MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

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VOLUME XLII

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INTRODUCTION.

In his survey of the geographical distribution of recorded earthquakes, F. de Montessus de Ballore, referring to Burma and adjoining regions, has remarked,— " Aussi les tremblements de terre sont-ils fréquents et redoubtables dans tous ces pays. Malheureusement, les informations séismiques sont encore bien insuffisantes dans le détail, et il n'a jamais été fait d'observations systématiques."(1)

Beyond the dates of a few earthquakes which occurred in Burma during the latter part of the 17th and in the 18th century, and the meagre details of the effects of two or three of them as collected and recorded by T. Oldham in 1883 (2), practically no accurate information exists about the seismic disturbances which universal traditions of the Burmese people assert to be frequent and severe in many parts of their country.

That these traditions are likely to be true is suggested by the intense folding of the mountains of the province, and by a consideration of the more recent geologic events to which the area has been subjected. In these accounts of the earthquakes which were felt throughout Burma during the latter part of May 1912, and which were also felt in Siam and in the Yünnan province

[1] F. de Montessus de Ballore. Les Tremblements de Terre. Geographie Séismologique. Paris, 1906, p. 192.

[2] Thomas Oldham. A Catalogue of Indian Earthquakes from the earliest time to the end of A.D. 1869. *Mem., Geol. Surv., Ind.*, Vol. XIX, Pt. 3, Calcutta, 1883.

of Western China, complete data of all observations will be given even at the risk of repetition of uninteresting details, for unless recorded here they will quickly pass into oblivion, and these earthquakes will share the fate of the earlier unrecorded ones. In most countries, earthquake effects, with the exception of those which accompany shocks of extreme intensity, are of an evanescent character, and this is particularly the case in Indo-Chinese countries in general and in Burma in particular, where the whole population exists in bamboo houses of the flimsiest construction, and where the only stone edifices are those of a religious character, or the semi-European, semi-indigenous structures erected in centres of British influence. If this report proves to be incomplete, the reasons must be sought for in the circumstances just mentioned, and in the fact that it has been found very difficult to collect evidence from areas, often of vast extent, which are sparsely inhabited by tribes to whom the earthquake is a capricious act of the denizens of the under-world, and as such, unless attended with dire consequences, being inexplicable, is treated with indifference and soon forgotten.

The first accounts of the shocks to reach India appeared in various newspapers on May 25th. At that time I was stationed on the Yenangyaung Oil Field. On the 27th May I received orders by telegram from the Director of the Geological Survey of India to start immediately and investigate the effects of the shocks. Owing to the infrequent steamer service on the Irrawaddy river I was unable to leave for two days, when I proceeded to Mandalay, and later visited Maymyo and the immediate district comprised in the epicentral tract beyond. On the completion of this examination urgent duties on the oil-field demanded my return to Yenangyaung. It will thus be seen that I was unable to visit enormous areas in Burma and the Shan States over which the shocks were felt, and for these I have had to depend on accounts furnished by local observers scattered throughout the province. It is doubtful whether any good purpose would have been fulfilled by a personal inspection of these other areas, as by the time I could have arrived therein owing to the distances involved and the slow means of communication, the temporary effects in such a land would have been almost if not entirely obliterated. The usual system in India of depending on filled-in question forms was not available to any extent, and I have to thank the district magistrates throughout the province for their cheerful assistance in answering the questions which I addressed to them, as soon as the extent of the disturbances was realised. The help of the educated public was invited by similar questions circulated in the daily press, and letters were addressed to the heads of various departments, and to many of the railway and postal officials in the affected areas. It is impossible to name all my helpers individually, and I must therefore be content to thank collectively on my own behalf, and on behalf of the Geological Survey, all members of the various civil departments under the Government of Burma, His Britannic Majesty's Consuls in Yünnan, the newspaper editors of Burma and Siam, and the numerous private persons for generous assistance so freely given.

It is hardly necessary to point out that such data must vary very greatly in accuracy, coming as they do from the careful official observer on the one hand, to the untrained and often terrified witness on the other. Again, the difficulty of stating the results of an earthquake in an Eastern land in terms of a scale established in Europe is well known. In spite of these difficulties, and by the elimination of doubtful observations, it is believed that the following pages approximate very closely to the actual facts, and that the conclusions drawn from them are as accurate as it is possible for them to be.

The following letter was addressed to all deputy commissioners in Burma :—

Under the orders of the Government of India, I am investigating the Maymyo earthquake of May 23rd last. In this connection I have the honour to request that you will kindly forward me any accounts of the shocks and the damage they may have done in your station or district. Reports of engineers, building inspectors of Municipalities and divisional officers, or indeed all trustworthy evidence of any kind will be invaluable in aiding towards elucidating the causes. Both this shock and a preceding one appear to have been felt to a greater or lesser degree throughout the province. Particulars are especially wanted concerning :—

1. The *time* at which the shock was felt. The means by which the time was observed, whether merely guessed, whether recorded at the moment by a watch, and whether the watch was compared with a clock known to keep a recognised standard time, such as a railway or telegraph office clock.

2. *Number of distinct shocks.*—Particulars of any preliminary tremulous vibrations, the number of principal and prominent shocks, and the existence of tremulous vibrations after the principal shocks and the time of their duration.

3. *Apparent direction* of shocks, judged by the fall of loose objects, hanging lamps, or movements of water in tanks and bath-tubs.

4. *Sound Phenomena.*—Please state the nature of any sounds noticed before, during or after the main shocks.

5. *Intensity of the shocks.*—Please state whether the shock was "hardly felt" or "distinctly felt". No apparently unimportant detail should be omitted, as in the absence of instrumental records, this evidence is the only means of making the approximate determination of the focus of disturbance.

6. *Effects of the Earthquake*—

(*a*) Particulars of objects overturned, their position and direction of fall.

(*b*) Details of cracks in buildings with their direction, and accurate direction of any affected wall.

(*c*) Direction and movement of free swinging objects, such as hanging lamps.

7. *Aftershocks.*—Date, time and approximate intensity of aftershocks.

8. *Place and district* in which the observations were made.

9. *Full name and address* of observer to permit of adequate acknowledgment in published report.

SUMMARY OF THE SHOCKS.

The earthquake of May 18th was the first disturbance which took place in Upper Burma during the summer of 1912. It occurred between 2-45 A.M. and 3 A.M. (B.S.T.)(1) as far as can be ascertained, and appears to have disturbed the western portions of the Northern and Southern Shan States. It caused no appreciable damage and probably did not exceed an intensity of V on the Rossi-Forel scale. No records have been received of aftershocks following this quake.

