scientific basis for the hypothesis that the Upper Sands were once as rich in fossils as the more clayey Barton beds of Hampshire. The hypothesis of 'decalcification' may be run too hard. We must be allowed to insist upon proof of the fact being given in any case before admitting it as an explanation. In the case before us we can understand perfectly well how atmospheric waters, charged with the humus acids furnished by the decay of forest-litter in this area of ancient forest-land have first taken up iron in the sands to form salts of the protoxide, and then, on coming into contact with the shells embedded in the sands, have by a simple chemical reaction or interchange of acids and bases substituted for the carbonate of lime carbonate of iron, to be subsequently broken up by the oxidation of the iron into the peroxide, which gives the pseudomorphic casts of the original shells.¹ I have not, after much study of the question, the slightest doubt that this is the true history of these 'iron casts'; and I think that the direct action of merely carbonated atmospheric waters has had very little to do with their production.

In connexion with these Upper Sands space prevents me from adding more than to draw attention to the fact that there are I believe signs in places of their beds having been formed by the planing down of the sand-dunes of the earlier deltaic stage; the materials having been stored up to a large extent during the long period occupied by that stage, and only needing redistribution by tidal action to give us in part the present beds of the Upper Sands.

The *time* represented by these few hundred feet of strata, as measured by the maximum development of their continental equivalents, is seen to be very great; and the study of their physical history tells us that such a lengthened period of time was required for their formation. The two series of deltaic clay deposits (entirely unfossiliferous), with their intervening and intimately associated green earths, probably occupied by far the greater portion of it. Compared with the necessarily slow accumulation of materials which the physical study of these reveals to us, the deposition of the fluvial sands which preceded them and of the marine-estuarine sands which succeeded them was probably what might almost be called a rapid process.

V.—ON THE BRITISH EARTHQUAKES OF 1889.¹

By CHARLES DAVISON, M.A.,

Mathematical Master at King Edward's High School, Birmingham.

(Continued from page 316.)

(PLATE X.²)

3. BEN NEVIS EARTHQUAKE: MAY 22, 1889.

Time of occurrence, 13 h. 58 m.; Intensity, about IV. Epicentrum, probably not far from Ben Nevis.

¹ There is nothing new in this. Dr. Alexis A. Julien explained in this way the formation of the iron casts in the "Northampton Sands," which are well known. See "Amer. Assoc. Adv. Sci." for 1879.

² Plate X. illustrates the area disturbed by the Lancashire Earthquake of February 10th, 1889, described in the GEOLOGICAL MAGAZINE for July, 1891, pp. 306-316, forming part 2 of this communication.

I am indebted to Mr. R. T. Omond, Director of the Ben Nevis Observatory, for the only information I have been able to obtain with reference to this earthquake. "It was," he says, "sufficiently strong to make part of the wooden roof creak, but was, as far as I know, not noticed in any other part of the country." The few inquiries that I have been able to make confirm this remark, and I think we may therefore conclude that the epicentrum cannot have been very distant from Ben Nevis. The great fault, which crosses Scotland from Inverness in a south-westerly direction, passes at the surface within a short distance from Ben Nevis; and being, in other parts of its course, closely associated with recent earthquakes, may possibly, by a slip, have given rise to the Ben Nevis shock.

In connexion with this earthquake may be mentioned a slight shock felt on June 19, 1889, at 7h. 40m., at Invergarry, a place 26 miles N.E. of Ben Nevis, and also close to the same great line of fault. Mr. John Grant, of Invergarry, was kind enough to send me a note of this shock, and also a list of several others felt between Jan. 1, 1888, and Jan. 19, 1890. I have followed the rule laid down by the Swiss Seismological Commission, of not treating as undoubted earthquakes those which rest on the authority of one observer only; but, at the same time, I think it is evident, from the opportunities which Mr. Grant has had for these observations, that this is a somewhat exceptional case. I add here his list of the earthquakes felt at Invergarry during the year 1888, as it has an obvious bearing on the seismic history of the district:

1888.

Jan. 5, 5h. 30m., four vibrations, strong enough to shake lamps, dishes, etc. (Intensity IV.)

