciers, dislocations, &c.' (p. 400). He pithily adds, 'the glacier is far less a chisel or a plough than a cargo loader and export agent of débris. It is a freight-sledge, whilst the ordinary torrent is a wild raftsman ("Flösser") and sawyer' (p. 401).

Section VIII. deals very fully with the geographical distribution and climatic conditions of glaciers, and the care with which this has been drawn up may be partly inferred from the fact that Dr. Güssfeldt's recent and very interesting discovery * of a glacier (the Ada glacier) nearly twelve miles in length, in the province of Colchagua (Chili, latitude 34° S.), is duly recorded, though the name of the distinguished explorer and mountaineer is not given. Eighty pages are devoted to this comprehensive sketch, and they bristle with facts and inferences of the highest interest in reference to climate, geology, &c.

Of the various glacier regions described, that of the Himálayas is, after Greenland, the most highly developed; for there, in the Karakorum range, we have at the sources of the Bascha the Arandu glacier, 48 kilomètres (30 miles) long and in its lower portion 2½ kilomètres (1½ mile) wide, with an inclination of only 1°·5 to 2° for the first 25 kilomètres (15½ miles) from its foot. Towards the Chayok

* See 'Proceedings of the Royal Geogr. Soc.' 1884, No. VI. p 60.

and Indus descend the glaciers of Saïtchar, Baltoro, Biafo, and Tchogo, all exceeding 50 kilomètres (31 miles) in length, and constituted by the union of from ten to thirty tributary ice streams. The Baltoro is said to have fifteen medial moraines and to measure 56 kilomètres (34¾ miles) in length, and the Biafo over 64 kilomètres (39½ miles)!

In referring to the comparative rarity of glaciers in North America, Professor Heim expresses a suspicion that the three reported by King on the north side of Mount Shasta (4,440 mètres, not 4,404 as stated) can only be regarded as the remains of former ones with no power of regeneration; but the evidence of photographs seems to me scarcely to support this view. Of the character of the glaciers of Mount Rainier (46° ¾ N. lat.—now frequently, but inaccurately, called Mount Tacoma—4,444, not 4,404 mètres), which I had the pleasure of seeing, though only from a distance, in 1884, there is no doubt, one of them being reported to be 10 miles long and nearly 3¾ miles wide. Between this superb peak and Mount Baker (lat. 48° ¾ N.) the 'Olympic Range' (48° N.), on the south sides of the Straits of Fuca and almost opposite Victoria in Vancouver's Island, seemed to me, as I examined it thence through the telescope, to show evidence of true glaciers, though I believe the loftiest summits of the group —Mount Olympus and Mount Constance—only reach a height of 8,150 and 7,777 feet respectively.

Attention is called to the practical disappearance of glaciers in Arctic North America west of Greenland (those of Grinnell Land being small, and not reaching the coast), though the mean annual temperature falls to −15° C. and even −17° C. Climatic conditions appear to be the cause of this, for the entire American Arctic archipelago is remarkable as an area of small precipitation. 'We are in the neighbourhood of a pole of cold, and the winters are dry and severe with a mean temperature of −30° C. to −40° C. Snow falls only in spring and autumn; in summer the mean temperature rises to +1° C. and +4° C., and the north-west and north winds prevailing throughout the year, and coming from cold regions and mostly over a frozen ocean, can bring no moisture. Now cold without moisture can produce no glaciers' (p. 482).

In Northern Asia again we have similar conditions with a practically 'continental climate on the coast, since the continent is bounded by a frozen ocean. Here, too, is a pole of cold and barometric maximum. The sky in winter is almost continuously clear, and snow only falls in autumn. In