The violent earthquake of May 21st appears to have been felt throughout the whole or greater part of the Northern and Southern Shan States, and the districts of Mandalay, Ruby Mines, Shwebo, Sagaing, Lower Chindwin, Kyaukse, Myingyan, Meiktila, Magwe, Yamethin, Toungoo, and Pegu as well as over Northern Siam. The minimum area over which it was sensible approximates, therefore, 125,000 square miles. In the central parts of this area, an intensity of at least VII on the Rossi-Forel scale was attained, and in some places loud rumbling noises accompanied the shock. The intensity appears to have died away rapidly, and in places like Kani in the Lower Chindwin district, and in Pegu, only reached degrees II or III on the Rossi-Forel scale. Unfortunately no exact time data exist, and the nearest approach to accuracy possible is to state that it took place about 3 P.M. (B.S.T.). This shock was recorded by the Omori seismograph at Rangoon College, and by the instruments at the meteorological stations throughout India. It was followed by continuous aftershocks felt during the remainder of that and the following day in Maymyo, Mandalay, Taunggyi, Kyaukse and other places, and which gradually became fewer, until the climax was reached by the great shock of the morning of May 23rd, which was sensible over an area of 375,000 square miles approximately, and disturbed recording instruments throughout the world.

This latter shock will be described first in the following pages. It was followed by innumerable small aftershocks in May, June, July and August, which gradually became fewer and finally ceased.

Unhappily there are signs that the forces which caused the quakes have not yet attained equilibrium, for on January 18th, 1913, a

1 Burma Standard Time.

severe shock was experienced during the early hours of the morning in Maymyo.

Comparison with other great earthquakes

The following list of areas affected by some of the larger tectonic earthquakes of historic times has been compiled by Tarr and Martin(2) and to it the Burma earthquake of May 23rd, 1912, has been added for comparison :—

Centre.	Date.	Approximate Area affected.
		Sq. miles.
Lisbon, Portugal	1755	2,240,000†
New Madrid, Mo.	1811	1,250,000
Charleston, S. C.	1886	2,800,000
Riviera	1887	219,000
Sonora, Mexico	1887	500,000
Japan	1891	330,000
Assam	1897	1,750,000
Yakutat Bay, Alaska	1899	1,539,000
Kangra	1905	1,500,000
San Francisco, Cal.	1906	372,700
Burma	1912	375,000

It will be seen that the Burma earthquake ranks with the smaller of the great tectonic earthquakes quoted in the above list as regards extent of area disturbed. Like the Yakutat Bay shocks the Burma disturbance is in decided contrast with the others, all of which took place in densely populated districts and caused great destruction of human life and property. In Burma with one or two doubtful exceptions, no loss of life was reported, and the damage caused to property, though extensive, was incomparably smaller than that caused by the other listed shocks. This is largely due to the scanty population of the severely shaken tracts, and to the character of the dwellings in which this population lives. It is also interesting to note that the ratio of the area over which buildings were damaged, to the total area over which the shock was sensible, is about the same in the cases of the Burma and Assam quakes.

[2] Ralph. S. Tarr. and Lawrence Martin : The earthquakes at Yakutat Bay, Alaska in September 1899. *U. S. Geol. Surv.*, Prof. Paper 69, 1912, p. 128.

† According to Oldham perhaps only 1,000,000 sq. miles.

GENERAL ACCOUNTS OF THE EARTHQUAKES.

General accounts of the shocks began to appear in the newspapers of Burma about the 25th May, and in the Indian press a few days later. The reports from Maymyo mentioned that nearly every year about this time, the station in common with other towns in Upper Burma is visited by an earthquake, the last big one being in 1908. At 3 A.M. on the morning of the 18th May 1912, the first slight quake was noticed, but it did not cause much alarm. After that the shocks continued at irregular intervals and with varying intensities. At 3 P.M. on the 21st there was a fairly severe shock and the worst took place at about 9 A.M. on the morning of the 23rd, causing a great deal of damage throughout the station. In the open it could be heard approaching from a considerable distance, the sound being like low thunder accompanied by the crash of falling bricks and plaster wherever buildings were in the vicinity. In Government House, Maymyo, wooden beams, bricks and plaster came down. In the Club two chimneys and several portions of the interior brick work fell, whilst nearly every fair-sized brick building in the station suffered more or less severe damage. The Alexandra Barracks seemed to have fared worst on the whole. Several chimney stacks fell on to the roofs of the bungalows, and many more had to be pulled down afterwards as they were unsafe. In the administrative block of the station hospital two chimney stacks came down, the veranda roof was ripped off the family hospital, most of the married quarters were badly damaged and four or five kitchens were wrecked. In the Chaplain's house the greater part of the drawing room walls collapsed. The Officers' mess of the Border Regiment was injured. The Mohammedan mosque looked as if it had only just escaped demolition, and an eye-witness said that the Baptist Church tower only seemed to stand by a miracle, so great was the swaying. On the Northern Shan States branch of the Burma Railways between Nawnghkio and Hsum-hsai, at mile 451 (29 miles by rail from Maymyo), 300 tons of earth fell from a rock cutting and blocked the line. A little further on an embankment slipped and fell 5 feet, and a section of the line running north and south was bent in a curve to the east. Slight shocks continued throughout the day and are described as being more like violent tremors than waves.

Accounts from Mandalay state that the severe shock was felt about 9 A.M. on the morning of the 23rd. It lasted about a minute and caused much damage which would have been enormous had the shaking continued a little longer. The Leper Asylum was cracked in every direction. The Roman Catholic cathedral was very badly cracked. The mosque in B. road lost ten feet at the top. The Wesleyan School had a loose mass of masonry resting over nearly every doorway. The 20,000 gallon water tank in the Zeygyo Bazaar, and the Tramway oil tanks slopped about like carelessly carried hand-basins. During the shocks inmates of houses bolted into the open. Later accounts described the dismantling and repairing which was going on in various parts of the city.

From Taunggyi came the news that the shock lasted over one minute there and caused considerable damage to the buildings in the station. The telegraph office suffered most and the staff had to take to tents. Almost all chimneys were thrown down or cracked, while the military hospital, treasury and military police quarter guard were in a critical condition.

At Mogok numerous foreshocks were felt, but most damage was caused by the shock which occurred about 9 A.M. on May 23rd. Almost all the brick buildings in the town were cracked while no less than 60 pagodas fell down. Owing to damage caused to waterpipes by falling rocks, the electric supply of the Ruby Mines Company, Ltd., was interfered with and the place was in darkness for two nights.

Reports also appeared from Meiktila, Toungoo, Sagaing, Hsipaw, Gokteik, Kalaw, Yamethin, Bhamo, Rangoon and various towns in Siam, which will be referred to later. It is proposed to arrange all the accounts which have been received according to the administrative divisions of the province, commencing first with those districts in Upper Burma where the shock of May 23rd was most severely felt.

PART I.—Records of Observations.

CHAPTER I.

EPICENTRAL AND SEVERELY SHAKEN AREAS.

Mandalay City and District.