Feb. 2, 5h. 5m., one vibration, like the passing of a heavy carriage.¹

Feb. 29, 20h. 10m., one vibration, like a carriage passing.

March 1, 9h. 15m., the same.

April 4, 9h. and 11h., like a light carriage passing.

May 20, 18h. 10m., the same.

July 3, 14h. 30m., the same.

Oct. 22, 13h. 25m., the same.

4. KINTYRE EARTHQUAKE: JULY 15, 1889.

Time of occurrence, about 18h.; Intensity, V. Epicentrum, about $3\frac{1}{2}$ miles S.E. of Clachan.

Disturbed area.—I have only succeeded in obtaining records of this shock from eight places; but the information received from these and other places is sufficient to enable the boundary to be drawn with a fair approach to accuracy. Thus, the shock was not felt at Campbeltown or Southend, nor on the west side of the ridge of Gigha Island. In Arran, the Rev. J. Johnstone informs me, it "was felt from Pionmill right by the Crawhill and Lochranza, passing through the glen that enters Lochranza from Sannox."

¹ This earthquake was felt over the greater part of northern Scotland.

The disturbed area is thus roughly elliptical; its longer axis, in a direction about N. 30° E. and S. 30° W., being about 25 miles long, and the shorter axis about 18 miles. The whole area disturbed, including that covered by the sea, is about 350 square miles. The boundary of the disturbed area corresponds to an isoseismal line of intensity IV.

Nature of the Shock.—From the few records I possess on this point, it would seem that the shock consisted of only one vibration; no tremulous motion, either before or after the shock, being noticed at any place.

Duration.—The estimates of the duration are fairly concordant. It is stated to have been not more than two to three seconds at Glen Saddell; several seconds at Kilberry; two seconds, or perhaps more, at Lochranza; and not more than four or five seconds at Gigha. But, as there was only one vibration noticed, it is probable that these estimates include also the duration of the sound that accompanied the shock.

Kintyre Earthquake: July 15. 1889.

Intensity.—At Lochranza, the intensity must have been V. or nearly so. It was probably greater than IV. at Killeen; and IV. at Glen Saddell, Kilberry, Clachan, and Gigha.

Sound-Phenomena.—So far as I can learn, the sound-area was approximately co-extensive with the disturbed area considered as bounded, as above stated, by an isoseismal of intensity IV. From Ardpatrik and Tarbert I have no particulars beyond the fact that

the shock was felt at those places. But, at the other six places marked on the map, the characteristic earthquake-sounds were heard. They were compared to the movement of heavy articles of furniture overhead (Glen Saddell and Killean), the passage of heavy vehicles (Kilberry and Lochranza), a strong blast of wind up the chimney (Gigha), and a cartload of stones being suddenly emptied (Gigha). The sound is said to have accompanied the shock at Kilberry, and to have preceded it at Glen Saddell and Lochranza.

Position of the Epicentrum and Geological Relations.—The centre of the disturbed area is about $3\frac{1}{2}$ miles S.E. of Clachan. That the earthquake can have had no connexion with the great southern boundary fault of the Highlands is evident from the distance of the epicentrum from the continuation of the line of this fault. Prof. C. Lapworth, F.R.S., has, however, been good enough to give me the following note on the possible geological relations of this earthquake.

"The geological structure of this district shows that between Loch Fyne and its prolongation, Loch Killisport, there is a band of slaty material more or less unaltered. A corresponding band occurs on the fringe of the Highland district, running from Stonehaven to Dunoon and Rothesay. Between these two well-marked lines of slate, lies a great area of gneiss. The relation of the gneissic rocks to the slaty rocks is disputed; by some it is suggested that the gneisses rise in an anticlinal form from below the schists; by others, that the gneisses lie on a synclinal formed of the slates. The apparent dips of the metamorphic strata make the latter interpretation the simpler and more probable one to geologists accustomed to lowland areas. If we recollect, however, that the Highlands are actually a denuded mountain complex, it becomes far more probable that this apparent synclinal is actually a fan-structure or inverted anticlinal, as suggested in my paper on "The Secret of the Highlands."¹ If this is the case, the slipping and movements caused by lateral pressure will take most effect along the two planes of contrary motion running midway between the crest of the main fold and its bounding synclines. Curiously enough, the line of direction of the axis of the disturbed area coincides precisely with the theoretical position of the southern zone of contrary movement, on the assumption that the gneisses form an inverted anticlinal."

