MEMOIRS

OF THE

GEOLOGICAL SURVEY

OF

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VOL. XIX, PT. 1.

OLDHAM: THE CHACHAR EARTHQUAKE OF 10TH JANUARY 1869.

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PREFACE.

THE Report on the Cachar Earthquake of 1869 has after all returned to its birthplace for publication. This is most fortunate, for it will thereby obtain a wider circulation in this country than if brought out independently in Europe, as was the intention of the late Dr. Oldham when he took the materials home with him on retiring from the direction of the Geological Survey of India. Failing health and other causes prevented his carrying his wishes into execution. Under these circumstances it is singularly fortunate and appropriate that the duty of completing the work should devolve upon his son, who got possession of the papers, and who has since joined the service which Dr. Oldham had so successfully controlled for many years.

Only the descriptive part, the first two and a half chapters, belongs to the original manuscript; the weightier matter of discussing the observations is entirely the work of Mr. R. D. Oldham, and he has done it in a very efficient manner. In a country where earthquake phenomena are of frequent occurrence, it is most important to have one good local example put through the ordeal of scientific examination. I trust that Mr. Oldham's labours will lead to observations of a more satisfactory nature than those he has handled with so much skill in the following pages.

H. B. MEDLICOTT,

Superintendent, Geological Survey of India.

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MEMOIRS

OF THE

GEOLOGICAL SURVEY OF INDIA.

THE CACHAR EARTHQUAKE OF 10TH JANUARY 1869, *by the late* THOMAS OLDHAM, L.L.D., F.R.S., ETC., *Superintendent of the Geological Survey of India, edited by* R. D. OLDHAM, A.R.S.M., *Geological Survey of India.*

INTRODUCTION.

On the afternoon of Sunday, the 10th day of January 1869, all Calcutta was startled by one of the sharpest shocks of earthquake ever felt there. On that evening I was myself sitting reading in a house at Barrackpore about 15 miles from the city when, without any warning, the chair was violently rocked under me, everything in the room was shaken, doors and windows rattled and the chandeliers hanging from the ceiling were set swinging with considerable force. At once noting the time of the shock by my own watch, and just then feeling a second but less violent shock pass under me, I got up to see more particularly what had occurred.

The loud cries of alarm raised by all the native servants in the compound, and from the bazaar at no great distance, first struck the ear. All stood in the open air, with mouths gaping or violently gasping out their short exclamations of entreaty or worship calling on their deities to protect them, and in the greater crowd of the bazaar surged back and forwards for a few minutes, when finding that no further shocks occurred, their amazement died away, and they quieted down to their wonted occupations as if nothing had happened.

During the succeeding hours a few trifling undulations were felt, but no distinct wave or shock. Carefully noting, from such indications as were available, the direction in which the great wave had passed under Barrackpore, we felt satisfied that, as soon as time admitted of the news reaching the capital, we should hear of some very violent and possibly very destructive shock in the country beyond the limits of the great alluvial plain far away in East Bengal, and, as we determined from such evidence as was then before us, in the direction of Sylhet and Cachar.

Nor were our anticipations in this respect without sound basis; for next morning the telegraph wires brought the intelligence that Silchar town had been shaken to its very centre, that serious destruction had ensued, and, allowing for the sensational terms in which some of the messages were conveyed, the result obviously of the first alarm before the facts had been realised, it was still clear that a very unusually severe shock had occurred, that much injury to property and possibly destruction of life had resulted and further that, as the news could be gathered up, it would be found that other places also as well as Silchar had suffered severely.

For some time, each successive morning's newspaper brought additions to the reports of damage done, and were filled with communications from various people who had experienced the shock. It soon became evident that the district of north Cachar or the hills between that and Assam must have been the centre of disturbance or near to it. Manipur also had been much shaken, and all the country between that and the Brahmaputra to the north.

I had noticed all these communications with great interest, trusting that some one of the numerous writers would give data on which to build up a satisfactory conclusion as to the true direction of the shock in various places, and so by inference as to the centre of disturbance. It was clear that among the buildings partly overthrown and injured, evidence could be obtained by careful investigation on the spot, which would lead to a knowledge of the position of the seismic focus, and possibly also as to the force of the wave and the rapidity of the motion of its particles. But no such information came in any of the published communications on the subject and all that could be made out was that the shock had been a serious one, and that much damage had resulted.

I had myself only returned a day or two before from the very extreme end of the Indian empire to the north-west, or in the opposite direction, whither I had [illegible] the request of the Government of India to examine and [illegible] the feasibility of enlarging into a tunnel roadway the small [illegible] had been carried under the bed of the Indus at Attock: and finding some arrears of work which had accumulated during my absence, I was not very desirous of leaving office again immediately. Very shortly afterwards, however, Mr., now Sir, William Grey, then Lieutenant Governor of Bengal, asked me if I could make it possible to visit the principal places where the damage done was most severe, and note what had occurred on the spot. To this I at once acceded.

I was unfortunate enough to arrive at Silchar just as the military expedition against the tribes to the south, who had committed various depredations in British territory, was about to start, and every one in the place was fully occupied with the numerous and varied preparations necessary for such an attack. Mr. Edgar, the Deputy Commissioner, very kindly came round part of the station with me, and pointed out several places where the injury done had been serious; but it would have been most unreasonable to have expected that he could do more than this, in the midst of such pressing occupations.

I remained a few days at Silchar busily occupied in measuring and noting what was observable there. I was very desirous to get on to Munipur to see what had occurred there; but although the Deputy Commissioner said he could procure me the few coolies which would have been necessary for transport of baggage, &c., still, as it was obvious that this would have to some extent interfered with their more urgent occupation elsewhere, and as he stated that it would be essential also, in the then state of the country, that I should have a small escort, not from any actual fear of disturbance, but to guard against the chance of meeting some stragling band, I determined not to make the attempt, the more so as there was great reason to fear that there might have been serious delay in my getting back again.

After a few days, therefore, at Silchar, I returned to Sylhet, where I examined the buildings which had been injured; and then dropping down the river to Chattuck, turned northwards from thence, intending to cross the Khasi Hills by Cherra Poonji and Shillong to Gowhatty.

CHAPTER I.

GENERAL DESCRIPTION OF EFFECTS OF EAR

Before proceeding to discuss in any detail such spec [illegible] have been observed tending to elucidate the history of this gr [illegible] hock, h. I will briefly relate the observations made by others and [illegible] either had [illegible] official returns or in the public newspapers of the da[illegible] be found, a general idea of the impression left upon [illegible] wil[illegible] For [illegible] will also be seen how far any precise conception [illegible] tl to the force which produced them, can be expected from such var[illegible]

Taking the observations somewhat in the order of the g[illegible] position of the localities at which these were noted, we begin w[illegible] and proceeding east thence round by north, west, and south, retu[illegible] to the same vicinity.

SILCHAR.—The Assistant Engineer reported on the 13th January, three days after the earthquake:—" All the pucka buildings belonging to the department of Public Works have been injured beyond the possibility of repair; besides, most of the kutcha buildings have been entirely thrown down. The store-shed has been thrown down, and several articles injured or destroyed. All the works are stopped, and I do not see any possibility of recommencing them, without further orders. My own life, and those of my family, together with my property, were on the verge of destruction. For this reason, I am unable to submit a full report of the state of the buildings. I shall be able to forward the report by tomorrow. The whole of the Cachar bazaar, buildings, boats, merchandise, the jail, sepoy lines, and villages on the peninsula are all in a complete scene of destruction."

I have quoted this verbatim, because it seems to me an excellent instance of how easily grossly exaggerated and therefore incorrect statements can find a place in the history of such phenomena; here is an official report by the Government officer in charge of the Public Works and buildings at Cachar made three days after the event and yet most largely at variance with the real state of the facts. But I suppose all allowance must be made for the alarm arising from his being on the verge of destruction.

Mr. McWilliam, the Assistant Commissioner of Cachar, on the morning after the shock, reported to the Commissioner of the division thus:—"In the absence of the Deputy Commissioner, I regret to report that Silchar was visited yesterday afternoon at 4 o'clock by a very severe shock of earthquake, which lasted for at least a minute; considerable damage has been done to property; but, as yet, I have heard of only two cases of death. Some idea of the force of the shock may be gained [illegible]itary [illegible] fact that the new pucka Church tower has fallen, and the [illegible] various the jail compound are level with the ground. The bank of the B[illegible] the adjoining the bazaar has given way, and sunk about 15 feet over an area of from three to four hundred yards long by two hundred broad, doing more or less damage to all buildings upon it. The bazaar itself and the jail compound are cut up in all directions by gaps, in some places eight inches or a foot wide, from many of which dark sand and warm water were forced up during the night."

The *Friend of India*, on the 20th January, published a letter from a correspondent which gives a fair account of the facts:—Previous to the 10th of January, there had been nothing remarkable in the weather, which, far from being sultry, had been rather colder than usual. The air was [illegible] hazy and wanting in clearness; there had been no rain, either at [illegible] usual, nor in the first week of November, and October was [illegible] in quantity. The year 1866 was remarkable for the number of earthquakes, six or eight shocks, the greater part of which took place [illegible] and April; 1867 and 1868 were free from them.

The shock of 10th January 1869 came on at ¼ to 5 P. M. with a gently undulating movement, which, however, rapidly increased, until neither men nor animals could keep their legs, but were thrown down, and such things as bottles, glasses, lamps, were upset, and the gumlas were half emptied of water. The water in tanks and rivers was violently agitated, and the Barak rose in huge waves, and wrecked numbers of boats. The landslips caused were numerous and extensive, and many homesteads were carried down into the stream.

The old cemetery at Silchar is a rectangular enclosure, secured by walls of coarse brick masonry with heavy mortar joints, the mortar showing only a very wretched power of adhesion. This wall had been built more than twelve years. Within the limits of the cemetery there are a good many monuments of various kinds, but the large space is by no means filled. Naturally I had anticipated that some of these structures would have shown evidence of the force of disturbance to which they had been subjected, and had been, therefore, surprised to find no reference, in any of the accounts published previously to my visit, to any injury done. I was, therefore, the more gratified to find, on visiting the place, some of the most valuable and important evidence that Silchar afforded as to the nature and direction of the shock; indeed the most valuable which I met with anywhere.

The first thing which struck me on approaching the enclosure, which lies a little to the north of the main road passing east and west through Silchar, was that the gate of the enclosure was all down. The gate was of wood, solid below with vertical bars above, in two parts or wings joining in the centre, and fastened solely by a bolt. These gates were carrie[illegible] by nearly square masonry pillars measuring 1′ 8″ × 1′ 6″ which ag[illegible] were supported by and connected with the walls surrounding the cemete[illegible] enclosure by a raised step in the wall. The plain square pillars we[illegible] topped by simple capitals capped or finished by small spherical [illegible] or earthen pots inverted and secured by being imbedded in [illegible] the summit of the pillar. This was 8 feet from the level of th[illegible] The elevation of the gates as they originally stood given in Pl. A, [illegible] will show the general character better than any detailed description. The opening of the gateway was 8 feet 6 inches. The entrance road passing through this gateway and straight on through the centre of the cemetery was here slightly raised above the general level of the ground, so that there was a little fall on either side of this road.

These gates were stated to have been secured, at the time of the shock, by the bolts in the middle; whether this really were so or not, it would be impossible to ascertain now, but they were doubtless closed to prevent cattle trespassing within the enclosure.

When I visited the place, the whole was in ruins, and stood as shown in Pl. V, fig. 2, reduced from a photograph which I had specially taken by Mr. Pearson at the time of my visit. Nothing whatever had been done to the place, and the ruined mass remained, as stated by every one, in exactly the same condition as it was the morning after the earthquake occurred.

The eastern gateway pillar lay flat on the ground not much broken up, having evidently fallen *en masse*, being simply overturned. It was, doubtless, held back partially by the supporting wall on the side, but all was upset, cleanly cut off along the smooth surface of the first course of bricks above the ground level. The mass of the brickwork was broken right across and partially separated at two distinct points, and the uppermost portion of the pillar lay in a separate heap overturned close by. These cracks in the mass appeared to me to be obviously the result of fractures caused by the falling of the pillar *en masse* on partially uneven ground, the whole having toppled over in all probability as one. The capital, however, which was separate from the shaft of the pillar and lay at a distance of 4 feet 3 inches from the top of the pillar, lay on the ground, in its natural position and not overturned, as it would have been had it rolled, would seem to have been shot off from the pillar, and being free to move, that is, not tied to the wall on one side and to the gate on the other, would seem to give a fair index to the direction and possibly to the force of the wave. The spherical cap of this pillar also was lying on the ground, and *apparently* as it fell, beyond the capital, though it would not be safe to assume as certain that the place where it was seen was the actual spot of its fall. It most certainly had not been moved by human hands for none of the people would voluntarily have touched it and no orders had been given for its removal; but it may very possibly have rolled a little after falling, to which its nearly spherical form would lend itself. The ruined portion of the adjoining wall which acted as a support to this gate-pillar, had also been thrown over in ruin and much broken by the fall. The eastern half of the gate itself, which was attached to the pillar by ordinary bolt and hook hinges, was lying flat beside the broken pillar, still attached by one of these hinges.

The western pillar of the gateway was also overthrown and broken up by the fall in similar way. The capital here also was separated from the shaft, and was lying overturned on the ground close by the top of the pillar. Its projecting mouldings had evidently struck the ground when the pillar fell over and the capital, separating from the pillar, was upset by the force of the blow. The spherical ball at the top was more than 7 feet from the capital, its position being no less than 17 feet 3 inches from the centre of base of the pillar over which it was originally placed; but the lie of the ground, sloping down from the roadway and the position in which this ball was found, with its base slewed half round towards the north-west, seem to prove that this position was due to its having rolled along the ground after it fell, rather than to its having been projected from the top of the pillar by the force of the wave.

The half of the gate attached to this western pillar was left standing on its side, leaning against, and supported by, the broken mass of the pillar. It had been thrown off its hinges, and been slightly moved towards the north.

In all there was abundant evidence of a sudden and violent force producing this general overthrow, but unfortunately not yielding as clear and convincing proof of the direction in which the force had acted as I had at first hoped; the peculiar conditions under which the gateway,

gate, and pillars, viewed as a mass, were held together, and tied on to the walls on either side, having materially affected the result. I shall notice this again.

Searching through the cemetery, only few traces of the action of the earthquake were noticed. A small simple monument, consisting merely of a flat plateau or table of brickwork with a head wall raised at the north end of it, into which a marble slab with inscription had been built was in ruins. The sides of the little table bore north and south, and of course the axis of the wall at the head, at right angles to this, was east and west. The whole of this wall was overthrown and lay in a heap of separate bricks, as it fell; this was clearly just overturned and lay unmoved, excepting in so far as it was shaken into its separate bricks, the brickwork being of the poorest kind, and the adhesion of the mortar more than usually slight. The direction of the fall, which could be ascertained with considerable accuracy was North 3° 20′ East.

None of the other smaller monuments showed evidence of the destructive force of the wave. A small plain stone cross, to the memory of the infant son of Captain Stewart, dating 1864, probably erected 1865, remained perfect. The shaft was rectangular of 5¼ by 4¾ inches, the total height being 3 feet 2 inches, and the breadth of cross arms 2 feet 1 inch. This was inserted into a plain terrace or plateau of steps, and it would give a good measure of the limits of the force, if needed.

But the most remarkable case of destruction remains to be noticed. Near the centre of the cemetery ground stood a very elaborate and costly white marble tomb or sarcophagus, erected to the memory of Charles Ruthnot Stewart, Esq., who died at Silchar in June 1864. This carefully-prepared and well-chiselled tomb had been constructed by Messrs. Llewellyn and Co., a well-known and long-established firm in Calcutta, and the parts had been by them transmitted to Silchar. It is but right, however, to add, with especial reference to any remarks I may have to make on the construction, that the monument was not put up by the Messrs. Llewellyn, or their workmen, but by some local masons. I am able to give a rough sketch of the tomb (Pl. X, fig. 2), as it stood prior to the earthquake of the 10th January, copied from a most faded photograph which is scarcely legible, and I took advantage of the fortunate presence of Mr. Pearson in Silchar, during my visit, to obtain through him a photograph showing the state of the mass as it appeared after the shock had passed, which has been reproduced in Pl. X, fig. 2. These views will give a much better idea of the wreck than any description; and yet this ruin in reality consisted only of the projection of the heavy upper slab, the rest of the tomb being almost uninjured.

As we shall return to this tomb, I will now merely state the upper heavy slab of marble was found fairly projected from the body of the tomb more than 8 feet towards the north-north-east, and thrown unequally, the west end of the slab being thrown further than the east. The tomb stood with its major axis bearing West 5° North and East 5° South; the sides of the heavy mass as it now lies bear West 10° North; the general direction of the throw or of the line joining centre of slab as it now lies with the centre of body of tomb over which it was placed, is 12° 30′ West of South or East of North.

The boundary walls of the cemetery enclosure had been cracked and broken in several places, but there was nothing very remarkable noticed. Still, in the absence of better observations, it may be noticed, that at 97 feet from the gateway to the west a marked crack extended from top to bottom of the wall, making an angle of 25° with horizon, and at 34 feet further in same direction there was another less marked crack, dividing as it passed to the bottom of the wall, and which gave an average angle of 16° with the horizon. These cracks were in all cases opened along the joints of the brickwork—nowhere across the bricks themselves. Between the two, the wall was slewed round fully 1 inch to the north at the east end, and ¾ of an inch to the south at the west end. Small thread-like fissures occurred at the corner also; at the north-east corner of the enclosure there were cracks in the wall, and several others showed, at varying intervals, in the northern wall, most of these being nearly vertical.

This cemetery enclosure is just on the edge of the Kandy lands; to the north the ground falls rapidly into the lower level of the peninsula of

Silchar, but no portion of this lower ground is included in the enclosure of the cemetery.

In the new cemetry, placed in a lovely spot, a slope of rising ground to the south of the town and at some distance from it, no mischief was done.

Among other buildings which had been injured by the earthquake prominence had naturally been given to the Deputy Commissioner's house which had received considerable damage. Mr. Edgar himself however at once said that this would afford no index to the force exerted, from the peculiar circumstances under which the shock occurred. The house was an ordinary bungalow with one of the heavy native thatched roofs; round the house was a raised verandah, at the outer edge of which a series of wooden pillars supported the lower edge of the roof, which was all in one slope. In the ordinary construction, each side of such roof is made in one piece, the whole is then merely tied together and slightly secured in addition by the plastering round the chimney, generally in the centre of the house.

When the earthquake of the 10th January came, preparations had been made for the removal of the old wooden pillars, with the view of putting in new ones round the verandah, and on one side these had been partially removed so that the very heavy roof had been deprived of the main support on that side. As the thatching was to be renewed, it had been weakened in other ways also, the natural consequence being that the whole of one side of the roof was dislodged and slipped bodily down, bringing with it of course portions of the walls, &c., and destroying some furniture in the verandah; part of the chimney, and of the internal dividing walls were also shaken down and falling in the rooms did some mischief; there was no one in the house as Mr. Edgar had moved into an adjoining bungalow to allow the repairs of his own to progress. This second bungalow and several others about were uninjured. Although the Commissioner's bungalow looked to be in actual ruins, it is more than probable that it would not have suffered at all but for the condition in which it happened to be.

The small hospital attached to the native infantry lines was a perfect ruin; this had been a simple rectangular building 80 feet long containing a central room round three sides of which was a verandah, the roof being supported on masonry pillars 2 feet square. The northern end of the building was open; at the southern end the verandah at either side was enclosed so as to form two small rooms for dispensing medicines, &c.; the brickwork of all was old, and of very poor quality; the plain ridge roof was of the ordinary heavy thatch in use in the country. All was in ruins, most of the debris had been removed before I saw the place, and the roof and much of the rubbish was gone, but the pillars still remained as they were first thrown down. That they went over *en masse*, was perfectly evident from the way in which they lay; portions of the pillars, more than 3 feet in length, were laid along the verandah floor quite unbroken and with as much regularity and parallelism as if they had been carefully alligned. All were separated from the base on the smooth surface of one course of bricks and simply turned over, and this was the case in both verandahs, whether to the west or east. The cross walls and additional division near the southern end of the building had to a certain extent so strengthened the fabric there that the walls were largely standing, but the whole of the heavy massive roof must have been started by the shock and have carried with it the pillars which supported it on either side, and the walls to the north. The axis of the building was magnetic north and south; the direction of the pillars as they lay was slightly affected by the action of the roof with which they were connected, but all lay at angles between 6° and 10° west of north.

The jail near the town at the south end of the bazaar presented a curious appearance. The high outside wall had been laid perfectly flat on the ground, a few courses next the ground here and there remained and a small portion of the curved corner of the wall, where each portion had supported the other, still stood as well as parts of the large gateway, where the walls had been strengthened by the heavier piers and buttresses, the rest was lying on the ground, every portion in its true position relatively to that which was next it in the wall originally, but all separated and disjointed. The whole must have gone over in one mass projected by the shock into the courtyard of the jail.

A small Hindu temple or *mal*, which lay under the shelter of a large banyan tree, was quite uninjured; and, naturally enough, the people, unaccustomed to reason as to the causes of these phenomena, attributed its safety to the protecting power of its sanctity. It was a small, nearly square cell, of solid heavy masonry and, as it stood close to the utter ruin of the jail wall and to the wild scene of destruction which the adjoining bazaar and banks of the river afforded, its preservation was striking. This was clearly due, not to any holiness in the ground which prevented the irreverent footsteps of the earthquake from penetrating there but to the binding effect of the wide-spread roots of the noble tree which covered it and which so tied together the whole ground that it must have been affected as a whole if disturbed at all. For this the force exerted was not sufficient, and the temple escaped.