75° ½ to 78° N. latitude we find hills 1,000 feet high always free from snow in summer, with a mean temperature of +5° and +6° C. No glaciers are formed, and the lowlands have here the most marked variations of temperature. In Yakutsk the thermometer sinks in winter to −62° C. (−79°·6 Fahr.), and the mean temperature of the coldest month is −40°·8 (−41°·4 Fahr.). In summer +38° C. (100°·4 Fahr.) is not unfrequently recorded, and the mean temperature of the warmest month is +17°·4 C. (63°·3 Fahr.). Here then we meet with temperature variations unequalled elsewhere, and extending over a range of 100° C. (180° Fahr.), or the difference between the freezing and boiling points! The great distinction between North Asia and North America lies in the greater warmth of the summers of the former. In the islands to the north glaciers are equally unknown, and traces of earlier glaciation are also entirely absent. *Thus the glacial period does not imply any universal glaciation of the northern regions.* From the Altai and Sajar to the frozen ocean, throughout the whole of Siberia and its islands, glaciers are absent except in northern Novaia Zemlia, and it is precisely there that the influence of the Gulf Stream is still felt. Eastern Asia holds out its hand to a similarly constituted North America. The Eskimo coast of northern Alaska is as cold and devoid of glaciers as the more southerly coast of the territory is the reverse. Looking at the Arctic regions then as a whole, one is struck by the fact that they are generally very poor in glaciers. For two-thirds of the circumpolar space they are almost entirely wanting, not from any deficiency in cold but from absence of adequate precipitation. Only in the one-third, where a warm oceanic current—the Gulf Stream—has access to it over a wide stretch of longitude, do we find all the islands coming under its influence glaciated. Districts of great cold, but without glaciers, cover wide areas; but those in which snow lies and is converted into ice are much more restricted.

'So far, then, from the withdrawal of the Gulf Stream causing a glacial period, an increase of its volume would be much more likely to bring about such a result. For glaciation is not an extensive and universal phenomenon of the cold zone; but only occurs where warm, moist winds and warm sea currents originating in the equinoctial regions are able to penetrate' (pp. 483–6).

In the South Polar region very different conditions prevail. From 40° S. lat. to the South Polar circle, with the exception of South America, a few scattered islands are the only land

encountered, and the South Polar Sea is in uninterrupted communication with the oceans of the temperate and torrid zones. Tierra del Fuego, in the latitude of Denmark, is the most southerly inhabited land, and, with this exception, probably no other spot south of 48° is practically habitable; whilst on the island of South Georgia, in latitude 54° 30′, the line of perpetual snow is reported to be at sea level, a circumstance not known to occur anywhere in the northern hemisphere. From the equator to about 40° S. the mean temperature of the southern hemisphere is somewhat lower than that of the northern, but further south the reverse is the case; and, taken as a whole, the former hemisphere is not colder than the latter, according to the latest investigations of Hann. 'But the life of plants and animals is not determined by the mean temperature. If the summer will admit of growth and development, a severe winter is endurable. It is the oceanic uniformity of the temperature which renders the climatic conditions of the southern hemisphere so unfavourable. There are some glaciers in the Kerguelen Islands, and they are numerous on the coasts of Victoria Land and the Admiralty Range in lat. 70° to 78°, but nowhere do they appear so developed as in Greenland or Spitzbergen' (pp. 488–9).

From the foregoing, and a much larger array of evidence to which I cannot allude in detail, Professor Heim concludes that 'mere low mean temperature has often been one-sidedly assumed as the cause of the formation of glaciers, and the existence of a much colder climate has been inferred from the traces of their former greater extension; but, just as excessive damp with high temperature, so, great cold with deficient humidity in the air is incapable of developing glaciers. If the Gulf Stream were removed, the mean temperature of Bergen, in Norway, would undoubtedly be lowered 10° to 13° C. (18° to 23°·5 Fahr.), and the climate of north Italy resemble that of Stockholm at the present time so far as temperature is concerned, but the glaciers in Scandinavia, Spitzbergen, Greenland, &c., would not increase but rather diminish, and possibly disappear. The glaciation would, indeed, attain greater development if, through subsidence, the freely evaporating water surfaces should increase and approach nearer to the mountains at the expense of the lowlands. Glaciation is primarily dependent on the distribution of moisture. The mean temperature, too, itself varies as much as 14° C. (25°·2 Fahr.) for similar latitudes, according to the distribution of land and water on the earth's

surface, whilst for the same latitude, but according to the height above sea level, it varies, in the case of the loftiest mountains, as much as 45° C. (81° Fahr.) between their base and summit.