Authorities.—The only published account of the earthquake that I have met with is contained in the "Oban Times" for July 20; and I am indebted to the courtesy of the Editor of this paper for searching his files and sending me the extract referred to. For the greater part of the information on which the above account is founded, I have to thank the following gentlemen: the Revs. J. Johnstone (Lochranza, Arran), D. N. Macdonald (Killean), J. F. McKenzie (Gigha), and H. W. Strang (Campbeltown); Mr. R. A. Cavana (Gigha); and especially Mr. J. N. Macleod of Kintarbert and Saddell, without whose aid the account of this earthquake would have been much more imperfect than it is.

¹ *GEOL. MAG.* Dec. II. Vol. X. pp. 120-8, 193-7, 337-44 (1883).

5. EAST CORNWALL EARTHQUAKE: OCT. 7, 1889.

Time of occurrence, about 13h. 45m.; Intensity, IV. Epicentrum, about $2\frac{3}{4}$ miles S.W. of Altarnon.

Disturbed Area.—All the places, 24 in number, at which the earthquake is recorded as having been felt, are included within an area which is roughly elliptical in form. The larger axis, which runs nearly east and west, is about 25 miles in length, the shorter axis about 20 miles, and the whole area disturbed about 400 square miles. The curve bounding this area is an isoseismal of intensity IV.

E. Cornwall Earthquake: Oct 7 1889.

Nature of the Shock.—The accounts of the shock, though few in number, are sufficient to indicate roughly the way in which the nature of the shock varied throughout the disturbed area. We may divide the observations into two groups. In the first we have:

Altarnon: a distinct rumbling was heard, as if the chimney were on fire or a heavy waggon passing up the road; very little if any perceptible vibration.

North Hill: a sound heard as though something had struck the wall of the house, and "then the sound seemed to vibrate at the back."

St. Clether : like a distant peal of thunder or the passing of a very heavy loaded waggon ; no tremors perceived.

Temple : like the rumbling of thunder for a few moments, followed by a tremulous motion.

Trenegloss : a loud rumbling noise like thunder ; no tremulous motion perceived.

With the exception of Laneast, from which I have no detailed account, these five places are nearer to the spot indicated as the epicentrum than any of the others from which records have been received. From this point, Altarnon is distant $2\frac{3}{4}$ miles, North Hill 5, St. Clether 4, Temple 4, and Trenegloss $6\frac{1}{4}$ miles.

The second group includes places in the neighbourhood of the boundary of the disturbed area :

Bodmin : as if some person were walking with a heavy tread three or four steps overhead.

Boscastle : two distinct shocks are said to have been felt.

Liskeard : (1) as if a heavy substance were thrown violently on the floor of the adjoining room and also against the partition dividing the two rooms, tremulous movements before the shock ; (2) one sudden crash like an explosion, no tremulous motion perceived.

North Petherwin : a slight vibration like that produced in a house by the passage of a heavy waggon.

St. Breward : like that produced by a cart passing along the road at the back of the house.

Warleggan : as if something very heavy had fallen in the house with great violence, followed by a tremulous motion.

From these accounts, we may conclude that, in the neighbourhood of the epicentrum, the sound-vibrations were most noticeable, but that these died out more rapidly towards the boundary of the disturbed area than the vibrations of longer period, and near the boundary the shock was felt as one or several thuds, or vibrations of much larger amplitude than those which preceded and followed them.

Duration.—The duration of the shock is variously estimated at from two to about twenty seconds. Thus, at Liskeard, according to one account, it is said to have been more than two seconds, according to another about fifteen seconds ; a tremulous movement before the principal vibration being included in the latter estimate. Other observations give about 2 seconds at North Petherwin, about 3 at St. Clether, 3 or 4 at Temple, 4 or 5 at Warleggan, 10 to 20 at Trenegloss, and 12 to 20 at St. Breward.