The city of Mandalay lies in the centre of the narrow belt of the Irrawaddy alluvium which in this neighbourhood diminishes to a minimum width of some 11 miles. To the west of the river the alluvial plain is bounded by the long narrow range of the Sagaing hills, belonging to the Mogok gneissic series, with terraces of yellow sand-rock of late Tertiary age covering its base. On the east rise the lofty limestone hills forming the rim of the Shan plateau. The alluvium probably does not attain a very great thickness, for to the north of the city Mandalay Hill rises steeply from the plain. Both this and other isolated hills in the vicinity are composed of gneisses and crystalline limestones of the Mogok series. The whole length of the western edge of the Shan plateau forms a great scrap marked by a fault, which is held to bear a considerable geological likeness to the outer bounding fault of the Himalaya.

Of the 2,100 square miles comprised within the Mandalay district only about 600 square miles are flat land. This lies along the Irrawaddy river with a few solitary hills rising in places from the level alluvium. The remaining 1,500 square miles, in the north and east of the district, are made up of high hills and plateaux forming a part of the Shan tableland of Upper Burma. At the edge of this the fall to the plains averages 3,000 to 4,000 feet in 10 miles.

Mandalay city is divided into—

1. The Municipal area.
2. The Cantonment.

The former is enclosed within an area which measures about 6 miles from north to south and 3 miles from east to west. It is laid out symetrically with wide roads, and although many brick buildings exist, especially in the commercial quarters, a large part of the population lives in wooden houses of the ordinary Burmese style.

The Cantonment comprises what was formerly known as the city, *i.e.*, the portion between the four brick walls built in 1856-57 by King Mindon. It is now often referred to as Fort Dufferin.

Within the total area three-quarters of the masonry structures were damaged, there were five total collapses, thirty-one buildings were severely damaged and seventy-five more or less cracked. Nearly every pagoda and masonry rest-house in the city was damaged.

I am indebted to Mr. Cecil Scott, Officiating Engineer of the Mandalay Municipality, for the following list of buildings damaged by the earthquake.

The part most affected is known as the "pucca area" and lies between C. Road on the north, 29th Road on the south, 80th Street on the east and 85th Street on the west. The damage outside this area was not great owing to the absence of masonry work. The following buildings collapsed :—

1. The Armenian Rest-House on C. Road.
2. Building known as Holding No. 17, Block No. 38, Pyigyikyetthaye Quarter.
3. The mosque on B. Road.
4. The furniture shop adjoining the mosque.
5. Building known as Holding No. 9, Block No. 26, Palengweyaung Quarter.

The following buildings were severely damaged :—

1. The Leper Asylum.
2. The Exchange.
3. The office of "The Mandalay Herald."
4. The "Upper Burma Gazette" Press.
5. The Roman Catholic Bishop's House.
6. The Cathedral.
7. The residential portion of the Public Library.
8. The Town Dispensary.
9. Building occupied by Mr. H. Strentz.
10. New Medical Hall.
11. Building situated at the junction of 29th and 81st Street.
12. Upper floor veranda of Bowyer & Sowden's.
13. Salween House.
14. Ally's Medical Hall.

15. Building known as Holding No. 43, Block No. 50, Pyigyikyetthaye Quarter.
16. Iyer's Building, C. Road.
17. Building known as Holding No. 45, Block No. 57, Pyigyikhetthaye Quarter.
18. Building known as Holding No. 22, Block No. 49, Pyigyikyetthaye Quarter.
19. Mandalay Medical Hall.
20. The Female Dispensary.
21. Building nearly opposite "The Mandalay Herald" Press.
22. Hanthawaddy Press.
23. Building known as Holding No. 37, Block No. 45, Pyigyikyetthaye Quarter.
24. Building known as Holding No. 17, Block No. 38, Pyigyikyetthaye Quarter.
25. Buildings known as Holdings Nos. 26 to 36, Block No. 36, Pyigyikyetthaye Quarter.
26. Buildings known as Holdings Nos. 22 and 23, Block No. 48, Pyigyikyetthaye Quarter.
27. Building known as Holding No. 26, Block No. 62, Chanethazan Quarter.
28. Building known as Holding No. 45, Block No. 57, Chanethazan Quarter.
29. Building known as Holding No. 3, Block No. 63, Chanethazan Quarter.
30. Building known as Holding No. 42, Block No. 59, Chanethazan Quarter.
31. Buildings known as Holdings Nos. 4 and 5, Block No. 154, Shwebonshein Quarter.

The remaining seventy-five damaged buildings enumerated by the Municipal Engineer were situated in the Chanethazan, Pyigyikyetthaye, Aungnanyeiktha, Yadanabonmi, Mahaaungmye, Shwebonshein, Thirihema and Hemazala Quarters of the city. They include the Taungdaman, Sagu and Masoeyein monasteries and the Chinese Temple. The clock-tower of the Zeygyo Bazaar swayed backwards and forwards and was undamaged, but the metal finial fell and bent over due north.

PERSONAL OBSERVATIONS IN MANDALAY.

The Palace.—The royal palace of Mandalay consists of a group of wooden buildings standing on a brick platform inside Fort Dufferin. As was to be expected very little damage was caused to the majority of these structures, with the exception of the following:—

The Bodazin or Bell Tower, of which the whole of the south-east corner had collapsed.

The Museum.—This was a one-storeyed rectangular building with massive masonry walls and raftered roof. The north and south running walls were badly broken and had partly fallen down, while the arches which were left were cracked through. The south end of the building had sunk slightly.

Burmese buildings often have a wooden core set into the walls, and pillars with a shell of brickwork on the outside. After the earthquakes in Mandalay I noticed that it was quite usual for the two to have separated. I also observed that many of the more severely damaged buildings in the city were built of very poor bricks. It appears to be a common custom of the Burmese builders to use badly burned or raw bricks in their work. A mixture of powdered brick and mud seemed often to have been used instead of lime in the poorer types of houses of this kind. I was informed by Taw Sein Ko, I.S.O., Government Archæologist in Burma, that between the years 1885-1895, many pagodas and monasteries were dismantled in Mandalay and the bricks from them largely used in the construction of dwelling houses. These facts doubtless have a bearing on the damaged walls, roofs and verandas.

The Palace wall.—Fort Dufferin is surrounded by four battlemented brick walls twenty-two and a half feet high. The walls form a perfect square, each side measuring six hundred "tas," (1 "ta" = 11·11 feet). Over the walls at regular intervals of fifty "tas," are watch-towers or turrets (called "pya-o"), each having gold tipped spires. There are twelve city gates, the four principal ones being in the centre of each side of the square, and bearing due north, south, east and west from the palace, which is built in the centre of the city square. The crenellations on the top of the walls had been shaken down in places, especially in the case of the north and south walls, *i.e.*, those running east and west. Loose bricks and mortar had also fallen in many places. In the case of the north gate the small "pyatha"[1] above the entrance was badly damaged.

[1] The wooden building erected above each main gate.