'Cosmic influences, such as variations in the excentricity of the earth's orbit, precession of the equinoxes, &c., could only modify the mean temperature to the extent of 2° or 3° C. The investigation of the geographical distribution of glaciers at the present day leads to the conclusion that local terrestial causes—the distribution of moisture and temperature in a horizontal and vertical direction—are incomparably more energetic than all cosmical causes of climatic variations, so that the latter can scarcely have been of an important or decisive character on glaciation under the then existing general planetary relations of the earth' (pp. 491–2).

Section IX. treats of the oscillations in the condition of glaciers during the historic period. 'As the movement and waste of a glacier are alike affected by a number of different factors, its position, or that of its lower end, is the resultant of the combination in each case of various influences which cannot as yet be adequately expressed in exact figures, and are, indeed, themselves partially interdependent. The end of the glacier descends further the more extensive the collecting basin, the greater the snowfall therein, the compacter the section of the ice stream, the more rapid its movement, the more extensive the covering of debris, the smaller the development of crevasses, the less the exposure to sunshine and warm and moist winds, and the deeper the warmth of the ground' (pp. 495–6).

Now, so far as the phenomena of oscillations are determined, they are subject to the following law (Forel):—The periods of retreat and advance extend, if considerable, over a whole series of years (five to thirty, or more), and within such a period, a pause or a year of reversed conditions never occurs in the case of large glaciers, and seldom in small ones. The state and variations of large glaciers are clearly conditioned by the sum total of a number of climatic factors acting through a long course of years; in small ones by the similar action of shorter periods. 'The large ones are sluggish climatometers measuring long intervals, whilst the smaller are of more sanguine temperament' (p. 500).

There is a tendency in all Alpine glaciers to undergo simultaneously changes in the same direction. Thus from 1815 to 1818, and from 1848 to 1850 they all advanced; whilst from 1822 to 1825 and from 1875 to 1880 almost all without excep-

tion simultaneously retreated. Still, we scarcely can find absolute uniformity in the changes; there are isolated exceptions. These last, however, appear in a different light as soon as we study the entire history of the glaciers affected. We then see that they, too, on the whole, share in the general oscillation, but some enter upon it a few years later, and others a few years sooner than the majority, and during such interval appear as exceptions to the rule. Under otherwise similar conditions the oscillations of the steeply-inclined and of the smaller glaciers are in advance, and those of the larger and leveller ones retarded. At the present time (1884) about twelve are known to be advancing, the movement apparently developing from W. to E., for, as late as 1880, the retreat in Graubünden was at its maximum when already advance had commenced in the west. Speaking generally, the recent great period of retreat began between 1850 and 1855, and is now (1880–1885) coming to an end. From 1871 to 1875 all Alpine glaciers, without a single known exception, were shrinking. A few instances will suffice to show the really important character of this phenomenon.

Between 1866 and 1878 the Mer de Glace (Gl. des Bois) retreated on the average 73 mètres annually, and between 1850 and 1878 had retired altogether 1,050 mètres. The Roseg and Morteratsch glaciers, between 1855 and 1881, retired 12 mètres annually. The centre of the Rhone glacier, below the icefall, had in 1880 sunk 112 to 137 mètres beneath the level of the old lateral moraine of 1856; but above the icefall, the lowering of the surface in the same period was only 30 mètres. Thus from 1856 to 1880 the entire glacier had lost 2 km² (2 square kilomètres), or 8 per cent. of surface, as determined in 1866, and 175,000,000 m³ (cubic mètres), or 7,000,000 yearly in volume! The Obersulzbach glacier, in the same interval, has retired about 500 mètres, or 9 per cent. of its entire length; has laid bare an area of 501,787 m²; and lost from 50 to 80, and even 100 mètres in thickness, and 60,000,000 m³ (2,000,000 annually) in volume. The Pasterze glacier between 1856 and 1883 has shrunk 328,000,000 m³ in volume, or 12,000,000 annually. The Hufi glacier between 1850 and 1875 shows a loss of 80,000,000 m³: and though the Unteraar glacier from 1871 to 1880 only lost about 60 to 80 mètres at its lower end, its thickness 4½ kilomètres higher up, at the Pavillon Dollfuss, diminished by 47 mètres, a figure which, if applicable to a considerable portion of the surface, would give an enormous shrinkage in volume.