The bazaar itself presented one almost unbroken scene of ruin. It had been chiefly composed of bamboo and mat structures, which, in other places, had remained undisturbed, yielding sufficiently to the wave by their elasticity, and quickly recovering themselves. With these there were a few *pucka* or masonry structures—some with flat-terraced roofs. But here all were in ruins. The views I have given, all taken from Mr. Pearson's photographs and therefore accurate and detailed representations of the facts, will convey a much better idea of the appearance of the place than the most detailed description.

However, it required very little examination to see that all this terrible destruction of property was due entirely—almost entirely—to secondary causes. This bazaar extended along the bank of the river, up the eastern reach of the great curve or bend which encompasses the town and peninsula of Silchar; and when one looked at the ground between the houses and the river the eye was met by a wavy sea of broken ground dropping to the river's edge by successive steps, trees thrown at every angle some buried or half-buried, the fragmentary ruins of houses and huts one-half standing here the other wildly thrown in a heap there, all in most inextricable confusion.

The sketches will themselves give the key to all this. In the foreground of several will be noticed long cracks or fissures even in the very road; and on looking from the bazaar road towards the river, the surface of which was there about 50 feet below the level of the bazaar, these cracks and fissures were seen to be repeated in successive steps down to the water's edge. Bamboo and mat huts, which on the unbroken surface of the ground adjoining to the west stood quite uninjured, here were torn to pieces and destroyed, not by the waves of short duration, which would have affected them here as little as elsewhere, but by the absolute separation and unequal sinking of the ground on which they stood. No elasticity and flexibility of material could withstand this, and these mat huts yielded with as much facility as the more permanent buildings.

One of the thoughts which first suggested themselves on the sight of such wide-spread ruin was that there must have been very serious loss of life in a place so crowded; but most fortunately this was not so. The earthquake occurred at a time of day when most of the inhabitants were outside their houses, or were sitting close to the doors and could therefore easily escape; while from a dread which had seized many, that they would be impressed as coolies, the number actually in the town was less than usual. The total number of lives lost, both in the town and district after very careful enquiry, were found not to exceed five or six, and very few serious injuries to persons were reported.

Kochela.—Near this a building had been years since erected as a saw-mill but had recently been disused. It consisted of a simple parallelogram, the walls enclosing the space being on all sides composed of a series of openings arched above. These openings, at the time of the earthquake, were quite free, having no wood-work or other enclosures. The sketch plan given in Pl. VII will indicate the proportions and mode of construction of the building. At one corner the masonry was enlarged and carried out so as to form a projecting square buttress as it were, through the centre of which a circular flue was carried up from the boiler of the steam engine which gave the motive power to the saw mills. The longer axis of the building bore south-south-east, the furnace chimney being placed at the north-west corner of the building.

After the shock of the 10th January, the only portions of this building left standing were the solid walls at the corners. All between these solid parts on the north, east, and south sides was overthrown, and of the five detached piers which supported the arched openings on the west side, three also were down. Two, those next to the furnace stack alone stood, together with the chimney, and very obviously owed their preservation to the additional strength given by the heavier and more massive construction of this part of the building.

The greater portion of the *débris* of the fallen walls lay in remarkably well-defined masses, the piers, arches &c. having clearly come down not piecemeal but in one mass, the breaking up being due to the fall and impingement on the solid ground. In this way, as will be more clearly seen by reference to the sketch plan Pl. VII, the east and west walls lay on the ground, so that the piers and arches of the original construction could readily be traced, the piers quite as parallel one to the other now that they lay shattered on the ground as they had been before, when standing in the finished building. The direction in which they were thrown was, therefore, very readily ascertainable; it was S. 39° W. At the ends, however, of the building the mass of *débris* seemed at first sight to have been simply broken out from the corner buttresses and laid down, so little broken was the larger portion of the brickwork; in both cases the walls were thrown outwards, that is in opposite directions—the southern wall being thrown to the south, and that of the northern end to the north. On the eastern side lay one solitary block of brickwork of no great size, a solid block originally part of the most northerly of the piers of the eastern wall near the base of which it lay after the destruction. It was not square with the base, but had been slewed round in its fall. But as I am unable, from the information at my command, to say how far this may have been due to a certain amount of rolling or changing place after touching the ground, and how far to the action of the disturbing force impressed upon it, I shall merely mention the fact, without attempting to base any conclusions on it. It is very possible that more careful examination might have shown how far its present position was due to each cause separately. From the top of the south-east corner buttress some bricks had been dislodged, and were found lying between the buttress and the fallen arch-work to the south.

The only two archways left standing, adjoining to the chimney shaft, were both badly cracked, these cracks passing right through the arch-work and wall above. I should mention that the building had no roof on when it was overthrown; it is said to have had a corrugated iron roof before.

It is clear that the mode in which the building was broken up has been materially affected by its construction; the corners had obviously far greater strength and power of resistance than any other portion, and not only had they this power of resistance due to the solidity and symmetry of the wall, but also from their being buttressed, as it were, by the two corner walls being at right angles to, and tied into, each other; the chimney stack in the north-west corner of the building acted still further as a buttress or support by its solidity and weight, and so supported the two adjoining arches, which, though seriously cracked by the rocking of the walls, stood. The walls were, in fact, precisely of the construction which would be most liable to result in an overthrow from such a wave shock as this earthquake sent through them—lofty arches, with slight piers and a comparatively heavy mass of masonry above, which could only act as the heavy bob of an inverted pendulum, producing a serious leverage on the whole and tending to prevent the possibility of recovery of the vertical when once moved therefrom.

The evidence which this building affords of the direction of wave transit I shall discuss in another place.

Sylhet.—Earthquake said to have been at 4 hours 22 minutes P.M., magnetic meridian time. The shock was sudden; lasted about a minute; direction toward the latter part of the shock was from north-north-east

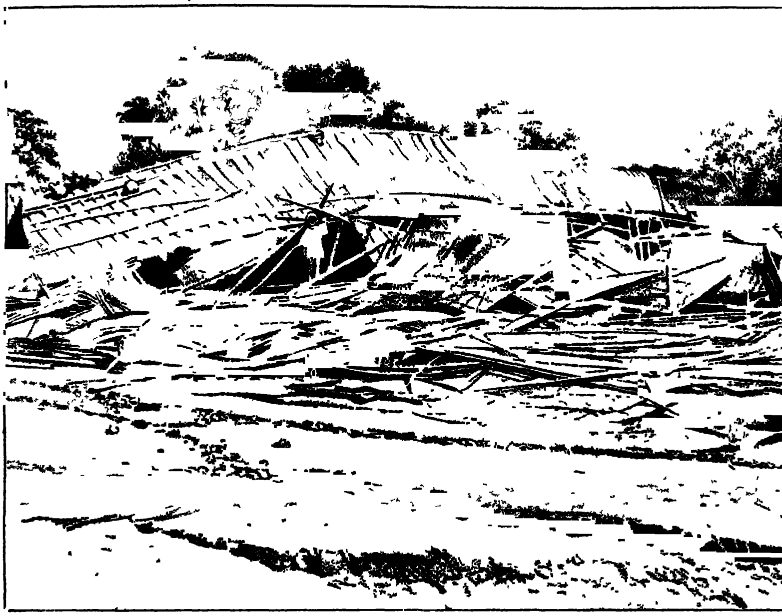
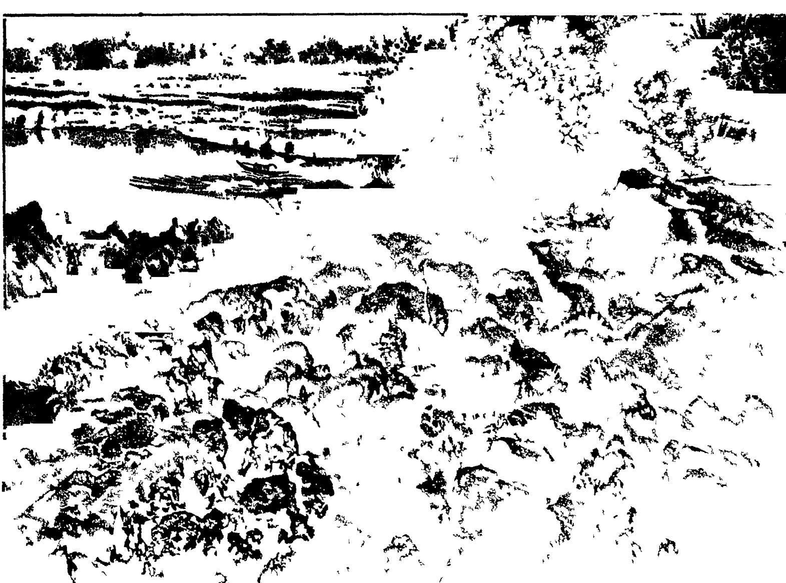


Fig 1 on Bazar road



T Schaumburg Lith

Fig 2 Fissured ground on banks of river

to south-south-west. The palm trees all rocked so, and the ripples in the river were in this direction. From the peculiar tremulous, "almost stinging" sensation experienced in the feet, the Executive Engineer thinks there must have been two shocks at same time, one commencing from the west (? east) crossed by another from the northward. A second shock occurred ten minutes after, and another 50 minutes later. At 7 P.M. a fourth, all much slighter than the first; the steeple of the church was shattered in all directions, two pinnacles fell and two were shifted. Court-houses and circuit bungalow heavily cracked. Pendulum clocks were stopped, vessels of water had their contents thrown out, &c., a large looking glass in circuit-house was thrown from the table and broken to pieces.—(*Executive Engineer, 11th January.*)

Pola (58 miles east of Sylhet.)—The overseer of the Sylhet and Cachar road states that he was at Pola when a violent earthquake took place. The shocks were violent for five or six minutes, and then abated and ended in three minutes more. He was obliged to sit down and hold on to the ground. About 600 feet west of the Pola River and 200 feet south of the Barak River, the earth cracked in several places, and sank 4 feet deep. The shocks were from south to north, and the water of the Barak River boiled, shook, roared and ran with tremendous force against the current northward, rising 6 feet over a sandbank; the houses on the north bank of the rivers were shaken into an inclined position. All the country between the Pola and Dhullesur Rivers was rent into cracks from 3 to 9 inches wide, and from which hot water, and sand soft and black, were thrown out with considerable force and deposited on the ground to a height in some places of more than 3 feet. On the west bank of the Pola the road was 4 feet high, but has sunk level with the main land.

From Pola to Thittia, as he passed up immediately after the earthquake, the hot water was rushing out of the cracks in the road, producing great heat and a sulphureous stench, and hot, black, soft sand was deposited over the cracked ground and excavations, which were from 3 to 4 feet deep, and filled with the same.

The inspection bungalow at Panchgaon was thrown down. From Panchgaon to Budderpore the soil was cracked in many places.

He was informed that the road near Katta Khall has been cracked and sunk. The villages between the road and the rivers at Kalinuggur had sunk so much that little is to be seen of them.

"At Sealtic bazaar houses have sunk 40 to 50 feet below the surface. Nut trees (*Areca*) from 40 to 50 feet high had disappeared below the surface in some places, and in others were 2 feet or 3 feet above the ground. A merchant's godown had sunk 15 feet below the ground. The Barak River, at this place, had become so shallow that boats passed with difficulty.

"A boat, laden with lime, which was sunk some years ago, and became imbedded in the mud, has been thrown out. I have also been informed that the Katta Khall has been blocked up, and that passengers are crossing dry shod.

"There were two shocks of an earthquake this morning (14th January) at 3 o'clock, the sound of which was quite violent."—(*Overseer Babu Rameshur Ghosal.*)

Cherra Poonjee.—The station of Cherra is very peculiarly situated, and it is necessary, before describing the effects of the earthquake of January 10th at this station, to notice briefly the physical characters of the ground.

The station is built on a level flat or plateau of sandstone. From the surface of this plateau, whatever soil at any time existed, has been almost entirely washed away by the excessive rains of this part of the hills, leaving a great slab of bare rock, forming a slightly undulating surface cut up here and there by water-courses. To the north of this plateau, small irregularly waving hills rise, on which the station of Cherra Poonjee is placed; to the west, with rolling interruption, the flat ground is inclined to the village of Maomlo beyond which it is interrupted by the deep and narrow glen of the Um Nangnian River; to the south-west small isolated hills of limestone (nummulitic), overlaid with beds of coal and sandstone, dot the plain; while to the south-east the plateau is bounded by deep and lovely valleys or gorges. These drop suddenly and for a considerable distance nearly vertically, thence with rapidly descending incline to a depth of some 2,000 feet, and at the bottom runs a stream, which in the rainy season becomes a roaring torrent. This deep gorge on the east does not extend into the hills much further than the station of Cherra, terminating to the north in a vast curved line of precipices. To the east and east by north the plateau of Cherra is as it were cut off from all communication with the adjacent hills by this deep glen, seldom near there more than a mile wide at top and of more than 2,000 feet in depth, while all the houses at Cherra may be said to be close to the edge of the plateau, that is, within a few hundred yards of the precipitous side of the gorge. Consequently the earthquake shock, coming from the east by north, was superficially extinguished by the breach of continuity of this deep glen so that the shock was not felt, or only very slightly so, passing under and not again emerging at the surface till it had passed beyond the station.

Shillong, Khasi Hills.—The Executive Engineer at Shillong summarised the injuries done to the public buildings thus. *Overseer's bungalow:* Nineteen arches cracked in various directions, north and south gables, also partition walls cracked, &c. *Deputy Commissioner's cutcherry;* Five arches cracked, &c. *Native Infantry Magazine* very seriously injured. He gave three sketches taken the morning after the earthquake, showing the serious cracks which had been formed in parts of this building. Although roughly done these sketches are of interest as almost the only record I have been able to trace of the physical effects of the shock. The Executive Engineer obviously gave them simply as showing in the simplest and most effective way the injuries done, without attempting to argue back from them to their causes, but if others had done the same thing in other places, the data for the history of this earthquake of 1869 would now be far more complete and satisfactory than they are.

Nungpoh.—At this village, which is one of the stages between Gowhatty and Shillong, the shock was severely felt by the Deputy Commissioner, who happened to be there that evening in the travellers' bungalow. A despatch box full of papers was thrown from a camp table, ink upset from an inkstand &c. It was only a mat and timber building and sustained no injury.

Manipur.—Dr. R. Brown, the Political Agent, Resident at Manipur, reported as follows on the 18th January:—

"On the 11th instant, the day after the occurrence, I sent a telegram to Cachar to be forwarded to you, briefly mentioning the main damage and loss of life which had occurred, so far as I could then ascertain. I am happy to be able to state now that no further loss of life seems to have taken place, and those injured are all, so far as I can ascertain, progressing favourably.

"At the commencement of the earthquake I was standing in the centre room of my house. I did not take alarm at the first one or two vibrations, thinking that, as is usual, they would rapidly cease: the vibrations increasing, however, I made at once for the door of exit. I experienced some difficulty in making my way through the front room, the ground at this time undulating so strongly that walking was a difficult matter. Arrived at the outside of the house, the ground was in such violent motion, that I found it impossible to proceed more than a few paces, when I either was thrown down or sank down involuntarily, my face turned towards the house, and on my hands and knees. At this time the motion of the ground was most remarkable; it seemed to rise and fall in waves of about 3 feet in height. A very short experience of this wavy motion sufficed to settle the fate of my house; after swaying about, and creaking and groaning for a brief space, the upper storey, built of wood and bamboo, settled down with a crash on the lower walls, which, fortunately, although much fissured and thrown out of the perpendicular, withstood the pressure.

"Almost immediately after the fall of the house the motion ceased, and I was enabled to regain my feet and see what damage had been done. I found the house inside in a deplorable state and one illustrating the wonderful force of the earthquake. Heavy book-cases and other articles of furniture had been literally thrown violently about, and the destruction of crockery, bottles, &c., was very great. Outside my compound I found the house, in which the treasure chest was kept, level with the ground, but no one hurt. A glance at the Rajbarrie close by showed me that the Raja's pucka house was in ruins, with many other less substantial buildings. In fact, in every direction fallen houses of all descriptions, slight or substantial, attested the great violence of the earthquake. Every one was in a state of very great alarm, never having experienced any thing of the kind, except the very slightest shocks, before.

"In a time of such terror and confusion, it is a difficult matter to make accurate observations as to time, &c. However I looked at my watch when the shock commenced, and found it 3 minutes past 5 (evening); on rising from the ground after the earthquake was over, it was exactly 5 minutes past 5. Allowing for errors, I think it may be almost assumed with certainty that the shock altogether lasted about a minute and a half. So far as I could observe, the lower animals did not seem to be at all affected by the phenomenon. There was nothing unusual in the weather or the temperature at the time of the shock. I had an excellent opportunity of observing the state of the weather on the day of the earthquake, as I rode into the capital from the foot of the hills to the south-west of the valley that morning; the only two things that struck me were the entire absence of the usual morning fog and the presence of a particularly dense bank of blackish cloud over the high hills to the north-west, the rest of the sky being clear.

"The Natives all say, and I agree with them, that the first shocks were almost due north and south, but, according to them, the undulations almost immediately after this assumed a circular character, and seemed to come from all quarters; this may be, but I did not at the time become conscious of any change of direction in the motion. About 15 minutes after the occurrence of the first shock, another took place, slight, however, in character. Without giving the particulars of every slight shock which followed the major one, it may be stated that up till

¼ before 10 P.M. on the 14th, the shocks, although slight, were very frequent, keeping the inhabitants in a constant state of alarm, most of them camping out all night, afraid to sleep inside their houses after the experience they had on the 10th. During the 15th, 16th, and 17th, I observed no shocks, but this morning, the 18th, they again recommenced, and I observed distinct shocks, slight, and not lasting more than a few seconds, one at 7 minutes to 2 A.M., another at 10 minutes to 8 A.M.

"On the morning after the occurrence of the earthquake, I visited the Rajbarrie and other places to witness its effects. In the Rajbarrie enclosure, which is of great size, there is a "Maidan" of some extent, which lies rather lower than most of the other parts of the ground. In this space were the remains of many openings, now closed with fine mud, where the ground had opened and great volumes of muddy water had been poured out; in this space also the ground was much fissured, and for 20 or 30 feet it was broken, and had sunk in portions more than a foot. Many of these closed apertures were quite soft, and allowed a walking stick to be pushed down 10 or 12 inches until the solid ground was reached. The main branch of the river which runs through the capital, flows at a short distance from the Rajbarrie, and an inspection of its banks showed most unmistakably that along the course of the river the disturbance of the earth had been much more severe than in places situated at a distance from it; the ground along the banks and near the river was most extensively and widely fissured, and it had sunk several feet in many places. On the morning of the 11th, the river had fallen about a foot, and the current was very sluggish, evidently the bed had been depressed; the following day the river had risen about a foot above its former level, and the current was re-established.

"In the fall of the Raja's two-storied brick house, a most substantial and ornamental building, and which had only been finished five years ago, I regret to say four women were crushed to death, and a number of people wounded. As intimated above, I have heard of no other fatal cases, and the wounded are all doing well; the more serious cases being looked after by the Native Doctor attached to the Agency acting on my instructions. The Raja's loss in property is very great, and is not yet fully known; he is especially sorry about his muskets, numbers of which, but recently received from Government, have been irretrievably destroyed.

"Full particulars from all the outlying districts and thannahs have not yet been received, but, so far as I can ascertain, the earthquake has been universal all over the valley and in every direction in the hills, and much damage has been done, but, so far as I can hear, without loss of life. At Morai Thannah, on the Burmese frontier, four days' journey from this, the earthquake is described as having been very severe, and the ground was extensively fissured. To the north, many villages belonging to the Nagas have been demolished. The hill streams have all risen from 1 to 2 feet. At the salt wells in the valley, some 14 miles east from this, but little damage was done to the houses, but the salt water in the wells is reported to have increased in depth 6 feet, and this increase was accompanied by much noise. I have made enquiries as to the behaviour of the large lake or jheel to the south of this about 14 miles, as I expected that it would show some remarkable phenomena, and I am informed that during the earthquake the water was violently agitated and became of a reddish colour. After the earthquake the water appeared permanently increased, and a most remarkably thick crop of water plants appeared on the surface, rendering the progress of boats very difficult. Altogether, I think that the surface of the valley has, so far as I have been able to observe, sunk probably a foot or more from its former level.

"The reports from the line of road between this and British territory all point to most extensive damage, the road in many places being completely destroyed. An enormous mass of rock, &c., is described as having blocked up the Eurung River close to the ford, leaving but a few feet for the passage of the water. So soon as matters somewhat settle down, I purpose visiting the damaged portions of the road, when I will report fully as to damage done, and if assistance will be necessary in order to effect the necessary repairs.

"I am much indebted to the Raja for the promptitude with which, in the midst of his own troubles, he sent men to build me a temporary house, my former one having been rendered uninhabitable by the earthquake.

"I have in preparation a few photographs illustrating the damage done, copies of which will be forwarded when they can be got ready."

In reply to enquiries made by Mr. Leonard, then Superintending Engineer in the Public Works Department for that Circle, Dr. Brown subsequently, under date of the 25th February, said:—" Since then I have heard that the earthquake penetrated a considerable distance into Upper Burmah, and was very severe. I have also had accounts from one of the Rajah's officers from a place in the hills north-east of this, seven days' march. He describes the earthquake as very severe; the ground opened into fissures; huts disappeared; water was poured out and in fact the same phenomena were observed as in Cachar, and apparently more severely than there.