The thick walls below were bulged out towards the east, and the main walls running in an east and west direction were cracked from top to bottom, by slight cracks meeting the ground at an angle of 45° approximately.

Watch tower, Jail wall.—This particular wall runs in a north and south direction, and the watch tower which was partly built into it had been broken away.

The Shwekyimyin pagoda.—This pagoda lies in the Pyigyikyet-thaye Quarter. It was built about the 13th century and is one of the most venerated shrines in Mandalay. A large part of the spire and the whole of the "hti"(1) were smashed off.

Municipal Office, Secretary's Room.—A brick nogging panel in the north-west corner had dropped bodily out.

St. Mary's Church.—Contained no new cracks, but an old crack in a wall coursing north and south was considerably widened.

The Exchange, Merchant Street.—This building is a typical example of the usual type of masonry buildings in Mandalay. The walls running in an east and west direction were so badly smashed that they had to be pulled down. The other walls moved towards the north.

The Women's Dispensary.—A two-storeyed brick building, badly cracked in all directions. It seemed to have been subjected to rapid shaking.

The Male Dispensary.—The walls built in a north and south direction appeared to have suffered most. They had also moved slightly towards the north.

Brick Building in B. Road.—A wall coursing in an east and west direction bulged so much that it had to be dismantled.

Mahomedan Mosque.—The large minaret collapsed and fell into the road, but the fragments had been cleared away before my arrival.

Brick Building belonging to Bowyer and Sowden.—The veranda on the first floor of this two-storeyed building was badly cracked, some of the rafters were displaced, and the whole veranda on the west side seemed to have been pulled away from the rest of the structure.

Roman Catholic Cathedral.—A large masonry building constructed in a heavy European style with a high steeple and belfry attached.

[1] The ornamental iron work finished off with a long rod, which crowns the top of a Burmese pagoda.

In the wall coursing north and south there were wide intersecting cracks which made angles of 53°—55° with the horizontal. In the wall running east and west a single crack met the ground at 55°. The eastern end wall of the cathedral was thoroughly cracked from top to bottom. The walls of the steeple running in a north and south direction contained great cracks for at least half their height.

Salween House.—A two-storeyed brick building used as an hotel was so badly damaged that it had to be dismantled.

Leper Home.—A heavy three-storeyed brick building with a brick tower supported on massive pillars. The main block runs east and west. Large cracks traversed the building from north to south. The pillars supporting the tower were cracked in many places and were bulging out at the time of my visit.

Wesleyan Boys' School.—A series of two-storeyed flat-topped masonry buildings oriented east and west and north and south. The walls coursing east and west were very much cracked but those running north and south were hardly damaged.

Wesleyan Church.—A brick building some 96 feet long, facing north and south. In both long walls running north and south there was a well marked horizontal crack about 4 feet from the ground. This could be followed along for half the length of the building, just below the base of the windows, the arches of which were not damaged. The eastern wall was also cracked vertically in two places.

Mandalay Clock Tower.—The spire of this tower was cracked in the middle and bent over towards the north.

I noticed that in the case of many of the flat-topped Burmese houses in Mandalay, which are built partly of brick and partly of wood, the wooden railings used as parapets for the roofs were often knocked over. In the case of walls coursing north and south this was very frequently the case, but it was not so common on walls running east and west.

Mandalay Railway Station.—A long series of brick buildings of massive construction, the central one surmounted by a clock tower. I noticed many small recent cracks in some of the walls and in the main entrance arches, but they did not follow any particular direction. There were bigger cracks between the window frames and the brickwork.

Amarapura.—The "hti" of the large pagoda in the centre of the old city of Amarapura was cracked in the middle and bent over towards the north. The "hti" and greater part of the top of the large pagoda which marks the site of the north-east corner of the old city were smashed away.

Accounts from Mandalay and district.

Mandalay.

Mr. P. N. Manackjee, Secretary to the Municipality.—Time 8-55 A.M. The shock came in gentle undulations from the N. N. W. and lasted for one minute. He has resided in Mandalay since 1889 and gave the information that there were yearly shocks after that date for 5 years, since when there has been a period of quiescence.

Mr. R. C. J. Swinhoe, Barrister.—Time about 9 A.M. He was seated working in his office, a one-storeyed brick building, when the shock commenced with a gentle shaking. This quickly became very severe and he fled into the open with his clerks, as the plaster began to fall from the walls. Outside they could only stand with great difficulty. The houses all around were shaking, and they saw the Mahommedan mosque collapse. The movement was from N. to S. and appeared to be a shaking directly underfoot rather than wave motion. It lasted ½ minute and caused sickness; towards the end, the road was noticed to be heaving in gentle undulations. In his residence ornaments had all fallen towards the north, and the lid of a Pegu jar was also knocked off in the same direction.

Rev. T. Phillips, Mandalay.—The movement came in gentle undulations with four big vibrations which are compared to a monsoon wave hitting a ship. Duration 1-1½ minutes. Schoolmaster and boys ran out of school but had to kneel on the road as they could not stand. Some of the school girls fainted.

The Postmaster, Mandalay.—In answer to my enquiry, wrote that no one in the Post Office kept a note of the exact time of the shock, but that it was about 9 A.M.

Mr. J. Owen, Deputy Superintendent, Mandalay Signal Office.—The shock was noted at 8-46 A.M. at the Mandalay Telegraph Office when the clock stopped.

Mr. W. C. Cantrill, District Engineer, Burma Railways, Mandalay.—Time according to railway clocks was just about 9 A.M. The time recorded by one Station Master was 8-57 A.M. Many clocks appear to have stopped at the start of the severe tremors. One observer stated that the sound before the earthquake was quite apparent and resembled the rumbling of a string of carts loaded with loose sheets of iron. People appear to have been too frightened to give any coherent statement of sound phenomena during the period of the actual shock. Those standing at the time of the shock felt it most, some who were travelling were not conscious of any vibrations at all. He personally did not know of the earthquake for this reason. Walls were cracked in all directions and no special law of failure was noticeable. Some objects fell from E. to W. He could not obtain any definite or reliable information about the number of distinct shocks.