Intensity.—Throughout the disturbed area, the intensity seems to have been remarkably uniform, indicating probably a great depth of the seismic focus. According to the Rossi-Forrel scale, the intensity was IV. at the following places : Bodmin, Camelford, Liskeard, Newport (near Launceston), St. Breward, Temple, Trenegloss, Tresmere, and Trevalga. It may have been slightly greater than IV., though probably not as great as V., at Altarnon, St. Clether, and Warleggan : and perhaps slightly less than IV. at North Hill.

Sound-Phenomena.—The sounds accompanying the earthquake have been already alluded to: they form perhaps its most noteworthy features. They seem to have been of the usual description, being compared to thunder, to heavy waggons passing rapidly along adjoining roads, and to the roaring of a chimney on fire. At the following places the sound is said to have accompanied the shock: Camelford, St. Breward, St. Clether, Temple and Trenegloss. It preceded the shock at North Petherwin, and perhaps also at North Hill and Tresmere. At Warleggan, the rumbling sound was heard just after the shock, "as if a waggon had run away down the hill outside our house: it increased in sound and then appeared to me like an express train going through a station. . . . The rumbling ended quite abruptly." At Liskeard, it preceded the shock; but another correspondent at the same place informs me that it was heard both before and after the shock, both times very low, but rather louder after than before.

The earthquake-sounds were heard at all places from which I have detailed accounts. The sound area and the disturbed area may therefore have been coextensive, or nearly so. Further, since the sounds were the most notable part of the phenomenon near the epicentrum, and at a place like Liskeard near the boundary of the disturbed area were only heard by a few persons, we may conclude that the intensity of the sound diminished more rapidly than that of the shock as the distance from the epicentrum increases; and, consequently, that the sound-focus was nearer to the surface than the rest of the seismic focus.

Position of the Epicentrum and Geological Relations.—The epicentrum of the earthquake is about $2\frac{3}{4}$ miles S.W. of Altarnon, i.e. not far from the centre of the great granite boss which occupies so large a part of East Cornwall. It is also noteworthy that the duration of the shock was in some parts considerable, as much as 10 or 12 seconds, arguing probably a larger seismic focus than in any of the previous cases; further, that the longer axis of the disturbed area runs east and west, i.e. parallel to the direction of folding of the district. Though we may not at present be in a position to assign a definite origin to this earthquake, it seems at least probable that it had some connexion with the geological structure of the district, and that the forces which have combined in producing that structure have not yet ceased to act.

Authorities.—"St. Austell Weekly News," Oct. 12; "West Briton and Cornwall Advertiser" (Truro), Oct. 10; "Western Morning News" (Plymouth), Oct. 8.

The earthquake was but slightly noticed in the local press, and nearly all that is of value in the preceding account I owe to the kindness of the following ladies and gentlemen: the Revs. R. H. Boles (St. Breward), C. Bridgewater (St. Tudy), J. R. Browne (Bodmin and Temple), W. Jago (Bodmin), A. H. Malan (Altarnon), C. Olive (Warleggan), J. Partridge (St. Clether), T. B. Trentham (North Petherwin), Canon Vautier (St. Mabyn), T. Walters (Boyton), and T. Willing (North Hill); Mr. J. C. Chapman (Trenegloss),

Mrs. L. Davy (Tresmere), Miss F. E. Jenkin (Liskeard), Mr. W. E. Parsons (St. Breward), and Miss L. Thorne (Liskeard).

DOUBTFUL EARTHQUAKES.

1. *Invergarry*, June 19, 1889, 7h. 40m. (see p. 365).

2. *Little Rhondda Valley* (South Wales), June 22, 1889, about 22h. 30m.; intensity, V.

A shock, supposed to be that of an earthquake, was felt at this date in and near the Little Rhondda Valley. The area disturbed by it was very small, probably not more than a few miles in its greatest diameter. It was felt at Llwynypia, Pontygwaith, Tylorstown, Watts Town, Ynishir and Ystrad.

The disturbance, which lasted a second or two, consisted of one vibration, and at Ynishir is described as having been like the shock of a blasting explosion, but much stronger. It was accompanied by a deep rumbling noise, like distant thunder, at Llwynypia, Pontygwaith, and Watts Town. The intensity was IV. at Pontygwaith, but cannot have been less than V. at Llwynypia and Ynishir. The shock was felt by workmen underground in the Ynishir Steam Colliery, and in one or two other collieries in the adjoining district.