"I have received lately accounts of the state of the road between this and the frontier, and the former reports as to damage done I find were exaggerated. At only one place near the Jeerie River has there been any considerable landslip, and the road at this place would most likely have gone this coming rains.

"The statement (in para. 9) as to the whole level of the Manipur valley having fallen should be modified, as it is perhaps rather too startling. The river beds, however, have sunk much, else how account for the decrease in the volume of water, the stoppage of the current, followed by a rise (not owing to rains) and a re-establishment of the current; this occupying three or four days altogether.[1]

[1] This may easily be explained without any alteration of the levels. The earthquake very probably shook down large quantities of *débris* from the steep sides of the khuds, which damming the streams caused a decrease in the quantity of water in the river beds lower down; afterwards the water rose and rapidly swept away the barrier of rubbish; this would cause the decrease and subsequent increase in the volume of water and the final return to its normal level.

"One thing I omitted in my report. I was not conscious of any subterranean noise at the time of the earthquake; the noise struck me as entirely due to the swaying of trees and houses, and was exactly like the sound heard in Bengal when a storm is coming up during the rains.

"Manipur itself, that is the large basti called the Capital, is almost flat; the houses cover a very large extent of ground, and are without exception built of wood and bamboos. The only two dwelling-houses built pucka were mine and the Rajahs; they both came down.

"There are several small nullahs flowing through the above, but the earthquake distinctly followed the main one, which runs south-east, the banks of the others were unaffected to any extent more than the surrounding land.

"All the ground occupied by houses is flat without rock; a bluish clay is the substratum over that deep soil.

"The shocks noted by me are as follow:—

		h.	m.	
January 10th ...	First shock very severe	5	3	P. M.
	Second " not "	5	15	"
	Third " " "	5	55	"
	Fourth " " "	6	10	"
	Fifth " " "	7	5	"
January 11th ...	Slight	7	49	"
" 12th ...	Rather severe	6	45	"
" 13th ...	Slight	2	50	"
" " ...	Do.	4	40	"

"After this the shocks ceased until the 18th when two slight ones occurred,—time not noted.

"On the 21st February another very slight shock was observed, lasting about 2 seconds, direction from north-east to south-west; time 9h. 6m. A.M. The shock was so slight that many of the natives about did not notice it. I did so satisfactorily, as I had before me at the time on the ground, outside my house, two large dishes full of water; the water in these moved up the side about 1 inch.

"My impression about the weather here this season is that the temperature has been much above what it was last season, but having no observations to be relied on before May last, this cannot be proved.

"I might have gained more information, but I have unfortunately been tied down to my post here by the Lushai disturbances."

We have no futher information from Manipur, Dr. Brown being the only person there who seems to have taken notes of the phenomena. As I have already mentioned, it was a source of great regret to me that the Lushai disturbances should have prevented my getting to Manipur, and noticing on the spot the evidences of the direction and force of the shock-wave.

Sibsaugor, Upper Assam—From this station we have it reported:—"Severe earthquakes about 5 P.M., lasted four or five minutes, followed by several slight shocks throughout the night. Three or four large arches in centre of cutcherry cracked in the crowns, and also at east end; several of the smaller arches similarly cracked."—*Lieut. Peel, Assistant Commissioner.* The *Executive Engineer,* Upper Assam, says:—The undulation was from south to north, lasted upwards of a minute; pucka houses so violently shaken that he thought the portico and verandah would come down, yet there were no cracks. The first and bad shock was about 5h. 15m. P.M.; another much slighter 15 minutes after; and a third two hours after several slight ones during the night.

Golághát.—The shock was preceded by a low rumbling sound from the direction of the Naga Hills, due south of the station. This increased in strength till the passage of the earth-wave. The first shock was so violent that the describer could with difficulty retain his seat. A glass of water standing on a small table discharged about one-half of its contents. Two shocks succeeded the first after an interval of two or three minutes, and a fourth about half an hour afterwards. Shortly after a great wave, 1½ foot deep, swept down the river, destroying many boats.

Kenomah (Nága Hills).—The earthquake began with a gentle motion followed by a great undulation, which produced several landslips, and fissured the hill sides; the fissures were about two fingers broad. Between Samanguting and Kenomah the rivers were discoloured and swollen, though no rain had fallen, and in the neighbourhood of the Dhunseri

River the ground was broken up, and water and sand were ejected from the fissures. The Dhunseri River rose 3 feet two days after the earthquake. The earthquake at Dimapur was accompanied by loud reports.—(*Deputy Commissioner.*)

Jaipur, Assam.—Mr. Peel, whose power of observation and carefulness in recording these I know, writes that the earthquake passed near Jaipur in a S. S. W. to N. N. E direction, or, to be more correct, from 5° to the west of south to 5° to the east of north. I had ample means of marking the direction of the waves, as about 30 men all stood together, and we could only *stand* at all by straddling our legs in that direction, which I noted. While they were passing it was impossible to stand steady with the feet close together. In about five minutes it was followed by *loud* series of *reports* like artillery that lasted about 5 minutes. I noticed a large semul or cotton tree, and it did not come to rest for 10 minutes and swayed (at first) in the same direction. A friend of mine, while riding over a flat plain, was thrown, the horse staggering, and he was regularly *sick* on the spot. Pucka work has suffered severely, but kutcha not at all, as far as I know.

Dibrooghur, Upper Assam.—Doctor J. B. White, the Civil Surgeon of the station, reports that the first shock occurred at 5h. 15m. exactly; that the direction of the wave course was from south-east to north-west; the shock lasting 2 minutes and 5 seconds. Other shocks are reported to have occurred on the following days, the 11th at 2h. P.M., at 3h. 45m., and at 5h. 30m.; also on the morning of the 12th (time not recorded) and at 3h. 30m. A.M. of the 14th.

A correspondent of the *Englishman* newspaper states that the first shock occurred at 4h. 58m., mean local time, a second at 5h. 10m. and a third at 7h. 2m. Two shocks also during the night. And again on the morning of the following day, the 11th, at 5h. 15m., 5h. 25m., and 5h. 38m. A.M.

The weather on the day previous to the earthquake (9th January) is said to have been unusually close and sultry. The shock was very severe. In one house, three clocks, one of which stood south-west and north-east, and one south-east and north-west, were stopped by the first shock. Twenty minutes after the great shock, repeated peals, like the sound of distant artillery, were heard in the direction of Sibsaugor. No damage was done beyond a few cracks in the pucka houses of the station; the public buildings remained uninjured, except that a crack in the church, produced by an earthquake fifteen years before, was re-opened.

Lakhimpur.—The earthquake is said to have been felt at about 10 minutes after 5 P.M. on the 10th. The shocks lasted for nearly two minutes and-a-half, and appeared to proceed from the south-west passing off to the north-east. The movement was described as a vast undulation which seemed to invest the solid earth with the motion of a great storm wave, before which the trees bent and rocked in the most extraordinary and fearful manner. Riders were compelled to dismount from their ponies, and even then kept their feet with difficulty. It was accompanied by a low rumbling noise, the motion creating a feeling of nausea. Half an hour after the great shock there was a second one, less severe, which was accompanied by *several distinct reports like the firing of distant cannon.*[1] Nearly an hour after the first, a still slighter shock occurred, and second slight shocks were noticed during the night. They recurred again at 4h. A.M. on the morning of the 12th, at 3 P.M. on the afternoon of the 13th, and again at 4h. A.M. on the morning of the 14th (*Englishman,* January 27th). Another correspondent stated that "*shelling*" had been heard every day since the 10th. Another report states that the loud explosive noises were heard about a

[1] These noises, like artillery reports, are among the most unaccountable of all the concomitants of this earthquake, the area over which they were heard being at once so extensive and so limited—extensive, inasmuch as the reports from Lukimpur, Sibsagur, and Jaipur show that they must have been heard over an area of at least 200 square miles; limited, inasmuch as they were not heard anywhere else over the vast area affected by the shock. The smallness of the area over which they were heard, coupled with the fact that that is placed at the extreme north-east of the seismic area, show that they can have been but a secondary effect of the earthquake.—R. D. O.

quarter of an hour after the shock, not half of an hour, as stated above. No Government buildings were injured, but the walls of two or three private houses were cracked.

Nowgong.—The Executive Engineer reported a terrible earthquake at 5h. 10m. P.M. on the 10th, which lasted more than two minutes. Furniture in houses was all thrown about; the water in the river rose and fell 2 or 3 feet; boats were torn from their moorings, &c. The Executive Engineer's office was reduced to a heap of ruins; hardly a square yard of solid wall being left. The Deputy Commissioner's Court suffered much, the walls were kutcha-pucka, and had either fallen down in a lump, or were left so insecure that they had to be taken down. The jail wall, although standing, was left in a very shattered condition. The hospital of the Jail, a new building lately completed by the Public Works Department, was cracked all over, but especially at the upper corners of the doors and windows. The school house escaped, "the brick-work seems to have been better put together than that of the other buildings." The old church was cracked all over.—*Executive Engineer,* under date January 11th.

The weather for a day or two before the 10th was exceedingly sultry. A rumbling noise like smothered thunder approaching from a distance preceded the shock, and accompanied its passage, sounding as if from deep in the earth. The undulations were very violent. The water in the river was affected as though a steamer had passed, and continued so for some time. It is rumoured that the earth is cracked and fissured in some parts of the district. The wall of the cutchery (court-house) was thrown down, and the whole edifice shaken beyond repair. The Jail wall and the hospital cracked; the church is cracked from top to bottom, and other brick buildings much shaken or destroyed. The shock was stated to have been from east to west.—(*Major Lloyd,* Deputy Commissioner.)

Gauhâti.—Colonel Davies, Chief Engineer of Assam, reported on the 22nd January that at this station the earthquake had been very severe, was felt at 5h. 15m. P.M.; the direction was north to south; the duration 45 seconds. The shock was not preceded by any rumbling noises, nor was the weather disturbed either before or after. The principal shock was followed by a slighter one ten minutes afterwards, and again by another two hours later. Several other shocks were felt during the night, and for the next two days, when the disturbances appear to have ceased. At the jail, the east and west walls have horizontal cracks, and are out of the perpendicular; wicket damaged, slight cracks in arches. The grave-yard porch shows one side of roof slipped down. The Native Infantry hospital has a bad crack owing to original faulty construction, or to settlement of wall.

The Deputy Commissioner reported that the earthquake was preceded by a loud rumbling noise compared to that of a heavily laden cart. The crows were much disturbed, flying about and cawing wildly immediately before the shock. The shock was very severe. Almost every brick building suffered more or less. The church spire badly cracked. None of the native houses in the bazaar suffered, and no loss of life was reported. The day had been warmer than usual.

Returning towards the north-west again, we find the first place from which any notice of the shock is given to be—

Goálpára.—There the shocks were severe and accompanied by loud rumbling. Several masonry buildings were slightly damaged; the motion was thought to be from north to south by one, from the south by another. Another slight shock was felt about 10 minutes after the first, and several others followed during the night. Again at 3h. 45m. A.M. on the 14th.

Jalpáiguri.—First shock felt at 4h. 55m. P.M. on the 10th. It was preceded by a loud rumbling, like that made by a railway train passing over a bridge. The oscillations continued about 50 seconds, at first smart, then decreasing, again smart, and then again the vibrations decreased. The direction as nearly as can be guessed was from north-west to south-east. A large pool of water in the bed of the river was slightly agitated, and objects, such as men and carts, coming up from the ferry appeared moving up and down. A building of bad masonry, and weakened by a former earthquake, was cracked through, but no other property was injured. Doctor Macleod reports that the sky was nearly obscured by clouds; the thermometer was two degrees higher than at the same hour on the previous day, and the wind was south-east.

Cooch Behar.—Shock occurred about 5 P.M., and lasted about four minutes, supposed to have come from the south-east.

Baxa (*Cooch Behar*).—Shock felt severely; no injury.

Mynagoree.—The earthquake occurred at 5h. 20m., and was preceded by a rumbling sound. It lasted two minutes, as timed by a watch. Two distinct shocks were felt in the direction of north-west to south-east as nearly as could be judged.

Rohimganj.—A rumbling sound, as of distant thunder, was heard at 4h. 40m., producing the impression that a storm was approaching. In an instant, before this rumbling had died away, the plain was heaved by a succession of earth-waves travelling from north-east to south-west at about the apparent rate of 4 miles an hour The undulations continued 2 minutes 10 seconds, heaving up the earth 3 or 4 inches. There was then a pause of one minute, and then a second series of undulations, similar in character but of less extent, lasting 60 seconds. After one minute and a half, a third series lasted 6 minutes. No further movements took place during the night, and no vertical shock was experienced.

Darjiling.—Shock occurred at 4h. 50m. or 4h. 55m. P.M.; house shook considerably, wood-work of roof cracked and groaned. Buildings not injured very perceptibly at Silligoree; wall of dâk bungalow cracked at Punkabari.—(*Executive Engineer,* January 15th.)

There was but little oscillation felt at Darjiling. Shock first felt at 4h. 50m. Mr. J. Müller had constructed a seismometer consisting of four pendulums, so suspended as to oscillate in the north, south, east and west planes, but it was not at all affected. If there were any undulation, it was in the line north-west and south-east. The sensation produced by the shock was that of a violent concussion rather than a subterranean movement of any kind.—(*Deputy Commissioner's report.*)

Several observers concur in the statement that the shock of 10th January 1869 was felt at Darjiling, more as a vertical concussion or blow than as an undulating or wave-like motion.

Kursiong on road to Darjiling.—The earthquake is stated to have been severely felt here; people rushed out of their houses, fearing every moment they would come down. Trees seemed to roll from side to side in the most extraordinary manner.—(*Englishman*, January 18th.)

Purneah.—At 4h. 45m. P.M., shock smart, some cracks in abutting arches in the southern verandah of church.—(*Executive Engineer.*)

Dinajpur.—Shock severe, felt at 4h. 30m. P.M. Several distinct shocks during an interval of about 3 minutes: motion apparently from west to east, with a rumbling sound like that of a heavy train in motion. Buildings not injured.—(*Executive Engineer.*)

Maldah.—Two smart shocks, about 5 o'clock accompanied by a noise like that of a heavy railway train.—(*Englishman*, January 14th.)

Bograh.—Old cracks in roofs increased slightly.—(*Executive Engineer.*)

Pubnah.—Two shocks felt. No injury to buildings.—(*Executive Engineer.*)

Dacca.—Shock at 4h. 45m. P.M., seemed to be from north to south. Some slight cracks in barrack and hospital.—(*Executive Engineer.*)

Nuddea.—Said to have been at 4h. 35m. P.M. Two sharp shocks, each about 30 or 40 seconds in duration, and at an interval of about a minute. The second was the more severe of the two, both accompanied by a loud rumbling noise; the vibrations passed from south-west to north-east. Barometer not affected. Supposes "from the motion and noise being simultaneous, from the loudness of the latter, and the regularity of the waves of vibration, that Berhampore must have been near the centre of disturbance!"—(*Executive Engineer*, January 11th.)

Meherpore, Nuddea.—The shock was keenly felt, lasting 3 minutes; the house vibrated violently, seemingly from north to south. Strange sounds are said to have been heard underground. It caused a good deal of consternation among the natives, being considered additional evidence of the famine that is to be in 1870. The writer adds :—" I am not quite sure of the time of day, as my watch had stopped, and my clock is not to be depended upon. The shock occurred about half past three." (I quote this sentence *verbatim*, to show how unreliable such casual statements of the time of occurrence are for any purposes of accurate determination. With the most perfect good faith and honesty this gentleman tells us that he had neither watch nor clock to give him information as to the time, and then without any qualification goes on to say the shock occurred at half past three.)—*Englishman, January 12th.*

Berhampore.—No great damage done; old cracks exhibited through the skin of plaster which covered them, but there are no new cracks.

Baraset, Barrackpore, Ishapore.—Shocks felt at 4-30 P.M. very marked, some arched doorways in the barracks cracked. Punkahs, hanging-lamps, &c., were put in motion, and a few light articles upset; direction from north-west to south-east, lasted 30—40 seconds.

Calcutta.—The Honourable Justice Phear noticed the direction of the wave-motion as indicated by the oscillation of the water in a tank at his house close to Calcutta, and recorded it as from south-east by east to north-west by west.

Passing still further to west and north from Calcutta, the shock was experienced at

Raniganj.—Two distinct shocks were felt between 18 and 20 minutes before 5 P.M. Shock severe, but no injury done.—(*Executive Engineer.*)

Monghyr.—Some slight injury to the jail buildings.

Patna.—Sufficiently strong to set glass-doors rattling and a book-case rocking. No sound was heard.

Hazaribagh.—The earthquake was felt, but the shocks were not violent. Doors that opened to north and south were set swinging quickly on their hinges, but not so those that opened east and west. The air previously to the earthquake was still and hazy, and the temperature was slightly higher than usual.

vore.—Very slight, between 4h. and 5h. P.M. No injury done.

Hidgellee.—Felt at 4h. 30m., appeared to come from the north-west to the south-east, and lasted 30 to 40 seconds.—(*Executive Engineer, January 11th.*)

I have not found any record of the shock being felt at sea by any of the ships in the Bay of Bengal. But on the east coast of the Bay we find it sharply felt.

Kussilong.—A correspondent of the *Englishman* (January 18th) writing from Kussilong, 90 miles from Chittagong, says:—"It burst with tremendous force. It was travelling apparently eastward and slightly north. The undulations were very severe and lasted nearly two minutes. It seemed as if some mighty wave were sweeping on under the earth, and as it passed the solid earth rose and fell with a motion distinctly visible along the banks of the river and in the hills beyond. The ground was seen to roll wave-like, the hills to reel, and the trees to wave to and fro. The spectacle was wonderful and fearful. Shock occurred at nearly 5h. 0m. P.M. on the 10th."

The shock was also felt sharply in Upper Burmah, but we have no detailed accounts of its effects.

In the preceding pages I have brought together all the notices of the results of this great earthquake which had been given by local observers and by local officers. That it was the same great shock which produced the rattling of the doors and windows at Patna, and the sharp blow-like sensation at Darjeeling as that which ruined Silchar, is, I think, abundantly established. But beyond this little else is fixed. The times, although sufficiently consentient to prove this, are of no use for any more accurate investigation as to rate of motion; while the naturally great difficulty of noting accurately the direction in which such wave oscillations occur is amply evidenced. In fact I think it will be obvious that so far as these notices go there is nothing to give a clue to the true direction in which the forces acted, to the position of the source from which those forces originated, nor as to the mode or rate of transmission of the shock. The only fact established seems to be that one and the same shock or group of shocks was experienced at slightly varying hours over an area, the extreme limits of which from north-west towards south-east must have exceeded 650 miles and in the conjugate direction of north-east to south-west of more than 400 miles, or, allowing for those districts over which the shock was felt, but from which we have no reports, an area of fully a quarter of a million of square miles, and independently of any other considerations, the immensity of this area will in itself give some index to the vastness of the forces developed.

CHAPTER II.

MORE LENGTHY NOTICES OF THE EARTHQUAKE.

In addition to these brief notices in the newspapers of the time and in the official reports of the engineers who had charge of the buildings in the stations visited by the earthquake, two or three other and more detailed statements were made public. H. Leonard, then Superintending Engineer of the division in which Cachar is located, visited Silchar and Sylhet a very short time previously to my own visit, to whom I am much indebted for having subsequently handed over to me all the information he collected, most of which is embodied in the preceding chapter. But he also made public his own impression. At a meeting of the Asiatic Society of Bengal, on the 3rd of March 1869, he stated that the reports regarding the severity of the earthquake, and especially as to its action in rupturing the earth, were considerably exaggerated, early reports were decidedly so, most people being so much surprised and alarmed by the shock and its results that they seemed to be incapacitated at the time for making anything like accurate observations and hence very great caution should be observed in accepting information as to the intensity of the shock or as to the direction of the wave. Highly exaggerated and most incorrect accounts had been received by himself on the subject.

Mr. Leonard was at first inclined to think that the point of greatest intensity was about Silchar or more to the west, but on subsequently seeing Dr. Brown's letters from Manipur, they seemed to prove that the shock had been as severe at Manipur as in Silchar. To the south of Silchar the shock seemed to have been felt less than at the station, while to the north-west again and on the road to Cherra Poonji the effects were decidedly less.

He noticed the great difficulty in deciding from observation of facts the direction of the wave. Individuals generally stated that the movement was from about the south. The church tower fell to the north, but an unfinished building of Mr. Snells, which consisted chiefly of unsupported pillars, was thrown down in all directions, the pillars really falling to all four points of the compass. Houses with the ordinary Indian flat roof all stood, while most of those with roofs which did not give support to the walls were thrown down or damaged.

The disturbances in the surface, in every case which he had seen, were caused by the slipping in of the banks of the large rivers or of old river beds, or partially filled up jheels; though he had travelled through the districts for over 150 miles, he had not seen a single case of disturbance or fracture of solid ground unaffected by rivers or jheels running through it. Many of the slips along the river banks were very extensive, in some cases being continuous for half a mile in length, from 500 to 1,500 feet in width, and the depth of the depression varied from a few feet to 30 feet. Very large quantities of sand and water were thrown up, but he considered that in every case the forcing up of the semi-liquid matter was due to the subsidence of the firm ground above.

The great majority of people said that the water thrown up was cool; a few, however, stated that it was decidedly warm; but generally the evidence went to show that it was very little, if it all, warmer than ordinary water.

Mr. Leonard has here brought forward his own careful observation on the nature of the remarkable fissurings and rupturing of the earth's surface, so well seen near Silchar, with singular force. Obviously unaware of the full bearing of the statement, he has not clearly shown that such elevations and depressions were *in every instance* only the secondary results of the earth-motion, their very existence depending on peculiar conditions of structure.