Mr. S. H. Armitage, Irrawaddy Match Co., Ltd., Mandalay.—The big shock of May 23rd finished at 9-1 A.M., by the works' clock, which is always accurate to one or two minutes. Subsequently he had occasion to visit Mandalay Railway Station, and found that the big clock had been stopped at exactly ½ minute to 9 A.M. Regards this as the time when the shock most probably reached its maximum. It came on fairly suddenly, increasing in power for perhaps 7 or 8 seconds, then slightly diminishing to increase immediately to greater violence, another slight diminution then followed and suddenly increased to the maximum effort which lasted quite half a minute. It was continuous for not less than 60 seconds, and not more than 90 seconds. During the last portion he was certain that a big chimney stack and the end walls of the building would come down. His position of observation was in the middle of the compound, and the above periods were noted by the swaying of a steel chimney 80 feet high, which partially pulled up two logs to which it was stayed on the N. and S. by wire hawsers. Those on the E. and W. were not apparently moved. Every few minutes after the principal shock, greater or lesser minor disturbances were noticed for some hours. They only lasted a very few seconds, the periods between them lengthening and the violence diminishing during the day. From 9 to 10 A.M. he distinctly felt 12 shocks which produced an appreciable sound in the office building, which is not very solid and stands on piles. No preliminary tremors were felt during the immediate period (of say 6 or 12 hours), before 9 A.M. Several were felt at intervals following on the shock which took place at 3 P.M. on May 21st, 1912, and which lasted about 30 seconds, but these are not regarded as preliminary tremors to that of the 23rd, although if the disturbances are regarded as a whole they were remotely preliminary.

All the evidence in his large compound unanimously shows that the shock occurred along a line N.N.W.—S.S.E. and certainly confined between the limits N.W.—S.E. and N.N.W.—S.S.E. One interesting fact is quoted :—a big wall and some smaller ones coursing E.N.E.—W.S.W., had loose mortar and bricks shaken from the top, but these only fell on the N.N.W. side. There is an entire absence of any local reason why this should be so, but not a brick or a piece of mortar were found on the ground on the south side.

There was no sound before the shock. During it a loud rumbling was heard, but this was *only* due to the straining of the various buildings. He has heard exactly the same noise during a subsidence due to brine pumping in Northwich, Cheshire. He supposes that many people will write of a great noise through being unable to differentiate between the actual shock and its results. The shock was intense, and it required a considerable muscular effort to stand. Many of the women employed at the works were thrown to the ground and some afterwards vomited. All the Europeans whom he afterwards met said that they felt "rather sick," not from fear but solely from the motion. He distinctly felt the rise and fall in the ground similar to the sensation felt in a lift but the alternations were very rapid.

All falls of bottles, lamp globes, and crockery conformed with the direction already given. Some of the machines in the works were half emptied of molten paraffin, which could not have taken place had they not inclined quite 10°—20° from the vertical, and yet they were not damaged. They rolled on their long bases and inclined N.N.W.—S.S.E.

During the aftershocks, he often watched the swinging of two hanging lamps suspended in a bungalow, which is built on piles on a slope so that the floor is from 18 to 24 feet from the ground. The lamps often attained a large swing from the vertical and the direction was in every case between N.W.—S.E. and N.N.W.—S.S.E.

In a later communication, Mr. Armitage again drew attention to the fact that the shock was cut up into three distinct periods of intense agitation of which the last was much the greatest. At first it was impossible to form any idea of the velocity, and it can be best described as the sensation felt in a big building in which a high speed engine is running. In fact at the outset he thought that the engine in the factory had "run away."

Mr. M. Paul, 1st Assistant, St. Xavier's School, Mandalay.—A rumbling noise attended by vibrations preceded the very severe shock, which was felt at 8-40 A.M (guessed), and lasted for 40 seconds. The "htis" of big pagodas dropped off. The walls of the fort cracked and portions crumbled down. The water in the moat danced to a height of 1 foot. Almost all buildings in the town cracked in all directions, and many of their ornamental fronts tumbled down. The mosque in B. road lost its minaret and was much damaged. The Cathedral swayed and the bell in it rang; the back portion was very much damaged and the bricks fell towards the E. and W. It now seems to slant a little to the south. In a piece of ground near the fort walls, two cracks were formed, each measuring about 12 feet in length and about 2 inches in breadth. There were 5 slightly felt aftershocks.

Mr. E. C. Beresford-Parnell, Mandalay.—The station clock, about half a mile away from the observer's house, stopped at 8-55 A.M. He was sitting in a chair facing S. and felt himself thrown in the same direction. He ran into the compound and still facing south, saw the earth moving towards him in waves about 1 foot high and about 2 feet distant from each other. Cannot state how far E. and W. the waves reached, but noticed the cook, at least 50 feet away, swaying backwards and forwards as he was doing. Duration between 50 and 60 seconds, calculated afterwards by 3 witnesses. All the cracks in the building were at right angles to the earth's plane. The S. wall, running E.—W., bulged outwards from $\frac{2}{3}$rd of its height to the top, and had to be dismantled and rebuilt.

Superintendent of the Observatory, Mandalay.—Time 8-57 A.M. Duration 3 minutes. One shock followed by 5 or 6 slight ones during the day. A sound was heard during the shock which conveyed the impression that a heavy engine was moving over the road close by. Permanent shelves with their contents were thrown down. Plaster and bricks fell from walls and injured a hospital servant. About 10 feet of the upper part of a pagoda fell down as if cut with a knife. Walls of brick buildings were so cracked as to render them unsafe.

Sub-Postmaster, Mandalay Military Police Lines.—Time 8-55 A.M., by office clock set to railway time. A sound was heard like that caused by a running train, for about ¼ minute before and until the shock ceased. Duration about 1 minute.

Sub-Postmaster, Mandalay General Hospital.—Time 8-55 to 8-59 A.M. Duration 3 minutes. A moderate shock, severe for 1 minute. A mail van moved a distance of one yard. An electric tram car stopped in front of the office as the trolley was shaken from the live wire. In his private quarters, things on the table fell off. His wife and baby slipped from one corner to another and very nearly fell from the ladder to the lower floor. The office clock stopped. Owing to the post office being built of wood no damage was caused. "There was some sound observed before shock."

Madaya.

U. Thin, Sub-divisional Officer.—Time about 9 A.M. Observer is 53 years old and has never noticed such a great shock before. It seemed to wave in a N. and S. direction and lasted for about 5 minutes. In the subdivision many pagodas were damaged and some were broken down from ½, ⅓, and ¼ of their heights.

Zigon.

Mr. A. E. Eades of Mandalay.—He was on the top of a hillock, seated against a rock, 2 miles N.W. of Zigon, a village about 5 miles N.E. of Singu, which is itself some 60 miles N. of Mandalay. Time 8-55 A.M., by a reliable watch set to the Mandalay tower clock. Duration 1 minute and 20 seconds. He heard a very distinct tremulous vibration as if the sound was passing underneath the hill. It seemed like a cavalry charge riding past a saluting base, and as if the charge had started from a long distance away and increased as it came nearer. The shock was distinctly felt, at first as 2 or 3 slight and distinct vibrations, and then one continuous motion like a child's cradle being roughly pushed forwards and backwards. After the principal shock there followed a minor one which was very slight and jerky.

Myohaung.