This is all the evidence I have been able to obtain, and I do not think it is sufficient to put beyond doubt the seismic origin of the shock. For so small a disturbed area, the intensity is unusually great, arguing a very small depth for the centre of disturbance; and, besides this, the mining operations of the district are being carried on so rapidly and extensively that, from time to time, considerable masses subside, occasionally, it is said, causing tremors very like those of an earthquake.

Authorities.—"Nature," vol. 40, p. 208; "South Wales Daily News" (Cardiff), June 24, 1889. For other information contained in the above account, I beg to thank Mr. W. Galloway, Mr. J. J. Thomas, of Ynishir, and Mr. R. R. Hood, of Gilfach.

3. *Lyme Regis*, July 5, 1889, between 23h. and 23h. 15m.

Noises were heard at intervals between the times stated. They "consisted of a distant rumble which grew nearer till at last the windows of the houses rattled and in some cases distinct vibrations of the houses were felt." They were probably not caused by the firing of guns at sea: and they may have been due to earthquakes, though the evidence is clearly incomplete.

This note is taken from a letter by Mr. A. R. Sharpe, in *Nature*, vol. 40, p. 294.

CONCLUSION.

With one possible exception (that of Ben Nevis), the earthquakes of 1889 are typical examples of British shocks—they occurred in districts where earthquakes are rarely felt, and their disturbed areas are circular or only slightly elliptical in form. Turning to a more distinctly seismic area, Switzerland for example, we find that the disturbed areas are often extremely elongated, the longer axes being parallel to those of the neighbouring Alpine chain; earth-

quakes are more frequent, their intensity, as a rule, is greater, and much larger areas are disturbed. Different stages in the geological history of a district are characterized by different kinds of earthquakes. The Alpine system is not yet old, fault-formation is still in progress, and the fault-slips are long and frequently recurring. In Great Britain, we meet with a later stage. Fault-formation in our seismic area is more advanced, and slipping takes place so slowly and over distances so short, that our earthquakes are rare and the areas disturbed by them more or less circular in form.

Every stage in the process, however, requires investigation, and that of which our British earthquakes are witness is certainly deserving of attentive study. Unattractive though it may be at first sight, the epoch immediately preceding the death of a mountain-chain, is at least as interesting to the geologist as the more vigorous periods of origin and growth.

ERRATA IN THE MAPS.

Edinburgh earthquake :	<i>For</i> Costorphine,	<i>read</i> Corstorphine.
	„ Georgie,	„ Gorgie.
	„ Curriehall,	„ Curriehill.
Lancashire earthquake :	„ Tongridge,	„ Longridge.
	„ Mihnrow,	„ Milnrow.
	„ Harwich,	„ Horwich.
Kintyre earthquake :	„ Tarber,	„ Tarbert.
	„ Glachan,	„ Clachan.

In the map of the Lancashire earthquake, the outermost of the two smaller circles should have been a dotted line. In the map of the E. Cornwall earthquake, the spot between North Hill and Callington should be erased.

VI.—THE AGE OF THE HIMALAYAS.

By W. T. BLANFORD, LL.D., F.R.S., etc.

I REGRET that I cannot accept as unquestionable the evidence brought forward by my friend Mr. Howorth in favour of the recent elevation of other mountain ranges in Asia besides the Himalayas. I dealt with the latter alone, because I have a slight acquaintance with parts of them, and some knowledge of the observers whose opinions are quoted. But I argue from the known to the unknown, and if I find reason to reject the evidence on which Mr. Howorth relies to prove the absence of extensive glacial markings in the Himalayas, I am disposed to be sceptical as to that on which he founds his argument in the case of other ranges. I decline to be drawn into a discussion about the latter.

I quite agree in the improbability of the Himalayan ice having ever reached the Indo-Gangetic plain, but I think I have shown that this is not the question at issue. I cannot, however, help remarking that if I depended chiefly, as Tschihatcheff and Cotta appear to have done in the case of the Altai, on the presence or absence of erratics, I might come to a different conclusion, for there are unmistakable "erratics"—huge blocks believed to have come from the higher Himalayas—in the Northern Punjab.

I hope I do no injustice to Mr. Howorth's argument in placing