Dr. F. Stoliczka pointed out how easily this throwing up of sand and water, which had been also noticed in previous earthquakes, could be explained if there existed a distinct stratum of sand below the layer of surface clay or soil. As soon as the fissures were formed, the slightest undulating motion would shift and force up the loosened sand, the force with which it was brought to the surface depending upon the local pressure under which the sand and water stood.

Mr. H. F. Blanford noticed the contradictory nature of the reports. He was quite unable to form a correct idea as to the velocity with which the wave had travelled. In one case he was informed that the water, which came up through one of the fissures, was 9° higher in temperature than the annual mean temperature of the locality. This increase was more likely the result of chemical agencies, decomposition of organic substances, &c., than due to the great depth from which it was supposed to have come up.

At the same meeting, and in fact giving rise to the preceding verbal notices, a paper was read by Captain Godwin-Austen, who, in charge of a party of the Topographical Survey of India, was at the time of the earthquake encamped near Assaloo, in North Cachar. He notices that the shock came without the least warning, a sound or rumbling, more or less loud, being generally heard for a few seconds before. The elevation above sea-level of his camp was about 3,000 feet near the base of a range with peaks rising to 6,000 feet. He alludes to the state of the weather, and states that there was nothing unusual or peculiar about the appearance of either the sky or the weather, but notices a rapid clearing off of great haziness toward the west which had just before prevented his seeing the hills in that direction.

Captain Godwin-Austen states that the earthquake was ushered in by one or two long waves of motion, succeeded in about 20 seconds "by others much higher and following in rapid succession, followed by a great quiet rolling or heaving, without any jarring motion." All "save tremor" had disappeared in about 2½ minutes. Ten minutes intervened between this and the second well-defined shock. "The horizontal undulating motion was decidedly combined with another force, a kind of jerking from side to side; the surface not only rose and fell, but its parts seemed to shift about, each in segments."

He describes the position of his camp, on the principal northern spur of the conspicuous hill of Mahadeo (5,751 feet) in the line of the North Cachar hills, "as well as on the principal line of elevation, the whole mass being here tilted up and dipping over southward some 40° or 50°. In fact Assaloo lies on the northern flexure of the great uniclinal that runs thence towards the west, marked conspicuously by the Jatinga and Kayeng valleys, and ultimately continuous with the same great feature at the base of the Cherra Poonji Hills. It marks the great bend and break in the stratified rocks, when this mountain system was first upheaved."

He describes forcibly the swaying of the magnificent forest on the flanks of the hill "as if swept by a mighty wind," and notices a "confused din" from the ground below mingled with the noise caused by the swaying of the trees. Most people sat down, and with great difficulty he and one or two others could keep on their legs.

In speaking of the direction of the wave-motion, he notices the great difference of opinion which existed among those in camp, but says there is very little doubt that it was from west to east. "The noise and motion in the trees certainly subsided and passed off in the east." A heliotroper, who was on the top of Mahadeo, declared that he could see the mountain peaks near at hand and in the east heaving about; the noise of falling rock was very great. The effects upon these hills are very great; ravines choked with rocks and *débris*; and one party of my men out-poling found the body of a fine stag that had been killed by the falling rocks when standing by the water-course.

"On the Diyung its effect seems to have been very severe; the high steep banks of recent clay and sand gave away in many places falling into the river, the ground along the valley was much rent and the houses, structures of poles and matting, were in many instances thrown over."

The peak of Sherfaisip, also in the north Cachar range and one of its culminating points, 5,612 feet, is about 26½ miles almost due west of where Captain Godwin-Austen's camp was near Assaloo. On this peak a heliotroper was stationed, and his account is given:—"He was on the peak by himself, sitting at the station mark with his heliotrope, facing east ready in case he was required to show to Mahadeo; all was still, and he was likely to hear and notice any peculiar sound. He says that about 15 or 20 minutes before the shock, he heard the sound of a distant cannon (*tóp* was the word used) as if fired some 30 or 40 miles distant. Before the shock came on, he heard the rumbling coming from the east, and when he felt it he caught hold of the heliotrope, but that the motion was so great he was thrown backwards. He distinctly says the motion passed away towards Marangsi peak, situated west north west from his station."

I quote this paragraph in full, because this man's statement of the motion at Sherfaisip [illegible] from the east, coupled with the observation of Captain Godwin-Austen [illegible] himself at Assaloo that the motion there was from the west, is made the basis of a long discussion of the origin, locality, and direction of action of the earthquake forces. Here it is said "it is most interesting to [illegible] two well-selected points, 26 miles apart situated nearly due east and west of each other; at the first the waves were travelling eastward, at the second westward, this places the divergence of the forces between the two."

Now, if we examine the evidence on which the statement is based we shall first find that in neither case was the direction truly east or west; and in this latter case the only evidence of the force having come from the east was the impression on the man's mind that the rumbling he heard, before feeling the shock, came from the east. If we consider for a moment the exceeding difficulty of deciding correctly the point from which a sound comes, the frequent and constant reflections which any such sound wave in the atmosphere meets with, and the very numerous cases in which, even under favourable circumstances, such waves of sound appear to come up in exactly the opposite direction from that which indicates their true motion, we shall certainly hesitate to admit as evidence this belief of the man as to the direction in which the rumbling passed. But this hesitation will be strengthened into full conviction, I think, when the only real fact of observation is taken into account. The position of the man is stated to have been facing eastwards; the shock came and seizing hold of the heliotrope, he and it were thrown backwards, that is, he was thrown to the west. The shock therefore *must* really have come from the west, not from the east. It would seem to have been supposed that he was projected with the shock, but this could not have been the case. His feet were moved forward with the shock, his body remaining comparatively stationary, until the line from the centre of gravity of his body fell beyond the base of support and he fell, as is always the case with unsupported bodies, towards the point from which the wave of motion came, in this case towards the west. It is necessary to notice this here, because the fact renders it unnecessary to notice further the discussion regarding the origin of the mo[illegible]s based on this supposed divergence of the waves from a line between Assaloo and Sherfaisip. I would also notice the absence of any attempt to fix the true direction of the motion by careful observation of any fact. Very possibly no such observations were practicable, but in questions of this nature the mere statement of the wave-motion being east or west is far too lax to yield any satisfactory result, the more especially as the places of observation were in reality at a considerable distance from the seismic focus.

Captain Godwin-Austen adds some interesting speculations as to the connection between the present form of the ground, the deep gorges of the rivers, and their coincidence with some very marked geological features of contortion and disturbance; and closes his notice by a detailed statement of the several shocks noticed at Assaloo from the 10th January up to the 2nd of February. He alludes also to the effect produced on streams by this earthquake, stating that a rise was caused in them. To these observations we may have to refer again.

Captain Godwin-Austen, writing to friends in England shortly after the occurrence of the earthquake, gave some particulars, subsequently published in the proceedings of the Royal Geographical Society, Vol. XIII, p. 370. Having just gone into his tent he heard the cry outside "an earthquake! an earthquake!" and ran out. He had just got out when the ground began to rise and fall tremendously and at last became so bad that it was with difficulty he could keep his feet. Children sitting on the ground all crying, the shouting of the servants, kicking of the ponies, prevented his hearing any particular noise, save the crashing of the large forest trees near the camp; these were tossed about in the wildest way, and one very large one came down.

The motion in addition to the waves that passed by consisted of a jerking or shaking. Everything upon tables or chairs was thrown off; no two-storied or even one-storied house of brick could have stood it; here where the houses are of wood and bamboo—a mere frame—it would require a terrible earthquake indeed to throw them over. After about fifty seconds he got out the chronometer. The intensity of the shock which must have occurred about twenty seconds from the time of first shock was then passed; the last waves "very like those of a gentle swell at sea" were just passing as he noted the time. "It was a curious sight to see the way in which the waves passed over the forest-clad mountain side, as if the trees were bowed by the passage of a mighty wind." The direction of the motion was from west to east.

After noting the several shocks which occurred up to the 14th he adds:—"I shall be anxious to hear whether these earthquakes have travelled from the westward far, but possibly they may have had their origin in this range. This part of Cachar is an area of great contortion and upheaval, where we may expect a weakness in the earthy crust, and a renewal of former disturbing action."

Later on, the 1st February, he wrote, quoting from newspaper reports, that the disturbances were still going on; the earth hardly ever seems firm; a constantly recurring tremor is very perceptible, and very disagreeable. The river Barak is stated to have flowed back for an hour, and near Sylhet to have been so lessened in depth that boats now navigate with difficulty. The earth opened in many places, swallowing up trees and houses; mud and hot water were thrown out of fissures; large areas have sunk, others have been raised. Near Cachar a village has been left on a slope where a long line of low hills has been formed. (I quote the writer's own words, as an excellent instance of how greatly exaggerated, and therefore absolutely unfounded, statements, made on the merest hearsay evidence, become part of the records regarding such phenomena.) His letter then concludes:—"It will be most interesting to find out how the levels of the country have been altered. I feel certain that great changes have taken place in the peaks. I am getting together all the data," &c., &c.

We may at once state that there has not been a shadow of evidence obtained to show that any change whatever has resulted in the general levels of the country. The local breaks, fissures, slips, falls, &c., were all merely secondary results of the disturbance, and produced no effect on the general relative surface of the country. To this we shall have to refer more fully again.

The Meteorological Repoter to the Government of Bengal, Mr. H. F. Blanford, in bringing together a tabular summary of the returns received by the Government, gave a brief but very interesting sketch of the phenomena so far as the information received enabled him to do so. He discusses some of the papers noticed above, shows clearly that Captain Godwin-Austen's inference as to the line of origin and its position, although in itself not improbable, required more evidence to warrant its acceptance. He points out the remarkable discrepancies between his statements as to the direction of the motions and the general conviction in Cachar, as obtained by Mr. Leonard, and justly remarks, "A careful observation of its effects on buildings, &c., will probably enable a more satisfactory opinion to be formed as to the progression of the earth-wave." He notices how easily the direction may be supposed to be, and stated to be, directly opposite to that which actually obtained. He briefly discusses the rate of the horizontal transmission of wave, and shows that as indicated by the observation at Asaloo, taken in connection with the time of stoppage of the astronomical clocks in the Surveyor General's Office, Calcutta, this rate would appear to be vastly greater than that of any earth-wave recorded, and while showing that this was highly improbable, he adds "it must be admitted that the data on which the calculation is based are at least as trustworthy as those of any earthquake quoted by Mr. Mallet," an assertion which certainly "requires confirmation." He proceeds to notice the geographical position of Cachar in relation to the great volcanic band stretching from the Sunda Islands to the east of the Andamans.

Mr. Blanford then refers to the structure of the surface in Cachar, &c., to show that the disturbance of the ground there was due not solely to the comparatively greater violence of the shock in those districts and their proximity to the centre of the disturbance, but in part also to the geological character of the surface rocks in these tracts, and notices also the remarkable similarity of these so-called sand-craters, earth-cracks, &c., to the results produced by the great Calabrian earthquake of 1783. And he also notices the absence of any peculiarity worth notice in the state of the atmosphere at the time or just previous to the earthquake. This report was dated the 13th March 1869.

In the *Christian Intelligencer* (Calcutta), Vol. XXXIX, April 1869, there appeared the most correct and trustworthy notice of this earthquake that I can refer to. The physical reasonings are sound and just, and the whole is characterised by that full appreciation of the facts which we should have expected from so distinguished a mathematician and physicist as its author, the late Archdeacon Pratt. He came to the district in the course of a visitation of that part of the diocese, and he gives the following notice.

Several indications were seen in passing up the river of the severity of the earthquake, but nowhere are they so strong as at Silchar itself. The church was nearly completed, but now the tower is a heap of ruins lying at the north-west angle. There is a piece of brick masonry

5 feet by 7 and by 9 which belonged to the tower, and now lies in one solid mass under a tree to the north-west, unbroken and without a crack, showing how excellent the masonry was. This mass fell and completely rolled over, for there are in it the remains of the top of a small window now upside down. The position of the ruins of the church tower, *viz.*, to the north-west, shows that the shock must have came from that quarter. The base of the tower would be evidently and abruptly carried towards the south-east, and, so to speak, leave the top to itself to fall over towards the quarter from which the shock came. In fact, a gentleman who saw it fall states that he saw it lean over to the north-west, a large crack occurring on the opposite side, that the crack collapsed, and then on a second wave coming the upper part of the tower, thus previously loosened from the lower part, fell over in ruins. Pieces of the tower fell on the chancel roof and the east end of the nave roof, and broke them both through. The roof is not of an expensive kind and can be replaced at a small cost. The Archdeacon has applied to Government to repair the two roofs, clear away the ruins at the base of the tower, and build a vestry in its place. He pronounces it to be the most elegant church he has seen in Bengal, and admirably built. Its walls are solid, lofty, and well buttressed; not a crack is to be found throughout them. The roof is of bamboo thatch, supported by elegant trusses, and is very lofty. In the older burial-ground, the gate and a new marble tomb have been completely thrown down. In the new cemetery, a most picturesque spot, no damage has been done.

The most striking permanent marks which the earthquake has left of its violence, besides the church tower, are to be seen near the river where the ground on being divided by the undulation into large parallel masses separated by cracks and ravines, did not resume its position from want of pressure on the river side to carry it back. The ravines still stand open. There is a tract called the Peninsula, round three sides of which, two longer and one shorter, the river flows. Here the ground is cut up excessively in this way. The line of ravines is north-east and south-west, showing that the undulations must have moved in the north-west and south-east, or in the south-east and north-west line, as the general run of the cracks would, of course, be perpendicular to the direction in which the wave moved. The ruins of the church show that it was the former. A sight of the peninsula gives a miniature view of the effects often seen in mountainous tracts of the breaking up of the earth's crust in former epochs by whatever cause. You see a series of (so to say, mountain) ridges parallel to each other, one side in each sloping up gradually, and the other, where the fracture took place, going down abruptly, and so of each in succession. The phenomenon, too, of what is called in Geology an anticlinal line, was distinctly visible in miniature, that is, the change of direction of the slopes, as it were, on that line of fracture there had been a greater force from below than on any other. There are still numerous accumulations of the slate-coloured mud or sand which oozed up through the cracks. It is said that Professor Oldham has taken specimens to Calcutta to have them analysed.

The bazaar is the scene of great havoc; and in the fish bazaar, or *haut*, between it and the river, the surface is gone down 40 feet or more. It is expected that when the rains set in, this and other parts will be under water, which have hitherto stood clear. The earthquake occurred at a time when the fish *haut* is generally crowded with natives. But it is said that on this occasion it was singularly unfrequented, a circumstance attributed to a panic which had seized the people that they were that day to be pressed into service as coolies for an expedition against the hill tribes, of which they already seem to have seen the probability. But for this many might have been killed in the crowd, heaped upon each other by the suddenly formed precipice of 40 feet in the midst of the space.

I have now given at some length every notice of this remarkable earthquake which I am aware of. I have done so with the object of showing how little even the most detailed of these notices afford of any data on which to base accurate conclusions as to either the nature, the direction, or the force of the shocks. With the exception of the reasoning of Archdeacon Pratt from the direction of the fall of the church tower in Silchar, there is scarcely a fact noticed which gives a clue to this direction based upon any thing more than conjecture or the rudest observation. Even the few facts which have been stated have led to erroneous conclusions, as it appears to us (the fall of the heliotroper in Sherfaisip for example), and when conclusions have been attempted to be drawn as to the rate of motion, the two entirely distinct and separate motions of the wave itself in translation, and of the particles of the mass affected by this wave, have been confounded.

One thing, however, remains clearly established, that a very serious shock or shocks did pass through the area; and that these were sufficient to destroy, or partially to injure, the most permanent buildings in parts of the area affected, and did result in certain very marked and serious disturbances of the surface of the earth. It was then the task set before me to see how far from these results it would be possible to reason back to the nature, position of origin, and force of this great wave or waves.

CHAPTER III.

THE EARTH FISSURES AND SAND CRATERS AND THEIR ORIGIN.

By far the most remarkable result known of this earthquake was the production of great fissures in the surface of the country, and the sinking of the ground over a very large area. This phenomenon was not confined to any special locality, but has been found to extend for many miles, showing a varying degree of intensity.

Almost immediately on entering the Soorma River the fissures in the banks became noticeable, and they gradually increased in intensity in proceeding up the river. These fissures were entirely confined to the newer alluvial deposits, what are called by the people of the district the *bhurti* lands, or 'filled in' lands; no trace of them being visible in the *kandy*, or old lands of the river valley, except indeed at the junction of the two where small portions of the latter in one or two places seem to have fallen in on the support of the others being removed. In every one of the many curves which the Soorma and Barak make below Cachar, and for scores of miles, these fissures might be observed, greatest near the river bank, but extending for miles across those peninsula-like extensions of the river flats, which have been formed by the river as it gradually worked further and further away from its original course.

In passing up to Silchar from Naraingunge, the effects of the earthquake became noticeable almost as soon as the steamer entered the defined channel of the Soorma River; there the high grassy banks, which formed either side of the river, were in many places cracked in long continuous and slightly open fissures, from which the lower portion had slipped down, not far but sufficiently to produce a marked, though slight, scarp in the bank. These cracks were seen along every reach of the river, notably along such as ran north and south or approximately so, and increased in intensity and number steadily as we progressed in the very winding and ever changing course of the stream towards the east. At Chattuck the steamer stopped, and there being no sufficient water for steamers higher up than this, I took to small country-boats. This enabled me to watch the effects more fully than I could otherwise have done, by getting out every day and following up the banks as the boat proceeded. Some of the long north and south reaches of the river afforded most remarkable instances of these winding fissures and dislocations of the banks, continuous cracks stretching away for more than half a mile, often 2 feet or more in width, open for depths of 8 feet, but they had all been partially closed by the falling in of the sides. These in places produced steps or irregular terraces along the sides of the banks, often marked by the disturbance which affected the scattered trees which had been growing on the sides and which had of course sunk with the earth in which their roots were imbedded. About here I could find no other injury that was done; the trees were said to have swayed visibly, some few came down, and the people were much alarmed; but beyond this little more,—they all ran out of their houses and of course cried at the tops of their voices, so that it was not likely that they would have heard any distinct noise which may have occurred. One rather more intelligent than the rest describes himself as being alone, away from the village and other people; he was nearly thrown down, but was just able to preserve his balance; he described a wave as coming up from the east before or almost accompanying the shock, which he described as marked with successive noises *ooom moom moom* like the roaring of an enraged bull. He was on the high bank of the river, and saw the earth open before his eyes in three long fissures and suddenly sink down for 5 or 6 feet, and asserted that this occurred with the first great shock, after which the second only led to a greater settlement of the disturbed mass, but to no more actual fissuring. Even in the high flat top of the bank, all cultivated ground, fissures could be traced within 100 yards from the edge of the bank. Hitherto I had seen nothing to account for this fissuring, but that the banks of the river were unsupported at the time in consequence of the river being at low water-level; all the fissures arranged themselves roughly parallel to the course of the stream and bent round with its course though they were not so visible when that course went in a direction approximately east and west, and it was clear that the true reading of the enigma was that the bank having been supported on the one side and unsupported on the other had given way when the wave or shock came. But as I advanced up the stream, and the bed of the river became more sharply cut into the mass of clay and sand on either hand, the cause of all this disturbance became evident enough.

Probably the point, in the river, at which these disturbances became most marked was just where the river divides into the Soorma, which flows down to Sylhet and the Barak or Koosteara, which keeps on to the south, and after winding in long sweeping curves through the flats of Sylhet enters the Brahmapootra. The stream here curves round nearly

at a right angle, in the winding course of which the Barák leaves it; the banks just at the point of junction are bold and lofty, while in general below the end of the Barák River they are lower, as is also the ground on the east of the curve. Here the left bank of the river had been shaken down, forming an almost precipitous face of more than forty feet in height, while the ground round the curve had also been separated and had slipped into the river in two rather long slices; the strong current sweeping along and against the left bank had, before I reached the place two months after the shock, removed the greater part of the fallen mass, but the portions which had fallen formed two small ridges, a few points of which were still above water, and on which the current was beating, with channels between. These great masses of fallen matter in the bed of the river had produced strong eddies and whirling currents, and it was with the greatest difficulty that the boatmen after a good deal of exertion, and only by getting out towing lines, succeeded in passing the boat up in safety.

Here for the first time the immediate cause of all this ruin became evident. Just at the water-level, and under a thickness of more than 40 feet of varying clays and sandy clays, was seen a band of soft and slimy, peaty stuff charged with ferruginous water, which oozed out on the edge of the cliff; this rested on, and was in fact mixed up with, a layer of fine arenaceous sand, which when wet and saturated with this black slimy water is dark coloured and nearly black, but which on drying became of a light blue colour; the whole bed is but little more than 3 feet thick. That the easy and unequal yielding of this soft slimy mass under the pressure of the heavy beds of clay above was really the source of the mischief, was very evident, because under this the recurring stiff clays formed a regular shelf sloping down to the water, but perfectly sound in places where the slips had been developed in the most marked way. In one or two small patches, before going thus far, I had been able to trace the existence of some such bed as this, and in other places the occurrence of a deposit of this light-bluish sand in the cheeks of some of the cracks had led me to other, and so long as the motion was sufficient to produce a separation of the mass by cracks at all, these cracks or fissures must have followed the line of least resistance and must therefore necessarily have been nearly parallel to the face of the bank. Though from this cause the direction of fissuring varied from north and south to nearly east and west, it was here evident that the main lines of motion must have been in some line between east and north, or even, to note it more particularly, between north-east and north.