Mr. T. Johannes, Station Master.—He was seated at an office table in a wooden building when the severe shock started at 8-55 A.M. Duration 1½ minutes. He ran out and remained standing on the platform, "which felt like a ship at sea." He suffered from giddiness for the rest of the day. Out of three clocks in use at this station, two in brick buildings stopped, but one in a wooden building did not do so. The pagodas round about were badly damaged and lost their "htis." Messrs. Finlay, Fleming and Co.'s dynamite magazine was slightly cracked but the detonator magazine which is smaller and lower, remained intact. After the main shock there were slighter ones at short intervals up to 9-2 A.M. Again at 9-44 A.M., at 11-30 A.M., and the last at 3-15 P.M.

Myohaung.

Mr. R. C. J. Swinhoe, Barrister of Mandalay.—He noticed that long stacks of bricks piled near the railway station at Myohaung and running in a N. and S. direction had the bricks at the S. end shaken off. This appears to indicate that the impulse was imparted to the heaps from the north. Of the 10 pagodas built in a straight line just outside the railway station at Myohaung, no less than 8 were badly damaged. The "hti," and some of the lower parts having in most cases fallen down.

Maymyo Sub-division, Mandalay District.

Maymyo Town.—Maymyo town and cantonment lie on the fringe of the plateau of the Shan States, forty-three miles by road east of Mandalay, and at a height of about 3,500 feet above the sea. (Mandalay itself is only 315 feet above mean sea-level.) The hollow in the plateau in which the town is situated is some 4 square miles in extent, and is surrounded on all sides by low hills, rising on the N.W. to the Thit-tabin-taung, some 4,000 feet in height. The town itself consists of a long bazaar of brick and wood houses and large numbers of bungalows inhabited by Europeans, for it is the summer capital of the province. It is also the headquarters of a British and a native regiment, the barracks being of more massive construction than the usual type of European building in Burma. Maymyo suffered more from the earthquake than any other town, as will be evident from the following pages. From the official reports of the damage caused, which I owe to the courtesy of the Hon'ble Mr. F. St. G. Manners-Smith, C.I.E., Chief Engineer, Public Works Department, Burma, the following details are taken :—

Military Police Lines.—The long barracks of brick in mud have had their end walls damaged, the walls having fallen over at the tops. The kitchen and married men's quarters suffered in a similar manner.

Mr. Butcher's quarters.—The walls of the kitchen and stable have come down.

Civil Hospital.—Damage not very serious. Besides cracks in various parts of the buildings, there are parts of the wall off in the Civil Surgeon's room, and the European ward kitchen.

Civil Police Station.—The stone walls of the lower rooms are badly damaged especially at the door and window openings. The office is brick nogged and has not suffered much.

Residential Buildings.—Have stood the shock very well. Besides the ordinary plaster cracks, the partial falling out of the brick nogged panels and the separating of the chimney stacks from the main buildings, nothing serious has happened.

Superintending Engineer's Office, Chindwin Circle.—The centre gable over the partition wall fell through the ceiling and damaged it.

Superintending Engineer's Office, Mandalay Circle.—A couple of gables fell through the ceiling and damaged it. Almost all the chimneys have rocked off their bases.

Superintending Engineer's Office, Irrigation Circle.—Damage similar to the above. In the record room a few bricks fell off the tops of the walls.

Forest Office.—A chimney stack came down.

Circuit House.—Both chimney stacks came down and damaged the eaves. A few ordinary cracks about the buildings.

District Bungalow.—The chimney stack came down.

Office of the Superintendent of Telegraphs.—Chimney stacks have rocked off their bases. There are a few cracks, and a few brick nogged panels worked out a little. The kitchen of the clerk's quarters was also damaged.

Branch Press Office.—The gables have been badly shaken and the bricks along the tops of the walls have been forced out.

Secretariat Camp Office.—Ordinary cracks all over the building. Plaster has come down in places.

Accountant's Quarters.—Ordinary cracks. Chimney damaged.

Government House, New Building.—Hardly any cracks. Large arch in ball room has a crack at the crown.

Old Government House.—The brick nogged panels at the gables have fallen in some places and have carried away the ceilings. Almost all the chimney stacks have rocked off their bases. There are a few ordinary cracks all over the walls.

Motor Garage.—This building is in a very sorry condition. The walls have been badly damaged.

Myook's House.—A few panels of the brick nogged walls have fallen in.

Private Secretary's Office.—The chimney stack was in a dangerous state and had to be carefully removed.

Station Hospital. Administration Block.—All chimneys dangerously cracked and had to be dismantled. All the cross walls cracked at their junctions with the long walls. The Executive Engineer thought that the swaying of the roof and girders had displaced a few bricks and plaster but did not think that there was any danger of the roof falling in.

Store Rooms.—Chimneys had to be dismantled. Walls cracked at the junction of long and cross walls.

"A" Block, No. 1 Ward.—Reinforced girders partially crushed the walls under them, because no bed plates were placed to support them.

No. 3 Ward.—Leaked along the expansion joints in two places. A petty crack in the chimney.

Attendant's Room.—Crack in partition wall.

"B" Block, No. 1 Ward.—Two reinforced girders as in "A" block.

No. 3 Ward.—Two reinforced girders as in "A" block.

Lamp room.—Two slight cracks over door and ventilator.

Kitchen.—All walls badly cracked.

"C" Block, No. 1 Ward.—Two reinforced girders as in "A" block.

No. 3 Ward.—Two reinforced girders as in "A" block.

Attendant's room.—Partition wall cracked.

West Lavatory.—Petty cracks over doors.

East Lavatory.—Petty cracks in wall.

"E" Block, No. 3 Ward.—Two reinforced girders as in "A" block.

Attendant's room.—Partition wall cracked.

No. 2 Ward.—Two reinforced girders as in "A" block.

West Lavatory.—Cornice damaged.

Room for Thresh's Disinfector.—East wall badly and west and partition walls slightly cracked.

Family Hospital. Outpatients' Department.—Petty cracks in arches over doors and windows.

Matron's Room.—Slight cracks over window and at junction of partition and cross walls.

Front Veranda.—Tiles of roof have slipped considerably and had to be replaced.

Back Veranda.—Numbers of the roof tiles slipped and had to be replaced.

Main Roof.—Numbers of the roof tiles slipped and had to be replaced. The ceiling was damaged in places by falling tiles.

Officers' Ward.—End walls cracked.

Laundry.—Front and back walls cracked slightly.

Married Quarters. No. 25.—All three chimneys had to be dismantled. The nogging walls of most of the quarters were slightly cracked. All the kitchen chimneys came down. All the kitchen walls were badly cracked and had to be rebuilt from window lintel level.

No. 10-1 Kitchen.—Only a few petty cracks in walls.

No. 11 Barracks.—Two chimneys were shaken down and other two had to be dismantled. The roof was badly damaged by them.

No. 12 Barracks.—All chimneys dismantled.

No. 12-1 Kitchen.—All walls extensively cracked.

No. 13 Barracks.—Two chimneys were dismantled.

No. 14 Barracks.—All chimneys had to be dismantled.

No. 14-2.—All walls cracked.