The revision in 1871–1880 of the original sheets of the Great Federal Map of canton Wallis on a scale of $\frac{1}{50000}$ indicates that, in the course of twenty-seven years belonging to the great period of retreat (1850–1880), there has been a total diminution of the snow and ice-covered area to the extent of fifty-four km². This amounts to $\frac{1}{20}$ of the whole of such surface in the basin of the Rhone as far as the Lake of Geneva, which in 1866 was determined to be 1,037 km²! (p. 508).

It is probable that both shrinkage and increase will first manifest themselves in the upper part of a glacier and be gradually experienced downwards and at the lower end, and this has, indeed, been proved to be the case by recent measurements on the Rhone glacier. In 1841, A. Escher observed the upper portion of the Aletsch glacier to be shrinking whilst its foot was advancing considerably, and between 1872 and 1884 an increase of snow in the region of its névé was observed before any advance of its lower end was reported. Further, it has been remarked that the difference in the position of the present surface of glaciers in relation to the outermost lateral moraines of 1818 or 1850 is much less in their upper portions than lower down, so that, as Forel puts it, 'the oscillations of the glacier increase with its progress downwards' (p. 509).

'Frequently the periods of advance are shorter than those of retreat, and in the former the rapidity of motion of the ice-stream is much greater than in the latter' (p. 510).

On the interesting subject of the oscillations of glaciers in the course of many centuries I cannot now enter further than to state that there seems abundant evidence that in the Middle Ages alpine glaciers must have had 'considerably less extension' than at the present time even after so marked a period of shrinkage. It is thus probable that the frequent oscillations in the course of a few centuries are themselves subordinate to some larger secular change. Comparing the phenomena observed in the glaciers of the Alps with those in the Pyrenees, Caucasus, Scandinavia, Spitzbergen, Greenland, and inner Asia, 'we find between 1850 and 1880, a sometimes identical, sometimes only similar, period of retreat, the correspondence being greater in the temperate and less in the polar zone, where considerable deviations occur' (p. 520).

As regards the cause of such oscillations, 'it becomes at once evident that they are a process which far transcends the possible result of annual variations whether of precipita-

tion or warmth, and can only be explained as the consequence of changes in these factors operating through a series of years and in the same direction. A similar conclusion is arrived at from the fact that a single very snowy winter followed by a cold summer is incapable of arresting a period of retreat, and that a single hot summer with a dry winter does not materially affect a cycle of advance' (p. 521). According to Professor Forel the most effectual or chief cause of the advance or retreat of a glacier is the increased or diminished rapidity —in other words, the increased or diminished depth—of the ice-stream, and this depends on (*a*) the quantity of material received in the shape of snowfall in the collecting basin, and (*b*) on the amount of ablation of the glacier. Of these the first (*a*) depends mainly on the character of the winter, and its effect on the glacier is only felt after a certain interval, varying in the case of different glaciers; whilst the second (*b*) is more powerful in summer. According as they act in opposition or in accord, the weaker or stronger will be the oscillations of the glacier, and a direct and perfect parallelism between its condition and the character of the actual seasons is not possible (p. 522).

To these views of Forel, in which other observers (including Professor Heim) entirely unite, 'must be added the questions: (1) are there many year-periods in the climatic factors which regulate the alimentation and waste of glaciers; and (2) after what interval does the variation in the material supplied make itself felt at the lower end of the glacier? Comparing the variations in precipitation and temperature with the glacier oscillations, we find a general, direct, prevailing parallelism, *with a mean retardation of only five to ten years*, in the action on the end of the glacier' (pp. 522–7). From various considerations and facts cited it would seem probable that 'swelling, or thickening of the ice-stream must result (after increased supply and diminished ablation), increasing in amount downwards like a wave, and advancing much faster than the simultaneous increase in the rate of flow of the glacier as a whole, but it is desirable clearly to determine whether the thickening of the ice does actually advance faster valleywards than the ice itself. Finally, it must be owned that glacier oscillations appear enormous in proportion to those of precipitation or temperature. Nature, however, often operates under complicated conditions of equilibrium, which by slight modifications of single factors are disturbed in a high degree. The recognition of this also shows us that the atmospheric conditions of the glacial

period need not have been so very different from existing ones, in order to cause the glaciers to increase to gigantic dimensions' (pp. 529–531).