* * * * * *

One conclusion pointed out in the foregoing pages cannot be too strongly insisted on, and even at the risk of wearisome repetition, I will say that nothing is so conclusively shown, or so certain, as that these great earth-fissures and cracks were in every case purely secondary results of the earthquake shock; there being no reason to suppose that an earthquake shock can, but on the contrary every reason to suppose that it cannot in any case, by its direct action, open fissures in solid rock or clay.[1]

In order to make the mechanism of the formation of these fissures clear, I will first take the case in which the beds overlying the soft yielding stratum, already mentioned, may be supposed to be perfectly homogeneous, and the direction of the wave-path in azimuth, normal to that of the river bank. As the wave passes on its way, the particles of clay are forced, first forwards and upwards, and then return backwards and downwards to their original position; but as the vertical movement takes but little part in producing these earth-fissures, we may for the moment neglect it and only consider the effects of the horizontal motion impressed on the particles of clay. We may take it then that the belt in which the particles of clay are in motion at any one moment, under the influence of the earth-wave, is divided into two equal or nearly equal zones, in the first of which the particles are in motion forwards while in the other they are moving back; and as the

[1] For a discussion of this same point, Refer Quart Journal Geological Society, London, Vol. XXVIII, p. 255, 1872.

motion in each case is away from a median plane, the momentum of the two zones, acting in opposite directions, tends to rupture the mass along that plane. But the action of this momentum is modified and restricted by three distinct causes: firstly, the molecular cohesion of the clay; secondly, the inertia of the motionless masses of clay in front of and behind the zones of motion; and thirdly, by friction on the sandy bed below. As long as the wave is at some considerable distance from the river's bank, the resistance offered by cohesion and inertia is sufficient to restrain the force of momentum and prevent the formation of fissures; but as the wave approaches the bank, the force of momentum remains, up to a certain point, unaltered, and of the various resistances, that of cohesion remains constant, that of friction may be neglected for though varying somewhat, it is always comparatively insignificant, but the inertia of the mass of motionless clays between the front of the anterior zone of motion and the river's bank diminishes as the wave approaches the latter, until at last it disappears just as the front of the wave reaches the river's bank; at this instant the momentum of the zone of forward motion is undiminished, the resistance of inertia has disappeared, and it is only resisted by cohesion and friction. As soon, however, as this critical moment has passed, the momentum begins to diminish as the motion of the wave particles is dissipated at the surface of the river's bank, and the strain rapidly diminishes till, when the central plane of no motion reaches the bank, it vanishes entirely; after this, as the momentum of the second or hindermost zone is away from the river, there is no tensional strain, and no tendency to fissure.

By consideration of the above remarks two conclusions are evident: firstly, that fissures will only be formed along the plane of separation between the two zones, and secondly, that the strain tending to produce rupture is greatest at what I have called the 'critical moment,' at which moment the plane of separation, in which the particles have attained their maximum forward excursion, or in other words the 'crest' of the wave, is distant from the river's bank by the thickness of one of the zones of motion or one-half the whole 'length' of the wave.

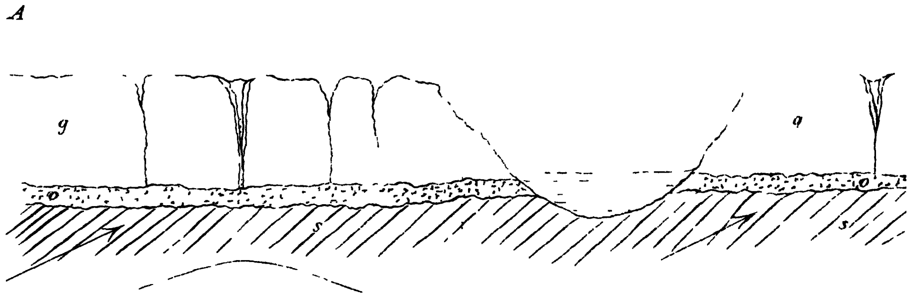
If the force of momentum be only just sufficient to overcome the resistances of cohesion and friction, only one fissure will be formed, and that at the critical moment and at a distance of one-half the length of the wave from the river's edge; but if the momentum of the zone of motion towards the bank be more than sufficient to overcome these two resistances, it will be able to overcome the inertia of a certain mass of clay in addition, or else it may suffer a greater or less reduction before it ceases to have the power of overcoming them, and in that case fissures will be formed both nearer to and farther from the river's bank than the main fissure or fissures, which will always lie at one-half the whole length of the wave from the river's edge.

As the wave passes on its way, the motion of the particles is extinguished by the breach of continuity caused by the river bed; but though the motion is thus extinguished in the superficial stratum of clay, the impulse, being of deep-seated origin, passes under the bed of the river and emerges on the opposite bank, where motion is once more communicated to the superficial stratum, and the train of phenomena is just the reverse of what happened as the wave approached the river. At first the motion of the particles is away from the river, and consequently there is no tendency to fracture in the mass; but as the wave progresses, the particles of clay begin to move backwards, and a strain is set up, as when the wave approached the river, which gradually augments till it reaches its maximum as the rear of the wave just reaches the river's edge, the critical moment in this case, and then diminishes. The same reasoning and considerations which applied to the case of the wave approaching the river apply to that of its passing away from the river, the position of the main and secondary cracks being in every way similar.[1]

The explanation given above may perhaps be rendered more intelligible by a reference to Pl. VI, fig. 1, taken from the Quarterly Journal of the

[1] Though this is qualitatively it is not quantitatively true, the upper stratum not being able to take up immediately the whole motion impressed on the lower clays, owing to the intervention of the soft yielding bed of sand, and it is the vertical motion—that which has least effect in producing these fissures—which would be most rapidly acquired.

Cf. remarks on angle of emergence and velocity of wave particle at Silchar, pp. 68, 71.



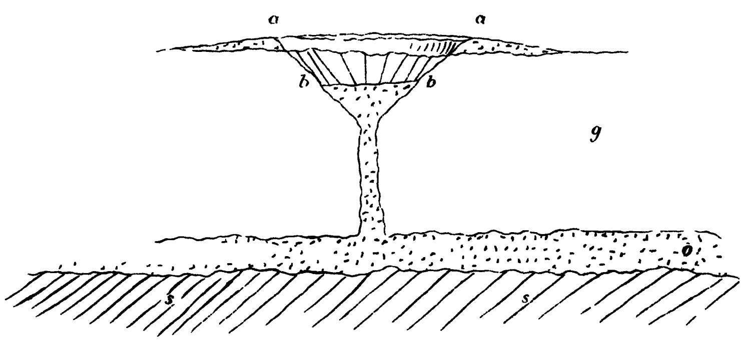


Fig 2 Diagrammatic section of a sand crater

Geological Society, Vol. XXVIII, p. 264; in it *s s* represent the lower strata of clay, *o o* represent the bed of sandy ooze lying on them, and on it lie the upper clays *g g*, in which the fissures were formed and through which the river bed is cut, the arrows serving to denote the direction of wave path. The line *e f* is meant to represent the length of the wave, while the ordinates of the curve *e c f* show graphically the relative amounts of motion of the particles from their normal positions, in the various phases of the wave, starting from zero at *e* gradually reaching the maximum at *c* and then diminishing to zero at *f*; in the semiphase represented by *f c*, which is the first semiphase, the particles are all in motion forwards, while in the semiphase *c e* the motion of the particles is backwards, in both cases away from *c*, at which point the particles are momentarily at rest, and which represents the 'crest' of the wave, along which the fissures are always formed. In the figure the wave is supposed to have reached that point at which the internal strain is greatest and the resistance least, here the front of the wave has just reached the river bank at *b* and the 'crest' of the wave is at *a* distant from the river's edge just half the length of the wave.

As yet we have only considered the hypothetical case in which the clays are perfectly homogenous and the direction of the wave-path is normal to the river bank; but as this can never be the case in nature, the fissures can never form mathematically straight lines normal to the wave-path, but will vary indefinitely from them. The first and foremost cause of this variation is of course that want of homogeneity which must be found in the clays forming the banks, in consequence of which the fissures will be formed along planes of weakness which need not be coincident with what would have been the planes of fissuring in a perfectly homogenous mass, thus giving rise to the irregularity and often branching or inosculation of the cracks as found in nature. Again if the wave course is not normal to the course of the river, the fissures will not be formed normal to the wave-path, but will tend to arrange themselves more or less parallel to the river course, and in this case any want of homogeneity in the clays will cause an irregularity in the fissures as great or even greater than where the wave is normal to the river banks.

The effects above described are produced almost, or quite, entirely by the mere throwing off of masses of clay, and the influence of those resistances tending to restrain the motion of the independent masses of clay have not been considered, except so far as they offer a resistance to actual rupture. We may assume that the effect of the momentum impressed on the clay is the same as that of a single force, equal to it in intensity, and acting at the centre of gravity of the detached mass, in the direction of the wave-path; if then the resultant of all the resistances passes through this same point, the centre of gravity, the mass will be thrown off without any tendency to overturning and the surface of the detached portion will retain its horizontality; but if, on the other hand, this resultant does not pass through the centre of gravity a dynamic couple will be set up tending to overturn the mass, the amount of overthrow being determined by the moment of the couple and the resistance of the contiguous masses of clay against which it may be thrown. To this cause, combined with the actual fissuring of the ground, the wildly broken and chaotic appearance, so strikingly shown in Pl. II fig. 2 and V, fig. 2, is due, which on examination is seen to be entirely owing to the fact that each separate portion of clay is more or less overturned on its base.

Having thus disposed of the earth-fissures, we may now turn to another very remarkable feature, likewise a mere secondary effect of the earthquake, and, like the above-mentioned fissures, due to the existence of a soft waterlogged stratum underlying a thick series of impermeable clays, and like them never found where this soft stratum does not occur, though not always found when it is present. The feature referred to is the production of the so-called 'volcanic mud craters,' about which there is nothing volcanic, being produced entirely by the washing down of soil by water, previously forced up by the earthquake shock, and which after the passage of the shock once more recedes. The action by which the water is forced up is two-fold. In the first place there is set up in the soft yielding bed of ooze a molecular motion precisely similar to that of the clays above and below, in virtue of which there are established two zones whose momentum drives them in opposite directions; and as the ooze is comparatively free to yield to any strain set up in it, the water contained in the bed, both in front of and immediately behind the wave will be subjected to an augmentation of pressure, and so the flow of a natural spring is increased, or in the case of an artificial well the level of the water rises and may even, if the water stands near the surface, rise above the level of the ground and overflow. But though this undoubtedly does take place to some extent, it may be, and in this case was, masked and eclipsed by a far more powerful action yet to be described. As the wave travels along, the lower clays are rapidly pressed upwards, and neglecting the horizontal component as not producing any effect in this case, the thrust is conveyed through the semi-liquid ooze to the mass of clays above, whose inertia prevents their rising at once, and so a sudden and tremendous pressure is brought to bear on the water-logged ooze; at the same or almost the same instant cracks are opened in the superincumbent mass of clays, and through these cracks the water is immediately forced out if the pressure is sufficient. But such a large quantity of semi-liquid matter, when once in motion, possesses a very considerable momentum and therefore cannot be suddenly brought to rest; so that, though the pressure due to the passage of the shock is but transient, the effects endure after it has passed away, the water still continues to rise in the fissure, and if it rises high enough will pour out on the surface. Further if, while the fissure is still full of water, the effect, whether primary or secondary, of the earthquake causes its sides to approach each other they will exert a pressure on the water contained in the fissure quite independent of that on the water-bearing bed, and thus the water will be forced to rise and overflow to a still greater extent. It can easily be understood that if the water-bearing stratum was impregnated with decomposing organic matter, this opening of connection with the surface, and forcing up of liquid matter, might be accompanied by the evolution of large quantities of gas which carrying with it spray and dust might, viewed through the light of a vivid imagination, produce all those appearances of fire, smoke, and sulphurous vapours which have been so often and so graphically described.

All these causes above described, however active and however powerful, are essentially transient, and soon the normal pressure is re-established in the water-bearing stratum; the water which has been forced up immediately begins to rush back, carrying with it the edges of the fissure at which it escaped, and ultimately leaving a funnel-shaped opening, either single or grouped with others, which is in fact the so-called 'crater.'

In the case of this shock the matter forced up was not pure water, but water charged with sand, a circumstance which has produced some important modifications in the aspect of these openings. Instead of the crack or opening through which the sand and water rose being left comparatively open or only choked by the debris of its sides, as soon as the current began to slacken there was deposited in and around its mouth a quantity of sand which has modified, and to a great extent reduced, the action of the water in rushing back again; the sharply washed and furrowed aspect produced by the water is only visible near the top of the aperture where the sand has been washed down, while the bottom, instead of narrowing down almost to a point, is broad and nearly flat, though slightly hollowed; this feature being produced by the filling up of the fissure with sand, through which the water filtered back as through a filter bed. The nature of these craters is shown in pl. VI fig. 2; *a a* represents the raised rim of sand, sloping gradually outwards, which is deposited round the mouth; from *a* to *b* represents that portion whose aspect is due mainly to the wash and scour of the water rushing downwards, and which is at most merely coated with a film of sand; the strong lines from *a* to *b* are continued downwards to show what would probably have been the form, had there been no sand forced up, while the slightly curved line connecting *b b* is the cross section of the actual base as found; below is the column of sand through which the water was returned to the bed *o o*.

The various appearances presented by these so-called craters, due to their combination in various ways, are well shown in the photograph [1] Frontispiece and Plates XI to XIII, which are reduced from those taken on the spot by Mr. Pearson of Silchar. The simplest case is shown in the Frontispiece; here there is a single, nearly round crater, the sloping bank of sand surrounding it is very distinct, and in it to the right of the picture a breach will be noticed; within this come the steep water-washed sides of the hollow, losing themselves in the nearly flat but slightly concave floor of sand, which has cracked in drying; in the same plate there are shown some other simple pits, one of which, it will be noticed, is surrounded by a very marked rim of sand. It is impossible to look at this photograph and the figures of the round ponds produced by the Calabrian earthquake of 1783, as given by Lyell in his Principles of Geology, without being struck by their resemblance; in fact, only fill the hollows at Cachar with water and the two are identical. This filling with water may be due to either of two causes, either the water may not completely drain out of the hollows, or it may do so leaving a more or less water-tight floor on which rain water could collect. The phenomena represented in Plate XI are rather more complicated, two 'craters' having run together and produced an irregular hollow. In Plate XII it will be seen that a number of vents have been formed, evidently along a line of fissure, and have more or less coalesced; while Plate XIII shows no distinct vents; but the sand and water has been forced out from a continuous open fissure, and this further shows the form of sides which is formed by the sand deposited from the ejected matter, there being only here and there any traces of those appearances produced by the washing down of soil by water, the whole presenting a much smoother and more rounded appearance than is the case in any of the other views.

[1] The vertical cliffs seen in these photographs represent one side of the fissure through which the sand &c., was forced up, the other having sunk; they are only 1 or 2 feet high.

In the foregoing pages I have endeavoured to show that, though these apparently vast and striking phenomena are in a certain sense due to the earthquake, they are equally due to the presence of a bed of oozy sand overlaid by a thick bed of clayey alluvium; the one being as important a cause as the other, but neither capable of producing the known results without the intervention of the other. Vast, however, as these effects appear, they are in reality insignificant, mere scratches in the paint of the earth in whose history they will leave no permanent record. Hundreds of acres of land may be broken up, thousands of tons of earth may be precipitated into the river, and for days and weeks, or even months, the stream may boil and foam through the wreck, carrying ton after ton of earth away in its turbid stream, but only to be deposited once more lower down, or even in its ultimate destination, the sea. Time, however, will put an end to all this disturbance; soon the river course will be cleared and once more the river will flow as placidly as ever; wind and rain will break down the sharp edges of the overturned masses, will fill up the cracks and holes, and in a few years at most the surface will be as smooth and as luxuriantly clad with vegetation as ever it was before the catastrophe. Indeed, so far from wondering at the wreck and ruin caused by this earthquake, we should rather wonder that no traditions exist of similar ruin produced by former earthquakes; for we know that before now earthquakes at least as violent have originated from the same region; and as the other determining cause, the existence of a soft yielding bed, has always been present, it is wonderful that we should have no record of such a striking phenomenon as would assuredly have been exhibited.

CHAPTER IV.

THE POSITION AND EXTENT OF THE SEISMIC VERTICAL.

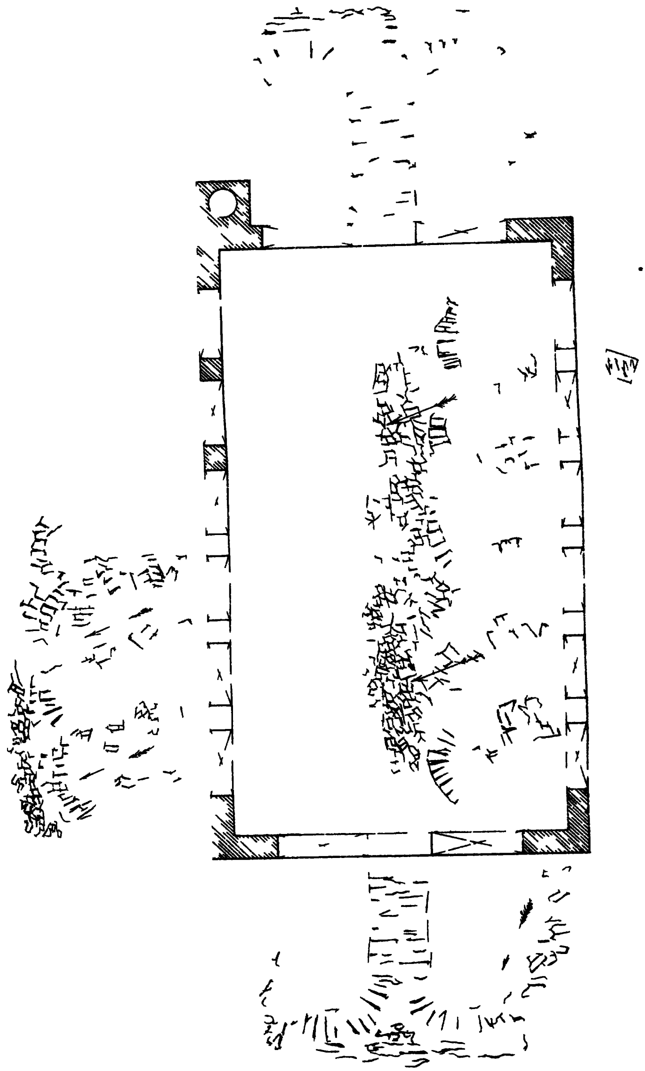
The determination of the actual position of the seismic vertical, or that portion of the earth's surface over which the shock had a vertical emergence, is not in itself of great importance; yet, as a knowledge of its position is necessary for the determination of the depth of the focus and other points of great interest, it becomes a matter of much importance that we should be able to fix its position with accuracy.

In the case of this earthquake we cannot, unfortunately, obtain such a large number of observations mutually confirming each other, as was the case in the great Neapolitan earthquake of 1857, which has been so ably described by Mr. Mallet; but when we consider the circumstances of the case, it is not surprising that the number of trustworthy observations is so few. In the first place, there was not the same number of towns with their concomitants of numerous buildings whose injuries would point out the direction of wave-path. The native huts being wretchedly built, and mostly of mats, could give no evidence at all, and the masonry or brickwork buildings, which could give any indications of value, were few and far between. Then, again, the disturbed state of the country, which allowed of but a small portion of the seismic area being visited, combined with the fact that at the point nearest to the seismic vertical which could be visited, it was nearly 50 miles distant;—all tend to diminish both the quantity and the quality of the evidence obtainable.

But as no one now doubts that an earthquake is a wave of elastic compression originating in a definite region, and spreading from it through the crust of the earth, we no longer require a great weight of evidence to prove the existence of a seismic focus and a seismic vertical; and consequently the few observations obtainable, which certainly agree very well with each other, will be sufficient for the present purpose.

Before tabulating the observations and pointing out the position of the seismic vertical, I shall discuss some of the observations which have as yet been only casually noticed or omitted altogether.

In the first place, I shall take the sawmill at Kochela, a sketch plan of which is given on Pl. VII; at the first glance it would seem as if the direction here had been N. 40° E., being the direction in which the piers of the side walls have been thrown. A comparison of this with the observations at other places, and a more careful inspection of the plan itself, throw much doubt on this conclusion. In the first place if the direction of wave-path had made so obtuse an angle with that of the end walls it is difficult to believe that they would have fallen so directly outwards without the slightest obliquity; but if we imagine the shock to have come from the north, or slightly west of north, a direction which would accord with the observations elsewhere, this difficulty disappears, and further the apparent anomaly of a very instable body being overthrown towards a point from whence the shock could not possibly have come is explained. Supposing the direction of emergence of the wave to have been from the north, it would make an angle of about 30° with the direction of the side walls; this would, of course, tend to make the walls rock in a north and south direction, while their shape and position would cause them to rock easiest east-north-east and west-south-west, the actual direction in which they swung being compounded of these two motions; the obliquity of the shock prevented its overthrowing the walls during the first semiphase but if the wave-period corresponded at all with the period of vibration of the wall as an inverted pendulum, its swing would be increased during the second semiphase; and this, combined with the already weakened state of the wall, would throw it over beyond possibility of recovery; the diagonal swing induced by the action of the earthquake-wave would have loosened the bricks, and so the fact is accounted for that the bricks of the side walls were all separated while those of the end walls still adhered to each other, though the wall as a mass was fractured in its fall. The end walls being much nearer normal to the direction of the shock were overthrown with greater facility, though there is no evident reason for their being thrown in opposite directions, and not both towards the same point; this was probably due to the presence of the chimney stack at the north-wetsern corner; this stood firmer than the unsupported north-eastern corner and so during the first semiphase the north wall was, as it were, stretched, and so, being to a certain extent deprived of support, was overthrown easier than the south wall where both ends swinging over equally it was more fully supported, and then, gaining impetus during the second semiphase, was precipitated outwards. These considerations show that much



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importance cannot be attached to any deductions drawn from this building, which I have noticed here chiefly because of its being a curious instance of how misleading what is apparently the clearest evidence may be.