No. 15 Barracks.—Both dining room chimneys had to be dismantled.

No. 16 Barracks.—One chimney of the dining room had to be dismantled.

No. 16-2.—Walls cracked very badly and will collapse if more shocks are experienced.

No. 17.—Two chimneys to be dismantled.

Followers' Quarters.—Walls of all kitchens badly damaged. Walls of all the quarters damaged.

British Infantry Officers' Quarters, No. 1.—One chimney dismantled. Slight cracks in the kitchen walls.

No. 2.—Two chimneys were dismantled at the roof level. A large number of brick nogging panels were cracked and rendered loose. The kitchen walls were cracked.

No. 3.—South chimney cracked and had to be dismantled. Numerous panels cracked as in No. 2. The kitchen range arch and side walls cracked.

No. 4.—Both chimneys had to be dismantled and the walls repaired. Kitchen walls slightly cracked.

No. 24.—All kitchens as above. All three chimneys of the quarters had to be dismantled as they were dangerously cracked. The walls were slightly cracked.

No. 23.—Kitchens as before. Two central chimneys had to be dismantled. The end ones were uninjured.

No. 22.—Kitchens as before. All four chimneys of the main building had to be dismantled.

No. 21.—Three chimneys of the main building and four of the kitchens had to be taken down.

No. 20.—Kitchen chimney cracked at the junction with the wall. Arch over range had to be rebuilt.

Main Building.—Petty cracks.

Warrant Officers' Quarters, No. 19.—Sustained a few cracks.

No. 18.—The chimney was cracked along its junction with the walls. The arches of both kitchen ranges were cracked.

Miscellaneous Buildings, Armourer's Shop.—Badly damaged. Front and back walls had to be rebuilt. Chimney had to be dismantled.

Workshop.—Slightly cracked.

Orderly Room.—One hole in the ceiling and one fine crack in the clerk's room.

Quarter Guard. Guard Detention Room.—East wall shaken and cracked. Partition wall wrecked.

Guard Room.—Four reinforced concrete girders partly crushed the walls under them, as they were not provided with bed plates. The west wall was cracked.

Detention Rooms.—A few petty cracks in the walls where the expansion joints were situated. One set of steps came away from the main wall.

Magazine.—Partition wall cracked. The roof was slightly cracked by the shock of the 21st.

Sergeants' Mess.—One chimney had to be taken down. Cracks in the kitchen roof.

School. Infants' Room.—All the walls except the partition badly cracked.

East Cloak Room.—One wall badly cracked.

West Cloak Room.—West wall badly and front wall slightly cracked.

Adults' Room.—West partition badly cracked at junction with the back wall.

West Room.—End wall badly cracked.

Barracks and Subsidiary Buildings. No. 1 Barrack.—No damage.

No. 1-1 Kitchen.—One slight crack in wall. Junction of flue pipe with the wall had to be repaired.

No. 2 Barrack.—All four chimneys dismantled at roof level.

No. 3 Barrack.—Two chimneys shaken down. One more had to be dismantled as it was dangerously cracked.

No. 4 Barrack.—South dormitory chimney dangerously cracked; west chimney of the dining room shaken down.

No. 5 Barrack.—All four chimneys had to be taken down.

No. 6 Barrack.—All four chimneys shaken down.

No. 6-1 Kitchen.—All walls badly cracked.

Nos. 7, 8, 9, and 10.—All four chimneys of each shaken down and roofs damaged. Chimneys of No. 9 barrack had to be dismantled to the floor level.

No. 8-1 Kitchen.—Only a few petty cracks in walls.

No. 5 Quarters.—Kitchen chimney slightly cracked.

No. 6 Quarters.—A few nogging panels of the main building had to be dismantled. The arch of the range in the kitchen had to be rebuilt.

No. 7 Quarters.—Same as No. 6.

No. 8 Quarters.—Kitchen arch and chimney cracked.

No. 9 Quarters.—Chimney and walls adjoining it were cracked. Front and side walls of kitchen badly cracked.

No. 10 Quarters.—Both chimneys of main building had to be taken down. The walls were cracked by their oscillations during the shocks. Some panels had to be reconstructed. The kitchen walls were badly cracked.

No. 11 Quarters.—Chimney had to be dismantled. Front and side walls cracked. Kitchen walls badly cracked.

No. 12 Quarters.—One chimney had to be dismantled. Walls had to be repaired. The front and side walls of the kitchen were cracked.

No. 13 Quarters.—Chimneys had to be dismantled. Walls cracked. Petty cracks appeared in the kitchen walls.

No. 14 Quarters.—North chimney had to be dismantled. The front and side walls of the kitchen were cracked.

No. 15 Quarters.—Both chimneys had to be dismantled. Walls were cracked. In the kitchen the front wall was badly, and the side walls slightly cracked.

Quarter No. 1 M.—Petty repairs needed in the main building. The kitchen range arch was badly cracked.

Quarter No. 2 M.—The chimney of the main building had to be dismantled. The kitchen range was cracked.

Quarter No. 3 M.—The chimney of the main building had to be dismantled and the walls had to be repaired.

British Officers' Quarters, Native Mountain Battery Lines. Block 1.—Both chimneys fell down destroying the north portico and part of the ceiling of the west bedroom. Both chimneys cracked down their entire length where they joined the wall. The dining room chimney had a horizontal crack about two feet from the floor level. Walls of east and west bedrooms as well as walls of other rooms cracked just below post-plate level. In the kitchen the walls above the door and window cracked badly.

Block 2.—Both chimneys fell down, and damaged the roof. There were cracks along the passage walls where the chimneys join them. Kitchen range arch, and east and west walls badly cracked.

Block 3.—Lamp room walls cracked. Both chimneys fell and damaged the shingle roof and part of the ceiling in the east bedroom. There are cracks at the junctions of the chimneys and the walls. In the kitchen all the arches were cracked.

Native Officers' Quarters, No. 1.—Kitchen partly fallen in. Back, front and central partition walls slightly cracked.

No. 2.—Partition wall slightly cracked.

No. 3.—Kitchen dismantled by earthquake. Central partition wall badly and other walls slightly cracked.

Gunners' Barrack, No. 1.—Walls above two windows cracked. Gable walls of kitchen cracked.

No. 2.—Gable walls of kitchen cracked.

No. 3.—Partition wall and side walls near the two windows badly cracked. Gable walls of kitchen slightly cracked.

Drivers' Barrack, No. 1.—Gable of two partition walls cracked badly. Gable wall of kitchen also cracked.

No. 2.—Partition gable walls and side walls near eight windows badly cracked. Kitchen gable walls and side walls cracked and had to be rebuilt.

No. 3.—Practically all the walls were cracked badly and had to be rebuilt. The kitchen walls were slightly cracked.

Gunshed.—East wall slightly damaged. Vertical pillars badly cracked.