Section X., completing the work, deals with ancient glaciers and the still remaining evidence—erratics, moraines, sand, polished surfaces, etc.—of their former existence and great development. To the foregoing may also be added erratic plants and animals—colonies whose original homes were in the same alpine regions as the transported blocks by which they are actually surrounded.

In the course of a survey of the indications of the presence of former glaciers in those regions of the globe where they now exist, Professor Heim remarks that 'on the inner (northern) Thibetan slopes and chains we seek in vain for a glacial period, and in the Altai the glaciers were very slightly larger than at the present day. In the most easterly ranges of northern China, Richthofen found no traces of glaciers, and almost throughout northern Asia up to the sea only negative reports reach us. Even the Ural mountains seem never to have had a glacier. In the Himálayas, Greenland, and Spitzbergen the difference between former and existing glaciers was much less than in the Alps, and in New Zealand and South America it was, at any rate, not greater. In fact, in ancient times great glaciers almost exclusively existed where they are still found, and were really important in Europe and North America alone. A general glacial cap over the entire Arctic region advancing radially southwards, such as there has been a disposition to assume, can nowhere be recognized; and it is clear that, even confining ourselves to the northern hemisphere, those areas which were unaffected by the greater extension of the ice and can scarcely even have undergone an important modification of climate, are infinitely more extensive than those which have experienced a glacial period' (pp. 554–6).

As to the causes of such a period, Professor Heim writes: 'We stand before a very mountain of conjectures, and many of them are very unsubstantial. Hypothesis has been piled on hypothesis without any adequate acquaintance with the conditions of glacier development. Amongst them are ingenious theoretical speculations and clever manipulation of ascertained facts, but with much one-sided exaggeration and straining of isolated observations, which are supposed to constitute the key of the entire problem. That other climatic conditions must have produced a glacial period is obvious from the constitution of glaciers. Climate is affected by

both terrestrial and cosmical agencies, and whilst some seek an explanation in the first and some in the second, others find it in a combination of both. It is certain that the terrestrial conditions influencing the climate of the Ice Age were different from those now prevailing in so far as the northern hemisphere was cooler and much moister, and therefore richer in precipitation and glaciers. To whichever set of agencies we attach most importance, we must bear in mind that increased moisture together with somewhat lower temperature are *both* requisite to explain a glacial period, which cannot be due to conditions modifying only one of the two. A combination of favourable terrestrial and cosmical causes may have brought it about, for nature seldom works so simply as to bring only a single agent into play. Up to this time we must admit that we do not know the deeper causes of the glacial period, however many different agencies may appear to us as possible. The final solution of this question is reserved for the future' (pp. 557–60).

Many of the views set forth in this volume had, of course, been previously arrived at and published by other investigators; and Professor Heim, whilst recording numerous important suggestions and conclusions of his own, based on personal investigation, makes no claim to a complete solution of the complicated problems to be dealt with. His object has rather been, in the production of a 'Handbook,' to present a careful, comprehensive, and impartial statement of existing facts and theories with such general deductions from the former and discussion of the latter as an independent witness and student may permit himself before summing up the actual state of our knowledge of the matter in hand.

In concluding this somewhat lengthy, but I hope careful, notice of an important work, I cannot, on the one hand, withhold the expression of a hope that it may appear in the form of an English translation enriched by the addition of a good index; nor, on the other, deny myself the pleasure of referring to the large amount of agreement existing between the views of Professor Heim and those put forth in 1883 by Mr. William Mathews in his address as President of the Birmingham Philosophical Society, which in a moderate compass contains as accurate, able, clear, and, as it appears to me, conclusive a presentation of many of the problems connected with glaciers and their former greater development as has yet appeared in any language.