From Sylhet I have drawings of cracks in the church tower, which give a direction of wave-path between N. 26° E. and N. 35° E., the true direction being probably N. 30° E. though the rocking of the tower might produce a difference between the true and the apparent direction of the emergence.

At Yeddo some chimneys were overthrown in a direction N. 30° E., and though their shape may to a slight degree have modified the direction of their fall, it could not introduce any very grave error. The cracks in the native hospital seem to give a much more easterly direction, as much as N. 60° E., but fissures are a much less trustworthy source of information than the overthrow of simple bodies.

At Silchar the direction as given by different bodies varies from N. 12° 30′ E. to N. 12° W.; the latter is that given by the verandah pillars of the native hospital, and is very probably modified by the effects of the heavy thatched roof; but at the same time it must be borne in mind that the same structure of the ground which gives rise to the formation of earth fissures will also to a certain extent modify the direction of the wave-path in the neighbourhood of the river.

Proceeding to the actual determination of the position of the seismic vertical, the first step will be to tabulate the direction of wave-path as observed at the various stations.

CLASS I.

Silchar—		
Mr. Stewart's tomb	...	N. 12° 30′ E.
Mr. Hunter's tomb	...	N. 3° 20′ E.
Infantry hospital	...	N. 6° W.
	to	N. 10° W.
Church tower	...	N. 12° W.
Sylhet—		
Church tower	...	N. 26° E.
		N. 35° E.
	Mean	N. 30° E.

Yeddo (the cantonment east of Shillong)—					
Chimneys overthrown ..	...	...	N. 30°		E.
Native hospital, cracks		...	...	N. 63°	E.
Gauháti[1] ...	...	...	...	E. 12°	S.
				E. 17°	S.
			Mean	E 14° 30′	S.
	Class II.				
Barrackpore ..	...	...	...	N. 45°	E.
Calcutta ...	...	...	...	N. 56°	E.
Sylhet ...	...	...	...	N. 22° 30′	E.
Supakatti ..	...	...	...	S. 5°	W.

In the above table I have divided the observations into two classes; the first class contains those *which were taken after* the passage of the earthquake and deduced from its effects in fracturing or overthrowing solid objects; the second class contains those observations made at the time of the earthquake, and which may be called observations proper as opposed to mere impressions.

On the map No. 1 I have plotted all the observations of the first class in firm lines, and it will be seen that the intersections of the lines, each of which should theoretically fall on some point of the seismic vertical, all or almost all fall close to each other and are spread over an area 40 miles long by 4 or 5 broad; and if we exclude the extremes given by the Sylhet church tower, the direction given by the cracks in the hospital at Yeddo and the directions obtained at Silchar, the intersections are all included in an area 20 miles long by about 3 or 4 miles broad.

Among the observations of the second class, which are plotted in broken lines, that from Barrackpore stands first; it was obtained from the swinging of a chandelier set in motion by the shock. As far as value goes this might well rank in the first class, and it is pleasant to find that a line drawn in the direction indicated falls in the midst of the intersections obtained from the first class.[2]

[1] I do not know the source of these observations, merely a note that such were the directions obtained, the original drawings and description having been lost or mislaid.

[2] This must to a certain extent be regarded as due to chance, for at the great distance of Barrackpore from the seismic vertical an error of a single degree in the observation would make a great difference, and the fact that it is plotted on a map and not on globe would also cause some difference in the true position of its intersection with the other lines.

From Calcutta we have one observation made on the direction of oscillation of the water in a tank; in an observation of this kind accuracy is not so attainable as in the more simple case of a pendulum, such as the chandelier above mentioned, and consequently it is not surprising that the direction given falls some way from the seismic vertical as already defined.

At Sylhet the direction was noted in which the trees were set swinging, and this, when plotted, also falls among the intersections of the first class.

At Supakatti the observation of S. 5° W. evidently does not point towards the seismic vertical; but we must not hastily conclude that this is altogether due to error of judgment, it being possible that the wave was reflected from the eastern portion of the Naga hills, which would give it a nearly north and south direction.

Thus we see that of the observations of the second class two agree well with those of the first class, one fairly well, and one is altogether at variance with them.

To sum up, then, there are 30 intersections of the first class and 6 of the second, in all 36, falling on an area 40 miles long by 4 or 5 broad; but of these it will be advisable to omit those obtained from the hospital at Yeddo and those from Cachar, where the direction seems to have been more or less modified by the proximity of the river banks. The intersections are comprised in an area about 3 or 4 miles broad and from 20 to 30 miles long, running approximately E. 15° N. and W. 15° S., situated in north latitude 26° and east longitude 92° 40″, lying on the northern borders of the Jaintia Hills.

The shock, we may conclude from this, probably originated in a fissure about 20 miles long running underneath the tract mentioned in the last paragraph and at a considerable depth below the surface.

Such is the direct evidence on this point. As regards the *position* of the seismic vertical, it is indeed satisfactory; but as to the shape of the seismic focus, *it is incompatible with that obtained from other sources.* As the discussion of this point will necessitate reference to *matters as* yet unmentioned, I shall defer it to another page.

CHAPTER V.

OF THE DEPTH OF THE SEISMIC FOCUS.

As the determination of the depth of the seismic focus, or in other words the depth at which the shock originated, is of great, and indeed primary, importance in the study of seismology, it is to be regretted that the data from which this point can be determined are of the scantiest, a fact which, as will presently be seen, is the more to be regretted since there is great reason for believing that the seismic focus was situated at an *exceptionally great distance* below the surface.

On account of this small number of trustworthy indications of the angle of emergence, it has been deemed advisable to describe and discuss the observations in a separate chapter, and not in the general description under the heads of the places at which they were obtained.

We will begin by considering the indications at Yeddo, as it is nearest to the seismic vertical, and because there the evidence is most complete and satisfactory. At this station the native hospital, magazine, and several bungalows were more or less severely cracked. The cracks in the native hospital building give an angle of emergence of 38°, but in one of the bungalows this is as low as 30°, the mean emergence being 34° at this station. These observations are quite the best that are accessible, and may be said to be good, as the buildings were well suited for seismometric purposes, and as there does not seem to have been any disturbing element which would augment or decrease the obliquity of emergence at this place.

The distance of the station of Yeddo from the seismic vertical being 46 miles by applying the formula—

$$D = C \tan E.$$

(where D is the depth of focus, C the distance from the seismic vertical, and E the angle of emergence), we obtain the depth of the seismic focus—

for an emergence of 38°

$$D = 35{\cdot}9 \text{ miles.}$$

for an emergence of 30°

$$D = 26{\cdot}5 \text{ miles.}$$

and for the mean value 34°

$$D = 31 \text{ miles.}$$

At Shillong the only building of which I have any drawings or notes is the magazine, which, like that at Yeddo, is a small rectangular building with a low-crowned roof and a sort of porch or ante-room attached, the buildings were unsuited for seismometry, and give no indications of any value.

At Teriaghat, a small village at the foot of the hills on the way up to Cherrapoonjee, the dâk bungalow was cracked; it is a small four-roomed building of rubble masonry, and the cracks show an angle of emergence of about 30°, which would give a depth of focus of 42·7 miles.

At Sylhet the church tower was cracked severely, and from the cracks the angle of emergence is deduced as 38°, which would give a depth of focus of 68 miles; this, however, is manifestly far too great, the obliquity of the cracks having been increased by the form of the tower, which would swing as an inverted pendulum and so alter the direction of the cracks considerably.

From Asalu and Kochela sketches of cracked and overthrown buildings have been communicated by Major Godwin-Austen. That from Asalu is of a guard-house severely cracked, but the cracks are evidently chiefly due to, or certainly very much modified by, the push of the heavy thatched roof of the building; while at Kochela the building, a disused sawmill, was almost completely overthrown, and the small portions left standing do not give any indication of the angle of emergence, though they seem to show that it was small.

Before proceeding to the discussion of the data at the remaining station, Silchar, it will be advisable to sum up what has been said so far. As will have been noticed, there are but two stations from which observations of any value have been obtained, but as the results obtained at these two stations confirm each other, their accuracy is certainly probable, though a greater number of observations would have been desirable. The altitudes of these two stations above the level of the sea I have not been able to obtain with accuracy, but they are Yeddo and Teriaghat, about ·7 and ·25 of a mile respectively. Reducing the observations to a common datum line, we obtain the following depths of focus:—

Yeddo—Max.	35·2 miles.
Min.	25·8
Mean	30 5
from mean emergence	30·3
Teriaghat	42·7

There is, it will be observed, a considerable discrepancy between the observations at Yeddo and Teriaghat; but the distance of the latter place from the seismic vertical would cause any slight error of determination to be greatly magnified. The observations from Yeddo do not I am inclined to think, give too great a depth of focus, notwithstanding that, if true, the depth in the case of this great earthquake exceeds that of any other which has as yet been investigated. Yet when we consider the vast extent of country over which it was felt, the great depth of focus ceases to be astonishing; for to effect this, not only is a high velocity of wave-particle required, but the focus must also be situated at a considerable depth; for the greater the velocity of wave-particle, the further, *cæteris paribus*, will the wave be propagated; while if the depth of focus be not great, the angle of emergence soon becomes nearly horizontal, and so every inequality of the surface of the ground tends rapidly to extinguish the shock. There are therefore good grounds for declaring that in the case of this earthquake the mean depth of focus was not less than 25 miles, but more probably about 30 miles, and may have been as much as 35 miles.

At Silchar, the evidence as to the angle of emergence is conflicting and untrustworthy,—untrustworthy, as what it gives is not the angle of emergence for that district, but merely an angle of emergence differing from the true one on account of the peculiar situation of that town.

The first evidence I shall produce is that given by the Police guard a small two-roomed rectangular building shown in Pl. VIII. The walls of this building bear N. 5°E., so that the shock was a subnormal one and the angle of emergence, as given by the cracks, is evidently not far from 45°. Now, as Silchar is more than 80 miles from the seismic verti-

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cal, this would give a depth of focus of not less than 80 miles, a result not only absurd in itself, but so totally different from that given by trustworthy evidence elsewhere, that it cannot be the true angle of emergence due to the distance from the seismic vertical. What then causes this high angle of emergence?

It will be remembered that in the neighbourhood of Silchar, as elsewhere, where fissures were formed, there was, at about the level of the river, a thin bed of soft slimy ooze, on which lay a mass of clays about 30 or 40 feet thick. Now when the earthquake-wave travelling from the north, came to the river, all motion in the superficial stratum was extinguished, and the shock was propagated through the deeper lying clays under the river bed; but when the river was passed and the wave once more emerged at the surface of the ground, motion had to be transmitted to the upper beds through this layer of ooze. As, however, the clays possessed considerable inertia, and as the ooze could oppose but a comparatively small resistance to change of shape, the full amount of motion could not be transmitted at once, and so the velocity of wave-particle could not, near the river, reach its full amount; further, this ooze, acting as a lubricant, would transmit less of the horizontal than of the vertical component of the motion, and consequently the angle of emergence would superficially and locally be increased. Supposing the motion of the wave-particle to be resolved into two components, one vertical and the other horizontal, and calling the first u and the last h, then

$$u : h :: \sin. \varepsilon : \cos. \varepsilon$$

Now, in the case of an emergence of 45°

$$u = h$$

and in the case of an emergence of 20°, which is close upon the true angle of emergence as deduced from the depth of the focus and the distance from the seismic vertical—

$$u : h :: 342 : 940$$

If we suppose the whole of the vertical component to be transmitted (and practically the portion lost would be small), then, in the alteration of the angle of emergence from 20° to 45°, the amount of horizontal velocity lost, or the amount of slips, would be

$$940-342=598$$

and the proportion of this to the whole would be

$$598 : 940$$

that is, about two-thirds of the whole velocity; so that to increase the angle of emergence from 20° to 45°, the whole of the vertical velocity must have been transmitted, but only one-third of the horizontal, or allowing for loss of vertical velocity in transmission, about three-quarters of the horizontal velocity must disappear by slippage.

This may seen to some rather a wild hypothesis, but I see no other way of explaining the abnormally high angle of emergence at Silchar. There is, however, confirmatory evidence at the station itself; about half a mile to the east of the Police guard stand the church and cutcherry; both were cracked, and though neither of them give very exact indications of the angle of emergence, yet they show it to have been much lower here than at the Police guard, not more than 30°. Thus at two places only half a mile apart the angle of emergence differs by at least 15°. This difference may be explained by referring to the map, plate A. Remembering that the shock was coming from the north, or nearly so, it will be seen that, after passing under the river, it had to travel twice as far to reach the church, as was necessary to reach the Police guard; and consequently in the former case the upper clays were able to take up a larger proportion of the horizontal component by which means the angle of emergence was decreased.

That this slipping of the deeper seated clays under the surface beds took place, is also suggested by the distribution of the earth fissures. As explained in chapter IV, they are caused by the momentum impressed on the clays by the earthquake-wave, and it is there shown that, provided sufficient motion was impressed on the clays, fissures would be formed whether the shock was travelling towards or away from the river. An inspection of the map will show that while almost the whole extent of the northern bank is marked as "much broken" or "great slips here," similar notes are placed against only two places on the southern bank; doubtless the bank was cracked in many places, but only in two sufficiently to deserve notice. These two spots have, both of them, *land to the north,* so that the clays had time to take up a certain amount of horizontal velocity, and the breakage and fissuring were certainly greatest near the bazaar, to reach which the shock would have to travel the whole length of the peninsula. Elsewhere, where the shock struck directly on to the southern bank, the ground is not fissured or but slightly so, showing that there the upper clays have not been able to take up at once any great amount of lateral motion, the lower clays at first slipping under the upper, but gradually more and more of the lateral motion is transmitted, till at last they move once more, appreciably as one mass.

I have put forward these ideas to try and account for the anomalously high angle of emergence, as shown by the Police guard at Silchar; but having propounded them here, I shall refer once more to this subject in the next chapter.

CHAPTER VI.

OF THE VELOCITY OF MOTION OF THE WAVE-PARTICLE.

The same causes which produced a paucity in the quantity of evidence from which we might obtain information as to the other main points of interest in connection with this earthquake have also affected this of the velocity of wave-particle. Fortunately, however, the evidence obtained at one station, that of Silchar, is unequivocal and, as giving a near approximation to the velocity of wave-particle, valuable.

The first piece of evidence which we will examine is that afforded by the overthrown gate-piers of the cemetery, and we will at present confine our attention to the cap of the eastern pier. This, as explained at p. 7, and as may easily be seen by an inspection of the plan, Pl. IX, fig. 2, has evidently been shot off the top of the pillar, and showed no traces of having been shifted from the position in which it originally fell, this being corroborated by the fact that it lies right side up in its natural position not having been overturned. What seems to have taken place in this case is as follows. During the first semiphase of the wave the pillar was, by its own inertia, thrown over towards the north; then, before it had fallen very far, the base was rapidly thrust backwards, and thus a thrust was communicated through the pier to its stone cap, by which the latter was thrown off towards the north or in the direction *from* which the shock came. The next question to determine is the angle that the line in which it was projected would make with the horizon. The line of motion of the top of the pillar would be complicated, for, in the first place, it would be moving in a circle due to the overturning of the pillar, and, in the second place, the movement impressed on it by the earth-wave would tend to cause it to travel in a straight line parallel to the direction of emergence at this point, and its actual line of motion would be produced by the combined action of these two causes. Thus, as far as the motion in space of the summit of the pillar goes, it would tend to throw the cap downwards at a greater angle with the horizon and with a greater velocity than that of the wave-particle; but as brickwork will not permit of the passage of stone through its substance, it is evident that the cap cannot have been shot off at a greater angle with the horizontal than that made by the upper surface of the pillar at the moment of projection. Now during the short time that intervened between the first and second semi-phases of the wave, the pillar could not have fallen over very far, and consequently the upper surface could not have been greatly inclined from the horizontal; further, as there does not seem to have been much adhesion between the pier and its cap, it is evident that the former could not have pulled the latter after it downwards to any great extent, so that little but the horizontal component of the shock would be communicated to the cap. The direction, therefore, in which the cap was projected may be taken as being as nearly as possible horizontal, and its velocity as that of the horizontal component of the velocity of wave-particle.

Taking the body as projected horizontally, and calling b the vertical

height through which its centre of gravity fell, and a the horizontal distance through which it was projected, then—

$$b = \frac{1}{2} g t^2$$
$$a = v t$$

where g is the accelerating force of gravity, t the time of flight and v the horizontal velocity of projection; since t is the same in both equations, we can easily obtain from them the formula—

$$v^2 = \frac{a g}{2 b}$$

In this particular case a=13 ft. and b=8 ft., and taking g as 32 ft. per sec.—

$$v^2 = \frac{169 \times 32}{16} = 338$$
$$v = 18 \cdot 4$$

If, as explained in the preceding chapter, we take the superficial angle of emergence at 30° and calling V the velocity of wave-particle at the surface—

$$V = v \sec. 30^\circ$$
$$= 21 \cdot 16$$

Thus much for the cap of the eastern gate pier. The western pier does not in this way give very much evidence; for, owing to the upper portion of the pillar being more shattered, and apparently owing to a greater want of cohesion in the brickwork, the cap was not so horizontally thrown off and consequently did not travel so far; it is also overturned, thus complicating the question; and altogether it does not give such definite information as its companion of the eastern pillar.

We will now speak of Mr. Stewart's tomb, and consider the evidence it affords. This tomb has been briefly described at p. 10, but it will be necessary to describe its construction more minutely than was there done, in order to realise exactly what took place; for without realising this, no satisfactory conclusions can be drawn.

The body of the sarcophagus was raised in the centre of a terrace or raised platform of two steps 5 inches each, and 1 foot 2 inches in breadth, or tread, made of Chunar stone, the gravel and grass had grown round the lower of these, so that it was partly hidden. From this rose the rectangular body or mass of the tomb, which was constructed of white marble admirably cut and moulded, and laid round and on a solid brickwork case or centre. The base mouldings rose to a height of 1 foot 1½ inches and above them were plain slabs of marble 1 foot 9½ inches high; in the centre of the southern face was inserted a black marble tablet which carried the inscription, and which measured 2 feet 8 inches × 1 foot 3 inches. The plaques or slabs of marble used for the sides of this portion of the body of the tomb were about 1 inch thick, and some had obviously been in use before, as they were polished on the back as well as face. They were built up against the brickwork core, but there evidently had been the slightest possible adhesion, the surface of the mortar between them and the brickwork being as smooth and polished as themselves; they were secured by being partially jointed and by small and much too slight copper clamps measuring ½ inch by ¼ inch in section let into the slabs and leaded.

The large upper slab, with small pillow ends, was then merely laid on the others. The lower surface was finely chiselled and dressed for a breadth of five inches all round, so as to admit of close neat joints, the rest of the under surface being roughly tooled down to the level. There had obviously been but very little mortar used in the bedding, and it may safely be taken as merely laid on the body of the tomb for the cohesion if any must have been exceedingly slight.

The railing round the tomb was of ⅝ inch square iron, let and leaded into the lower of the two steps of the floor on which the tomb was raised. The upright bars passed through and were leaded into a flat tie piece, of 2 inches by ½, and the upper ends, projecting 5 inches, had been flattened and shaped out into rude spear heads. There was also a second outer fence consisting of stone pillars, with chains suspended between, as seen in the drawings.

It will thus be seen that the tomb consisted of a brickwork core covered with *plaques* of marble; and this core was divided into two portions by a slab of marble which extended right through the tomb; this marked *a* in Pl. X, fig. 1, and can be seen lying almost in its original position in Pl. X, fig. 2.

The tomb may then be considered as being divided into two portions, one above and the other below this marble slab; we may consequently regard it as two solid rectangular prisms superimposed one on the other, and, practically, without any cohesion between them. A body of this description may be overthrown in either of two ways: the whole may fall as one mass, or the upper portion only may be overthrown. If the shock required to overthrow the whole is less than that which would overthrow the upper portion by itself, the whole must fall as one mass if overthrown at all; but if the upper prism requires a less violent shock for its overthrow than that necessary to overturn the mass as a whole, it will be overthrown separately and the relief thus afforded may enable the lower portion to retain its position unmoved. In this particular instance the only obstacle to the overthrow of the upper prism is its own inertia, while the lower one would in addition have to be fractured from its base.

The tomb, viewed as a whole, may be regarded, with sufficient approach to accuracy, as a solid prism, 5 ft. 9 inches high by 2 ft. 6 inches broad, the shock being in this case a *subnormal* one, *i.e.*, the direction was emergent, but very nearly orthogonal to the face of the prism in azimuth. The formula for the overthrow of the tomb as a whole is in this case—

$$v_1^2 = \frac{4}{3} g \times \sqrt{a^2 + b^2} \quad \frac{1 - \cos\theta}{\cos^2(\theta + \epsilon)}$$

here * $\theta = 23°{\cdot}30$, $a = 5{\cdot}75$, $b = 2{\cdot}5$, and ϵ as before $= 30°$: from this we get the result that

$$v_1 = 7{\cdot}9 \text{ feet per second.}$$

This is the velocity of wave-particle necessary for the overthrow of

* θ is the angle which a line, drawn through the centre of gravity of the prism and the arris on which it is overturned, makes with the vertical.

the prism, but in addition it must be fractured from its base, for which a velocity is required of

$$v_2^2 = \frac{2}{3} g \times \frac{L\, b}{a^2} \times \frac{\cos \theta}{\cos (\theta + \varepsilon)}$$

whence

$$v_2 = 9{\cdot}9$$

where $L = 4$.* Adding these together we obtain the result that a velocity of 17·8 feet per second would be required to fracture from its base and overturn this tomb as a whole.

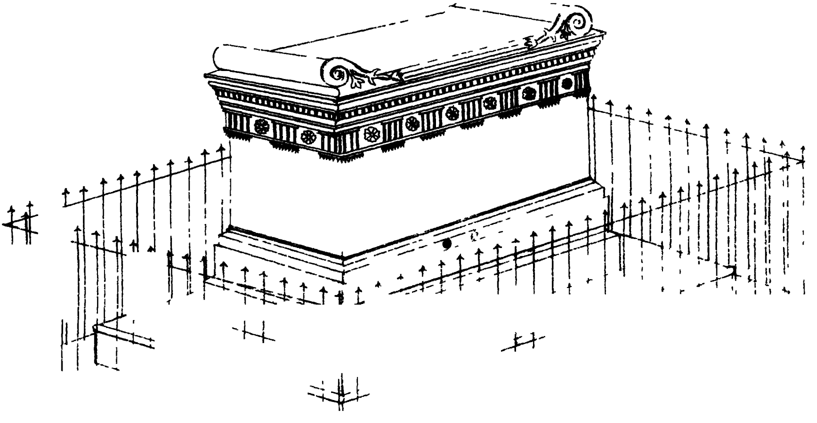
But what is the velocity of wave-particle which will suffice to overthrow the upper half of the tomb by itself? Here there is no adhesion to overcome, and the only resistance is that of inertia; we may regard this as that of a prism of 3 feet 3 inches in height and 1 foot 10 inches in breadth; here $a = 3{\cdot}25$, $b = 1{\cdot}8$, θ $29°8'$—whence by the same formula as before we obtain the result

$$v_1 = 8{\cdot}6 \text{ feet per second.}$$

As the lower part of the tomb by itself would require for its overthrow a far greater velocity of wave-particle than can be conceived as possible, I shall not here enter into any detailed discussion of the subject.

These calculations show that if the velocity of wave-particle exceeded 8½ feet per second, the upper portion of the tomb would be overthrown by itself, and that in consequence of the break of continuity in its substance, it could not be overthrown as a whole except by a velocity of wave-particle far greater than what we have any grounds for regarding as possible. The aspect of the tomb after the passage of the shock, as shown in pl. X, fig. 2, exactly fits in with the former supposition; the lower portion of the tomb is still standing, only the upper has been overthrown, and the slab marking the junction of the two portions can be seen almost in its original position. This proves that the velocity of wave-particle exceeded 8·6 feet per second.

* L is the modulus of dynamic cohesion, or the length in feet of a column of material whose weight, if suddenly applied, would produce a fracture in its substance by tension.



But this tomb can be made to yield more valuable data for the determination of the velocity of wave-particle. The top slab, described as having been shot clear off the tomb to a distance of 8 feet to the north, was evidently projected in the same manner as the cap of the gate pillar, but the case is not quite so simple. The twisting of the stone on its axis through an angle of 5° need not be noticed, as many causes might have led to this, and it will not affect the accuracy of the results to be obtained in any appreciable degree. A much more serious complication is introduced by the iron railings, which, as is shown in Pl. X, fig. 2, are all torn up and bent over; the question to be decided is how much of this must be attributed to the capping slab and how much to the weight of the upper portion of the tomb which was precipitated on to them and is shown in the figure lying on the bent-down rails. These railings were made of iron rods $\frac{5}{8}$ inch square, flattened out into a spear-head at the top, near to which they were leaded into a horizontal bar of iron 2 inches broad by $\frac{1}{2}$ an inch thick. The tops of those bars which lay in the path of the heavy marble slab were bent over at a right angle, evidently by its drive, thus showing that the slab was shot clear off the top of the tomb and that it must have hit the rails close to their upper ends; indeed, it is very probable that the bending was produced by the bottom of the slab knocking against the tips of the spear-heads, and as at the same or almost the same moment the whole of the overturned upper portion of the tomb was precipitated on to the rails, it is probable that the motion of the slab was arrested to but a small degree; in any case, this slab will give a useful minimum measure of the velocity of wave-particle.

The formulæ will, of course, be the same as in the case of the cap of the gate pillar; here $a = 8$ feet $1\frac{1}{2}$ inch and $b = 5$ feet 4 inches.

$$v = 14{\cdot}06 \text{ feet per second.}$$

This is a little more than 4 feet per second less than the value given by the cap of the gate pillar, the difference being due to the velocity absorbed in bending the rails. If, as before, we take the superficial angle of emergence at 30°.

$$V = 14{\cdot}06 \sec. 30°.$$
$$= 16{\cdot}22 \text{ feet per second.}$$

There remains one more index as yet not noticed. The boundary wall of the cemetery, which, though cracked, was not overthrown, will give a maximum value for the velocity of wave particle. It may be regarded as a rectangular prism affected by a subnormal shock, for the direction of the wall is orthogonal to the direction of emergence of the shock. Here $\theta = 18^\circ\ 26'$ $a = 3$ and $b = 1$.

$$v_1^2 = \tfrac{4}{3} g \times \sqrt{a^2 + b^2} \times \frac{1 - \cos\theta}{\cos^2(\theta + \varepsilon)}$$

$$v_1 = 3{\cdot}96 \text{ feet per second.}$$

This is the velocity for overthrow when fractured from its base. The velocity for fracture taking $L = 4$ is

$$v_2^2 = \tfrac{2}{3} g \times \frac{L\,b}{a} \times \frac{\cos\theta}{\cos(\theta + \varepsilon)}$$

$$v_2 = 14{\cdot}17$$

Adding these together we obtain the total velocity required for fracture and overthrow

$$V = v_1 + v_2 = 18{\cdot}13$$

Or about 3 feet less than that given by the cap of the gate pillar. As there are not sufficient data for determining the proper value of L in this case, I have purposely taken it low. We are told that the mortar was indifferent, but if the bricks had only a low specific gravity, this would to a great extent counterbalance the want of quality and age in the mortar work; indeed, if we only take $L = 5$ feet instead of 4 feet, then

$$v_2 = 17{\cdot}89$$
$$\text{and } V = 21{\cdot}85$$

rather higher than that given by the cap of the gate pillar.

As it is almost certain that in this case L could not have had a very high value, it is evident that the wall was in a very critical state, and that a slightly higher velocity of wave-particle would have sufficed for its overthrow.

Placing the velocities obtained together they are—

1. Cap of gate pillar	21·16	
2. Cap of Mr Stewart's tomb	16 22	
3. Cemetery wall	21 85	max.
Mean	19 74	
Mean, omitting No. 2	21·5	
Mean of means	20 62	

We may therefore say that the velocity of wave-particle at the surface was not far from 20 feet per second.

But, as I have before explained, there is good reason for supposing that, in transmission from the lower to the superficial beds of clay, the velocity of wave-particle was diminished, while the angle of emergence was increased. From this it follows that the true velocity of wave-particle was greater than 20 feet per second. Assuming that in transmission no part of the vertical velocity was lost, then the vertical component of the velocity of wave-particle, in what we may call the true shock, was the same as that of the surface shock, which for a superficial angle of emergence of 30° is one-half of the total velocity of wave-particle at the surface, or say 10·5 feet per second. Taking the true angle of emergence as 20,° we get the true velocity of wave-particle by the formula—

$$V = 10{\cdot}5 \times \text{cosec. } 20.^\circ$$
$$= 30{\cdot}7 \text{ ft. per second.}$$

This constitutes the evidence we have of the velocity of wave-particle in the case of this great earthquake. Though sadly deficient, it is at any rate definite; it only gives the velocity at one station, but at that station there is no lack of certainty. We have proofs of a velocity of wave-particle of at least 20 feet per second, and by what I believe to be a warrantable deduction we obtain a velocity as high as 30 feet per second. Thus giving a velocity of wave-particle double that observed by Mr. Mallet in the Neapolitan Earthquake of 1857, and that at a distance of 85 miles from the seismic vertical against a distance of

25 miles in the latter case. That the velocity of wave-particle should have been much greater in the case of this earthquake than in the Neapolitan one is, as I have already shown on *a priori* grounds, more than probable.

Yet although the violence of the shock was so much greater actually, there is little or none of that awful interest which attaches to the Neapolitan Earthquake of 1857, where the mind is bewildered by the utter annihilation of so many towns and the vast destruction of human life; that it can hardly look on the facts in that calm and philosophical manner that is essential for a proper understanding of the true course of events. Here it is but occasionally that we hear of lives being lost, and but seldom of a house being overthrown. The reason of this is not hard to find. Where, as is the case in almost all the native habitations, the houses are built of wood and bamboo, their elasticity protects them from overthrow, and where the buildings are constructed of brickwork or masonry, they are mostly large well-built buildings, all the rooms being on the ground-floor: a structure is thus produced composed of a series of walls of no great height running into each other and supporting each other against overthrow, and from the houses being always detached from each other the fall of one does not involve its neighbour in the ruin. When we hear of a building being overthrown, we also find either that it was badly built, or that it departed from the ordinary style of architecture. At Yeddo chimneys were overthrown, but the bungalows, though severely cracked, stood firm; at Silchar the cutcherry and bungalows stood, though more or less injured, the only structures overthrown were some walls and the church tower, which by its form courted destruction; at Kochela a deserted saw mill was ruined, but that again was structurally unstable as compared with the average bungalow; and lastly, at Manipur, where we hear that the Rajah's palace was overthrown, we also hear that it was a two-storied building. It is entirely to these peculiarities in the domestic architecture of the country that we must attribute the small loss of property and life by the overthrow and destruction of buildings.

CHAPTER VII.

OF THE RATE OF TRANSLATION OF THE WAVE.

We would at once declare that, in the present state of earthquake enquiries, the determination of the transit velocity of the shock, that is, the rate at which the wave-form is transmitted from part to part of the perceptibly shaken portion of earth's surface, appears to us of minor importance, and we shall not therefore delay to discuss it in much detail.

In truth, the difficulties which we have already indicated, as affecting our observation of the shock at all, the comparatively wild and uninhabited nature of the country, the absence of most of those ordinary indices of civilisation which could become the permanent indices of the extraneous forces applied to them and resulting in their overthrow or destruction,—all these difficulties combined with others most seriously affect any observations, which seek for precise and accurate measurements of time. Where the motion of transit is so rapid, as in the case of great earthquakes, that even fractions of a second become essentially important in ascertaining the true rate, it seems almost absurd to think of depending upon the ordinary measurements of time, by clocks in every-day use, unregulated and often differing by not only seconds, but minutes or even hours from the true time. During my own experience in India I have known the station gun—the gun usually fired with the intention of indicating midday in the more important military stations—to vary from the true mean time by not less than 53 minutes. I have more than once seen sun-dials which had been removed from one station to another, these stations differing in their latitude by four or five degrees, and reset the meridian being obtained by the use of a common magnetic compass without any consideration of variation, and the inclination of the gnomon left quite unaltered, and still the instrument trusted to in one place quite as unhesitatingly as in the other, and it is by no means an uncommon thing to find persons, who have really good watches, abandon the use of them, and trust to the gong or *ghurri* of the neighbouring barrack or court-house as their only guide to the hours. This is perhaps the only public announcement of the time, and as one of the chief objects is to bring people together, it is of little consequence, provided they do really meet, whether the meeting be a little later or a little earlier than the true time stated.

But with such sources of error, valuable as may be the indications of time given by many observers, and especially valuable as placing the identity of the shock felt at different points almost beyond the possibility of doubt, still they are open to far too many and too serious sources of error to admit of their being applied in the discussion of the transit velocity of the wave-form with any precision. The statements themselves are for the most part so vague and undefined, the errors of observation probably so great, and the errors in the time-measures so variable and so large, that out of some hundreds or thousands such statements of time, it is rarely indeed that we can find more than one or two, perhaps not even this small number, which can be trusted.

Nor will this pregnant source of error in any attempt to calculate with precision the velocity with which such a wave-form is translated from point to point be satisfactorily removed, until self-registering instruments have been established at favourable points within the areas subject to such disturbances. Even the possession of carefully noted and timed chronometers will be a very inefficient substitute for this. Observers cannot be always on the watch, and when such a shock comes there is often too much astonishment or even alarm, too much disturbance of all the elements that contribute to accurate observation, to admit of a careful and calm noting of the precise time, while further the moment of such observation is gone by before the instrument is ready for observation.

In the case of the great shock which we have now been describing, I find only two, among all the observations, which can be supposed to give even an approximation to data sufficiently accurate to admit of a calculation of the transit velocity of the wave. One of these we owe to the fortunate accident of Captain Godwin-Austin, an officer in charge of the Topographical Survey Party engaged in the north Cachar hills at the time, having been near the centre of the area shaken, and having noted his chronometer time almost immediately on the occurrence of the shock. The other observation is due to the circumstance that the two astronomical clocks used at the Surveyor General's office in Park Street, Calcutta, were actually stopped by the transit of the wave. As the shock occurred on Sunday evening no one was at the office, and we should have been without a careful record of the time, but for this. The observed times of the shocks on the 10th of January at Asalu, for which we are indebted to Major (now Colonel) Godwin-Austin, are given in the table appended.[1]

The time at which the clocks of the observatory at Calcutta were stopped was 4h. 43′ 30″.

Synopsis showing observed Chronometer Times of Shocks of Earthquake of 10th January 1869, with the error and rate of Chronometer from observations made on 12th and 24th January 1869, together with corrected times of shocks, at Asalu, North Cachar Hills.

Date.	Computed Time of Observation.	Observed Chronometer Times of Shocks of Earthquake on the 10th January.	Interval.		Rate gaining.	Correction for Rate for Interval Elapsed.	Correction to Error of Chronometer for Interval.	True Times of Shocks of Earthquake.
			In Hrs.	Decimals of Hrs.			Error of chronometer on 12 observation + 1 14 18.	
	H. m. s.	H. m. s.	H. m. s.	H.	D.	+	H. m. s.	H. m. s.
12th January...	9 2 56·2	3 45 50	41 17 6	41·285	24 Hours=17·38. Per Hour =0·724.	29·89	1 14 47·9	5 0 37 9
		3 46 10	41 16 46	41·279		29·89	1 14 47·9	5 0 57·9
		3 47 40	41 15 16	41·254		29·89	1 14 47·9	5 2 27·9
		3 58 30	41 4 26	41·074		29·74	1 14 47·7	5 13 17 7

The longitudes of the two stations are respectively—

Calcutta observatory	88°	23′	59″
Asalu	93°	13′	10″
Difference	4°	49′	11″
Local time of shock at Asalu	5*h*	0′	37·9″
Subtract for difference in Long.	0*h*	19′	16·8″
Calcutta time of shock at Asalu	4°	41′	21·1″
Time of shock at Calcutta	4°	43′	30″
Difference	0°	2′	8·9″

The distances from the seismic vertical are—

	Miles.
Calcutta	256
Asalu	76
	180

So that, to judge from these two observations, the time occupied by the earthquake-wave in passing over a distance of 180 miles could have been 2′ 9″, or an average rate of 7,375 feet per second, a velocity which, to say the least, is improbable.

Of the two observations from which this result has been obtained, one precludes all possibility of error, yet it is difficult to believe that so experienced an observer as Major Godwin-Austin could have made a serious error in his observations;[1] such, however, is the conclusion forced upon us by a comparison of these, the only two observations which can have even the slightest pretence to trustworthiness.

We are consequently unable to determine, with accuracy, the rate of transit of the wave-form in the case of this great earthquake; but as there is no reason to suppose that it differed much from what is known to have been the velocity in other earthquakes, this is of little importance.

[1] The inaccuracy is probably only in the time of the first shock, and represents the time taken in unpacking the chronometer; unfortunately we have not any accurate observations of the later shocks besides those of Colonel Godwin-Austin.

CHAPTER VIII.

OF THE SHAPE AND EXTENT OF THE SEISMIC AREA.

On account of the vast extent of country over which this earthquake was felt, of the unsatisfactory nature of the reports obtained from most of the places at which it was felt, and of the unsettled and uncivilised state of other districts where the shock must have been sensibly felt but no records could be obtained, we are not able to lay down isoseismal lines as numerous, or with the same accuracy, as is desirable. We can, however, form a very good idea of the shape and extent of the area affected by the shock; and with this object in view I have laid down on the map No. 1 a line which marks, as near as can be ascertained, the boundary of the area over which the shock was perceptible to the unaided senses.

Starting from a point on the western shore of the Bay of Bengal, not far from Hidgellee, the line runs north-westward to Hazaribagh, thence northward to Patna; it then passes over a tract in which its course is uncertain, and the next definite point is Darjiling, which must have been situated not far from the boundary of the area whose limits we are describing; far to the east of this station we hear of the shock being severely felt at Lakhimpur; we may therefore take the line as passing through the Himalayas, and perhaps extending beyond them on the north; eastward again we hear of the shock being severely felt at Dibrughur, and from further east we have no reports and could expect none. At Manipur the shock was very severe, and this, combined with the report that the shock was felt in Upper Burmah, justifies us in taking the line down through Upper Burmah to Kussilong and Chittagong. The boundary thus drawn includes an area of roughly oval form, from 650 miles long from north-east to south-west, and 400 miles in the co-ordinate direction of north-west and south-east, thus enclosing a total area of a quarter of a million (250,000) square miles.

We have not sufficient information to enable us to draw any isoseismal lines within this area, but on the map I have laid down part of a line which would enclose that area over which the shock was really severe; this starting near Gowhatti runs east to Nowgong, and then curves down to Munnipur whence it turns westward and passes to Silchar.

An inspection of these lines shows that the dimensions of the area included are much greater in a north-east and south-west direction than in the co-ordinate direction of north-west and south-east. This of course, to a certain extent, depends on the fact that no reports could have been obtained from the country lying to the north of the southern boundary of the Himalayan range, nor from all that portion of Burmah over which the shock may very probably have been felt; but yet the fact remains that the area affected undoubtedly extended much further East and West than North and South. This extension might have been produced by either of two causes,—firstly, the structure of the country, which might be such as would favour the transmissions of the shock further in one direction than another; and secondly, the direction of the fissure from which the shock originated. We will examine the circumstances of the case, and see to what extent the action of one or both of these causes must be invoked to explain the facts.

From the Jaintia hills in which the shock originated a range of mountains composed of more or less hard and crystalline rocks extends eastwards; through these cystalline rocks the shock would be transmitted with great readiness; but as we know neither the structure of the country nor the effects of the earthquake in Upper Burmah with sufficient detail, no further reference will be made to this portion of the seismic area. To the north of the Khasi range, but separated from it by the valley of the Brahmapootra, lies the range of the Himalaya mountains. These are composed of indurated rocks well adapted for the transmission of the shock; this superior elasticity of the rocks is to a certain extent counterbalanced by the fact that the shock would have to cross the strike of the strata flanking the range, and its force would therefore be lessened in passing from stratum to stratum; but the flattening of the isoseismal on the north is to a great extent due to the absence of records from that region. To the south and south-west the structure of the country does not offer any special impediment to the transmission of the shock, but it is on the west that the shock was transmitted for the greatest distance. Westward from the Khasi hills the crystalline rocks soon give place to the great alluvial plains of the Ganges and Brahmapootra which, with those of the Barak, surround the Khasi range on three sides and form a very large portion of the area affected by the shock. These alluvial plains extend westward, far beyond the furthest point at which the shock was felt; but in the south-west the shock was felt over a district in which the gneiss of the peninsula forms the groundwork of the country, in whose hollows are lodged the principal coal-fields of British India. On the gneiss, which, from its elasticity, is well adapted for the tansmission of the earthquake-wave, the furthest point at which the shock was felt was Hazaribagh, 454 miles from the seismic vertical; while Patna, to reach which the shock would have to travel for two-thirds of its journey through the alluvial plains of the Ganges, is 446 miles from the seismic vertical, from which it would seem that the shock would travel as far through alluvial plains such as those of the Ganges as through the highly crystalline gneiss of the peninsula, the absence of joints in the former case compensating for deficient elasticity; we must therefore consider the country to the west of the Khasi hills as rather suitable than otherwise for the transmission of the earthquake-wave.

Though, as has been shown, the nature of the country, whether as to its structure or accessibility, would to a certain extent account for the east and west elongation of the isoseismal, it is not in itself sufficient and the facts noticed cannot be explained without calling in the action of some other cause. If, as it would seem to be the case from an inspection of map No. 1, the seismic focus took the shape of a rent running nearly east and west, the impulse communicated to the surrounding rock would be greater in a direction north and south than in the orthogonal direction of east and west, and the impulse would tend to propagate itself further in the former than in the latter direction. On the north we cannot hope to trace any great extension of the isoseismal, but no such difficulty would exist to the south; nor would the structure of the country oppose any great obstacle to the transmission of the shock in that direction; and we should therefore be able to trace the shock down the shores of the Bay of Bengal to a point further from the seismic vertical than the furthest point on the west at which the shock was felt. But such is by no means the case, and we must consequently acknowledge that the fissure in which the shock originated ran nearer north and south than east and west.

How then is this conclusion to be reconciled with that obtained from the evidence of the direction of the shock? If the map is examined, it will be noticed that, with a single exception, all the stations at which the direction of shock was obtainable bear from south to south-30°-west of the seismic vertical and that the single station which is not so situated lies nearly due west. Of lines so drawn, the intersections must necessarily form a series very narrow from north to south and broad from east to west. It is therefore evident that, though the observations of direction of the shock have given the *position* of the seismic vertical, we cannot trust them in determining the size and dimensions of the seismic focus which, unfortunately, cannot be otherwise determined.

APPENDIX.

Simple instructions for earthquake observations.

The foregoing pages, which contain many notices and extracts which are fair samples of ordinary unscientific descriptions of an earthquake, show well how little is known by most of the true nature of an earthquake, and consequently what very imperfect observations it is possible to collect in a country so well suited for systematic seismological enquiry as the Assam province, and, to a less degree, nearly the whole of India; and yet there are few who could not make observations which, when collated with those made by other observers in different positions, would not be of considerable value.

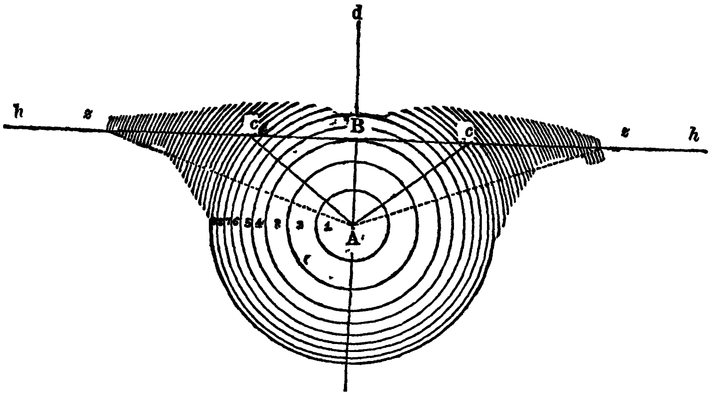
As it is impossible to make observations of an earthquake, which will be of any use, without some previous knowledge of what an earthquake really is; and as, even up to the present day, the common manuals of geology contain erroneous or misleading notices of this branch of terrestrial physics,—it will be advisable to devote some space to the description, in as few words as possible, of what an earthquake really is; and on this point the vaguest ideas and wildest impressions are prevalent—not unfrequently it is spoken of as a heaving of the solid earth, caused by the pent-up forces beneath, which find an outlet in the fissures and rendings of the earth which they produce. Now this, which may be looked upon as a fair and impartial description of the ordinary idea of an earthquake, could not well be more at variance with the facts than it is.

Suppose a long beam of wood to be lying on the ground—against one end of this hangs a small weight suspended by a string, the opposite end of the beam being struck by a hammer this weight is driven away from the wood without the beam being moved the fraction of an inch; what has happened is that a wave of elastic compression has been sent through the beam: when the end was struck by the hammer the particles were driven before it, but by their elasticity recovered their original position; meanwhile they had pushed forward the particles immediately in front of them, which, in their turn, having communicated the motion to those in front of them, returned to their original position, and so the impulse was transmitted through the beam, and on reaching the opposite extremity the outermost particles were pushed forward, and, in doing so, communicated their motion to the small weight hanging against the end of the beam, which was in consequence thrown off: it is just such a wave of elastic compression which passes through the earth's crust when what is commonly called an earthquake takes place.

We must now explain how it is that we can, from observations at the surface, deduce the position and depth below the surface of the focus from which the shock originated.

In figure 1, let *h h* represent the surface of the earth, and A the focus at which, from

Fig. 1.



whatever cause, an impulse of an explosive nature is communicated to the surrounding rocks; the particles of rock immediately surrounding A are driven asunder and then return to their normal positions, thus originating a wave of elastic compression, which spreads outwards in every direction from the focus, as is represented by the concentric circles surrounding the point A. Now, as the motion of the particles of rock is, except where interfered with by want of homogeneity in the rock, always directly outwards from the focus, it will be seen that the direction of motion of the particles is the same at no two points of the area over which the shock is felt, and that at each point the direction of motion points to the focus or point of origin of the wave; if then, at any two or more points, we can get the true direction of movement of the wave particles, we can deduce the true position of the focus.

The object of all seismological observations should be, primarily, to determine both the true direction and velocity of motion of the particles set in motion by the earthquake wave. This motion, which is at an angle to the horizontal, may be considered as being composed of a vertical and a horizontal component. For the determination of these two components, we have to depend on observations which may be divided into two great classes—subjective and instrumental; the first consisting of those impressions or sensations which may be personally noted during the passage of the earthquake shock; the second, of those observations made with properly designed instruments; while a third sub-division consists of observations, made after the passage of the wave, of damage done to permanent structures.

Beginning, then, with the subjective observations, I would say at once that all impressions of the direction in which the shock travels are, from a scientific point of view, almost, if not utterly, useless, for it is but seldom, and then mainly by accident, that these impressions agree with the facts. But, though guesses at the direction in which the shock travels are useless; general impressions of the nature of the shock should be carefully noticed, as also any effects it may have on the lower animals.

The time at which the shock is felt should, of course, be noted; but this, which in India it is impossible to expect done with accuracy, is fortunately of comparatively small importance, its purpose being mainly to obtain the rate of transmission of the wave impulse through various media; but, though the actual time at which the principal shock is felt may not be determinable with accuracy, the intervals between a great shock and the numerous minor ones which follow it should, if possible, be determined with rigorous accuracy. And here we may diverge to say that it is not by any means the great and disastrous shocks which are of greatest scientific interest; in them the chief wave is so interfered with by minor cross undulations that the general motion, instead of being simple, is much complicated. Let every fact that can be ascertained about such a shock be recorded, but let it be taken rather as a warning to be on the alert and notice any following shocks, to read off the instruments and set them again ready for the next shock, than as the main point to which observation should be directed.

The duration of the shock should be noticed; this, as given in most ordinary accounts, is very misleading: for instance, the shock may be said to have lasted for 'several minutes' or 'quarter of an hour,' whereas what is really meant is, that during that period there was a rapid succession of shocks. If possible, in the case of a violent earthquake, the main wave should be distinguished from the accompanying minor undulations, and it should be noticed to what extent the latter precede or follow it.

The nature of any sounds heard should be recorded, and whether they accompanied, preceded, or followed the shock.

It is but seldom that any of the Indian earthquakes originate under the sea, and consequently sea-waves are seldom found accompanying earthquakes; but in the case of observers residing near the seashore, any such phenomenon should be carefully recorded.

Often chandeliers, trees, or other flexible objects are set swinging by the shock, in which case the direction of movement, with reference to external objects, should be noticed, and the actual direction of this motion afterwards observed with the compass.

Among those observations which should be made after the passage of the shock, the principal are those of damage done to buildings. These should in every case be carefully observed, and drawings should be made of the faces of the building cracked, and particulars given of size and construction, thickness of walls, number and size of doorways and other openings. From these particulars valuable information may often be derived; but as a rule little can be expected, unless the observer is acquainted with the principles on which these facts are interpreted. Should, however, any walls or other structures be overthrown, they should be most carefully described. A rough, or, if possible, a detailed ground plan of the overthrown structure should be made, accompanied by drawings and a description of the structure as it originally stood. The direction in which the mass is overthrown should be carefully recorded; in the case of bodies projected by the shock their dimensions and nature should be detailed, and the horizontal and vertical distances through which they have travelled from be noted.

The effects of an earthquake in altering the superficial features of the ground sho be recorded; but here care must be taken not to confound such a purely secondary caus as that to which the sinkings and fissurings of the river banks in the Cachar earthquake of 1869 were due, with actual alteration of level accompanying the earthquake.

We now come to such observations as can only be made with the aid of instruments, of which the simplest, and one which may often be of considerable service, is—

(1) A round tub or basin half filled with water, which should be coloured—a little ink answers as well as anything else—while the sides of the tub are whitened; when the shock comes, the water surges up on that side from which the shock is travelling and leaves a mark.

(2) An elastic rod firmly fixed in the ground, with a heavy weight, such as a spherical 4-pound shot, at the top; the free portion of the rod, which may be of stout rattan, should be the length of a second's pendulum, and the spherical weight must be surrounded by a wooden hoop, leaving an annular space of 6″ or 8″ in breadth between it and the surface of the ball. In this, eight holes are to be bored and fitted with cylindrical rods of wood, such as lead-pencils, sliding easily in their respective holes; these rods to face the cardinal points and their bisections.

(3) The best of all pendulum apparati is that suggested by Mr. R. Mallet, which consists of four inverted pendula, with broad, thin, flexible, supports, capable of vibrating only in one direction and placed facing the four cardinal points of the compass. Each of these is provided with a ratchet and pawl, which allows of its bending over in one direction only, and retains it in position when so bent.

Besides the above, several other forms have been suggested, all considerably complicated; but as they all suffer from the drawbacks inherent in any seismometer which depends on the principle of the pendulum, it would serve no useful purpose to describe them: we will therefore pass on to a consideration of the advantages or defects of those already described:—

(1) The water in the circular basin is, theoretically, set in motion in a single plane, but practically the unequal friction with the sides gives it a swirling motion, which causes it to surge round the basin, often making it a very difficult matter to decide where the mark reaches highest, and consequently from whence the shock came. When, as is the case in most violent shocks, the main wave is accompanied by minor oscillations, more or less transverse to it, this swirling is very much exaggerated. There is another drawback; in that, under the action of violent shocks, the water first rises against the side from which the shock came, but is then dragged forwards and thrown up against the opposite side of the basin, and if the period of oscillation of the water in the basin at all corresponds with that of the earthquake wave, it will rise highest on that side towards which the earthquake is travelling. Notwithstanding these drawbacks, the ease with which this instrument can be impro-

vised, and, for moderate shocks, the accuracy with which it gives the horizontal direction of motion of the wave particles, make it particularly useful. In the case of a great earthquake, one should, if no other instruments are set up, be immediately improvised, and the intervals between, and direction of, subsequent shocks be noted.

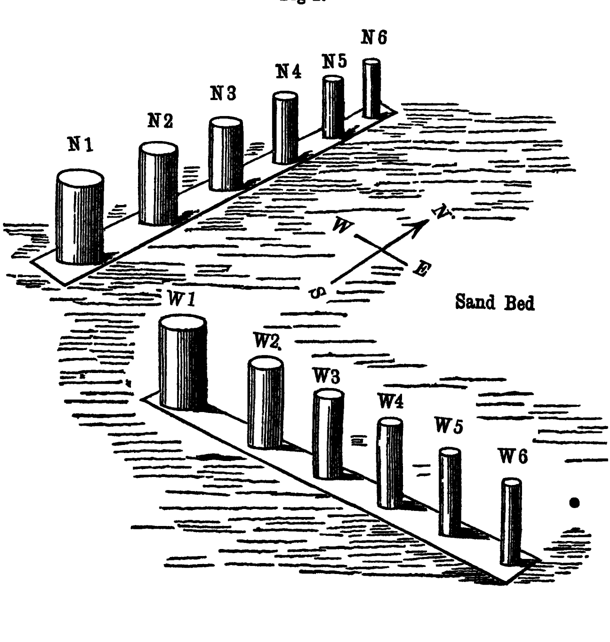
(2) This is one of the most untrustworthy forms of seismometer that has been suggested. It is impossible to arrange it so that the centre of gravity shall lie in the axis of oscillation, and consequently the pendulum, first set in motion in a vertical plane, will very soon acquire a circular motion; added to which, the dragging of the bob by violent shocks, and the subsequent throwing of it forwards, are more noticeable than in the first described form.

(3) This is undoubtedly that form of pendulum seismometer which is least open to objection; but as it is more troublesome to construct than the instrument which will be described below, while at the same time its observations are both less exact and not comparable with those of other instruments not very carefully constructed to be duplicates of itself, we will not here describe it further.

These pendulum seismometers, though under certain circumstances of great value, should be regarded rather as makeshifts than as instruments to be permanently established; but the two which will be now described differ from them in that they give absolute and not merely roughly comparative determinations of the velocity of motion of the wave particles.

The first of these depends on the circumstance that a solid right cylinder will be overturned towards the point from which an earthquake shock comes, and that it requires a definite minimum force to overthrow it, which can be readily calculated. In fig. 2 we have given a rough perspective view of an instrument of this sort, which is copied from Mr. R. Mallet's article in the Admiralty Manual of scientific enquiry. The instrument consists of two series of right cylinders, all of equal altitude but of gradually diminishing diameters, the two series being exactly similar. These stand on a pair of slips of wood, which

Fig 2.



taper so that their width shall equal the diameter of the cylinders standing on them at various points, the two slips being placed one due north and south, the other east and west; soft, dry sand is then filled in up to the level of the two slips. Under the influence of an earthquake shock a greater or less number of the cylinders are overthrown, and the horizontal component of the shock is then intermediate between that required for the overthrow of the largest cylinder overturned and the smallest still standing.

The cylinders may be made of stone, pottery, metal, or any other homogeneous material whose density is immaterial, as the overthrow is due to inertia, which is proportional to the mass: probably the most convenient material will be found to be good, straight-grained, seasoned wood, free from knots, which can be turned to the requisite diameter with great ease. The dimensions for a series of cylinders, 12 inches in height, are given below, with the horizontal velocity of shock required for their respective overthrow.—

	Diameter of cylinder in inches.	Horizontal velocity of shock for overthrow in feet per second.
1	11½ inches.	5·54
2	10¾ „	5·08
3	9¾ „	4·48
4	9 „	4·05
5	8 „	3·50
6	7 „	2·98
7	6 „	2·50
8	5 „	2·03
9	3¾ „	1·49
10	2½ „	·98
11	1½ „	·57

It will be seen that this form of seismometer is only adapted to the measurement of moderate shocks, but it is just these which are most important from a scientific point of view.

As regards the fixing of the instrument, the following modification of Mr. Mallet's plan will, we think, be found advantageous, as it allows of equally accurate results being obtained with a single series of cylinders; or if the same total number is used, the instrument may be made to give more closely accurate results. If, then, it be determined to set up an apparatus consisting of 11 cylinders, as given in the table, a patch of ground, 12 feet by 10 feet, should first be carefully levelled and smoothed, with the longer axis running preferably north and south. Then let a series of stands be made for the cylinders, each exactly the same diameter as the cylinder intended to stand on it; for the larger sizes they may be discs of about 2 inches in thickness, to be firmly fixed to the ground by long spikes driven through them; while for the smaller cylinders they may be rods of about a foot long, pointed at one end, and driven into the ground. The cylinders should be arranged as below:—

	1	2
	3	4
	5	6
	7	8
9	10	11

By this arrangement a clear space of 18 inches can be left between each pair of cylinders and a clear margin of 3 feet round the outside of the group. The stands being all fixed in position, and all projecting the same distance above the previously levelled ground, and dry sand filled in up to the level of the tops of the stands, nothing now remains but to place the cylinders each on its respective stand and await the arrival of an earthquake.

To use this instrument, it will be necessary to have some means of reading off the exact direction in which the cylinders are overthrown; and for this nothing could be more convenient than a compass with a swinging card, mounted in a square wooden box; the edges of this box should be square to each other, and on the side of the circular well in which the card works there should be a vertical mark so placed that a line drawn through it and the point of suspension of the card will be parallel to two of the sides of the box; then by simply placing one of these against the overthrown cylinder, the mark will coincide with the exact direction in which the cylinder has fallen. If such a compass is not obtainable, one with an ordinary needle will do, using it in the same way as before, and remembering that whatever number of degrees the needle may stand over, the true direction is that number of degrees on the opposite side of north; thus, if the needle stands over north 50° east, the direction in which the cylinder has fallen is north 50° west. It will be well to add here that the readings should always be taken in degrees east or west of north; such phrases as north-west or south-south-east are far too vague.

Observations taken by this instrument should be entered in a regular form in a special book. The first page should be occupied by details of the number of cylinders, the dimensions of each, and the variation of the compass.[1] The remaining pages should be ruled according to the form given below. The first column is for the date, and the second for the time at which the earthquake was experienced; and for this it would be well to abolish A.M. and P.M., and consider the day as divided into 24 hours; thus, 3-40 P.M. would be written 15 *h.* 40′. The third column is for the number of cylinders overthrown; the fourth for the direction in which they are overthrown, and if, as is probable will be found to be the case when more than one or two cylinders are overthrown, the direction is not the same in every case, the direction in which each separate cylinder is overthrown should be noted; in the fifth column this direction should be entered, corrected for magnetic variation; the sixth column should contain the velocity of shock corresponding to the largest cylinder overthrown; and the last column is for any remarks as to the general nature of the earthquake, or its effects, that may be noticed. These directions will, perhaps, be made clearer by the examples given below, which, it is probably needless to remark, are purely imaginary :—

Record of Earthquakes during the month of January 188 at Cachar.

Date.	Hour.	No. of cylinders overthrown.	Observed direction of overthrow.	Corrected for mag. var. =2° 30′ E.	Velocity of hor. comp. of shock.	REMARKS.
January, 2nd	3 h. 30′	1	N. 15° W.	N. 12° 30′ W.	·6	
Ditto, 8th	12 h. 27′	3	N. 5° E.	N. 7° 30′ E.	1·5	
Ditto, 26th	0 h. 40′	10	...	...	5·0	
		1	N. 5° E.	N. 7° 30′ E.		
		2	N. 4° E.	N. 6° 30′ E.		
		3, 4, 5	N. 3°·30′ E.	N. 6° E.		
		6, 7, 8, 9, 10	N. 3° E.	N. 5° 30′ E.		

This instrument gives us the direction and velocity of the horizontal component of the shock, the only other elements needful to form a complete seismometer are the exact time and the velocity of motion of the vertical component; of these, the former necessitates an accurate time-keeper, while for the latter no simple instrument has yet been proposed, but we would suggest that the following modification of one of Mr. Mallet's self-registering seismometers will be found effective: Let a piece of wood, say 6 inches square and 6 or 7 feet long, be taken; then at each corner of one end a

[1] This may be obtained by so placing two plumb lines that a line drawn through both of them may point to the pole star when the pointers of the Great Bear are either vertically above or vertically below it, and then observing the angle between the direction given by these two plumb lines and that given by the compass.

cubical recess must be cut, into which a spherical leaden ball will just fit,—a 12-bore spherical bullet will do, but a larger size would be better; now, taking the inner corner of each cube as a centre and the length of its side as radius, describe a quadrant on the base of each; up to this quadrant the wood must be bevelled, and the bevel continued along each longitudinal edge of the log to a point exactly 4·05, or 4 feet ½ inch approximately, from the centre of the ball as resting in its cubical hollow, where the bevel will end abruptly in a horizontal ledge; the bevel should have been increased so that this ledge shall be a quadrant of exactly similar shape to that forming the base of the recess above, but of course reversed. These directions may seem rather complicated, but the three sections given on plate XIV will, we fancy, render them easily intelligible. On each of these lower ledges a projecting pin should be placed, so that when the whole affair is set upright the pin will be vertically underneath the centre of gravity of the ball above it. This post must be set absolutely vertical in the ground, and dry sand be filled in up to the level of the lower ledges. To read the instrument, a straight-edge of some 6 feet in length should be made, with one edge bevelled and one end cut away towards the bevelled edge, at an angle of about 30°. Close to this pointed end a small notch must be made on the bevelled edge, and from this notch a scale of inches and tenths of an inch carefully laid off.

After the passage of a shock it will probably be found that all four balls are displaced, two will be found lying on the ground, more or less directly underneath their original positions, while either one or both of the others have been projected to some distance; one of these should be cautiously lifted, and the point which lies directly underneath the centre of the ball as it lay on the ground should be marked. Then take the wooden straight-edge and place the notch against the pin, underneath the original position of the ball, and bring the edge over the mark, showing where the centre of the ball lay; then read off the direction and length of the line joining these two points. Should two balls be projected, the same must be done in the case of the second, and both results recorded separately. The results may be entered on the same form as those of the cylinder seismometer by adding two columns, one for the direction and the other for the distance to which the balls are projected.

The height, 4·05 feet, is selected, as it is the height through which a body falls in one-half of a second; any other height would of course answer, but by taking this particular value, the subsequent calculations by which the observations are reduced are very much simplified.

It is evident that this would not be a suitable form of instrument to set up by itself, as the projection of the bullets to any particular distance might be due either to a high angle of emergence and a moderate velocity or to a low angle of emergence and a higher velocity of shock. If, however, the velocity of motion of the horizontal component of the shock be known, as would be the case approximately wherever a series of cylinders was established, this instrument will give a datum from which, by a simple calculation, the velocity of motion in the vertical component can be obtained.

From these two instruments, which are well within the constructive power of any native carpenter, results of very great value in the present state of seismology can be obtained, though there are doubtless many more perfect instruments than these; yet from their very perfection they are necessarily so expensive as to put them practically beyond the reach of private observers, while the expenditure is not one that could be recommended to Government; besides, while these instruments, to develope to the full their capacities, must be situated either at or in electrical connection with some astronomical observatory where the results would be automatically recorded on a chronograph, there is no astronomical observatory in India advantageously situated for seismological observations. It is otherwise with the two instruments above described, they would be inexpensive and could be attended to by any one able to read meteorological instruments.

The day may not yet be far off when every meteorological observatory throughout the arthquake-shaken districts of India may have attached to it these two instruments or some more perfect form of seismometer; and it is not too much to say that when such is the case, and these observations are communicated to a single centre, there to be compared and developed, five years will see more done towards learning the true cause of origin of earthquakes than has been effected by all the speculative theorizing of the past.

R. D. O.