Quarter Guard.—West veranda wall very badly cracked. All the walls of the three cells were badly cracked and had to be dismantled and rebuilt. The long walls of the quarter guard were cracked. The east partition wall of the store room was cracked away from the main walls, which were also slightly damaged. The back wall of the end store room was badly shaken, the others were slightly cracked. The central store room was in the the same state.

Miscellaneous Buildings, Single Followers' Office.—All the walls were very badly cracked. The whole building had to be dismantled and rebuilt.

Shoeing Shop.—Gable walls cracked badly.

Married Followers' Quarters, No. 6.—Practically all the long and end walls cracked badly and were in need of reconstruction. Kitchen walls very badly cracked.

No. 3.—Long and end walls cracked badly and had to be reconstructed.

Harness Room.—Walls cracked slightly in places.

Grain Room.—Arches above door and windows cracked.

Native Officers' Quarters, Gurkha Lines, No. 1.—Brick nogging walls cracked in places.

Nos. 2, 3, 4.—Brick nogging walls cracked in places.

No. 5.—Veranda partition wall fell in, and other walls cracked slightly.

No. 6.—Some walls slightly cracked.

No. 7.—Veranda partition wall and east wall of north room partly fell in. Other walls cracked slightly.

No. 8.—Veranda and other walls of south and north rooms damaged in places.

British Officers' Quarters, Block A.—Nothing seriously damaged, but the plaster fell in some places.

Block B.—One chimney above the roof damaged.

Blocks C and D.—No serious damage but the plaster came down in places.

Block E.—One of the chimneys was damaged and the walls above two of the bedroom doors were cracked. All the walls of the kitchen were badly cracked.

Block F.—One of the chimneys was damaged. Some of the walls were damaged and the plaster cornice fell.

Block G.—Walls on either side of the chimney were badly cracked. In the kitchen all the walls were badly damaged and needed reconstruction. The servants' quarters were equally damaged.

Block H.—One of the chimneys was damaged and some of the brick nogging panels separated from their frames.

Supply and Transport Lines, Godown No. 2.—Walls and arches above the doors and windows were slightly cracked.

Mule Corps Lines, Single Men's Barrack F. G. E.—Slightly cracked in places above the door and window arches.

Family Quarters, No. 1 Quarters.—Both end gables tumbled down two feet from the top. Partition walls cracked at junction with main walls. All the arches cracked badly and had to be rebuilt.

No. 11, 5 Quarters.—Same as No. 1, except that one kitchen was razed to the ground.

No. 3, 4 Quarters.—Same as No. 1, except that some of the cross walls cracked throughout and required rebuilding. Only petty damage was caused to the kitchen.

No. 4, 4 Quarters.—Rather worse than No. 3. Petty damage to the kitchens.

Nos. 5, 5 Quarters.—Same as No. 3. One kitchen came down and another had to be rebuilt.

Survey Office.—The room above the porch in the Survey Office was dangerously cracked. It was reported that another shock would bring it down.

Personal Observations in Maymyo.

Maymyo Zigon Zayat.—"Hti" on the top of the pagoda bent over in a W. 15° S. direction.

Naungin Pagoda.—Upper part of masonry shattered and thrown down, but the "hti" with its central supporting rod was left and bent over due E. Large, wide, perpendicular cracks ran through the superstructure from the bottom almost to the top.

Pagoda near the Naungin Pagoda.—Base wall on the N. side shaken out exposing the rough brick-work of the interior.

Station Hospital.—In the block running E. and W., the junction between the main and partition wall, which runs in a N. and S. direction, was cracked. Two girders set in a N. and S. direction in the reinforced concrete roof, had their northern ends dislodged, *i.e.*, they had acted as rams to the N. In the 2nd ward the same thing happened, but only the two girders at the ends had moved in both cases. The other three in the middle of each roof had remained intact.

Kitchen.—The walls running in a N. and S. direction were full of irregular cracks. The other walls were not injured.

Blocks A, B, C, D and E.—Exactly the same damage as in the case of the ward described above, *i.e.*, two of the girders in the roof acted as rams from the S. to the N. and knocked out the brick-work near their ends. The walls were not cracked and the other girders did not move.

Station Family Hospital.—A one-storeyed brick building running in a N.W.—S.E., direction. The tiles on the W. side of the main roof and on the veranda slid completely off. On the E. side the tiles slid off both the main roof and the veranda for a width of 15 feet. There were various petty cracks in the walls of the matron's quarters.

Rows of Bricks.—Rows of bricks which had been stacked in a N. and S. direction had the ones at the S. end tumbled off.

Married Quarters, British Infantry Lines.—These have timber frames and are built on timber posts, hence the damage was less. In some cases the brick nogging panels were cracked and shaken loose.

Kitchens of Married Quarters, British Infantry Lines.—Six heavy brick buildings with tiled roofs, running in a N. and S. direction. In most of these the N. and S. walls, *i.e.*, the walls running in an E. and W. direction were broken away from the roofs. Large cracks stretching from the corners of the walls to the corners of the windows were also common. Many of the walls were badly cracked.

Armourer's shop.—A single storeyed brick building running in a N.W.—S.E. direction. In the S. wall there were cracks running from the windows to the corners. The chimney of the forge split away from the N. wall. There were minor cracks in the E. and in the W. walls.

School.—A one-storeyed building of massive brick construction. In the walls coursing in an E.—W. direction there were wide cracks making an angle of 70° with the horizontal. A similar wall in the Adult school had cracked away from one coursing N.—S. The other walls contained minor cracks.

Barrack Kitchen.—The two walls running in an E. and W. direction contained a longitudinal horizontal crack 1½ feet from the roof in each wall. This line of weakness was marked by wooden beams which had been let into the walls.

No. 8 Barracks.—A single storeyed solid brick building running in a N.N.E.—W.S.W. direction. All the chimneys had fallen and broken through the roofs. The only one which I was able to measure seemed to have tumbled over in a S. 10° E. direction. It is interesting to note that in the barracks taken as a whole, the chimneys of the reinforced concrete roofs stood the shock while those of the shingle roofs fell.

Quarter-Master's Stores.—A one-storeyed brick building running in a N.—S. direction. The division wall which runs E.—W. between the guard room and the detention room was dangerously cracked in all directions. The iron lintel over the door was also bent out of shape.

Old Government House.—The chimneys had a tendency to swing N.E.—S.W. as was seen by the crushed bricks when dismantling was going on. In a room on the 2nd storey the brick nogging of the top gable on the E. fell in towards the W. In another bed room a similar gable fell in towards the E. The gables on the N. and S. sides were unmoved.

New Government House.—Practically no serious damage was caused. A few minor cracks were noticed in the plaster of some of the walls.

Sitting Room.—A cupboard, 4 feet high, 3 feet broad and 1½ feet deep, which was standing on a table near a wall coursing N. W.—S. E. fell towards the S.W.

Private Secretary's Office.—The chimney fell towards the N.W. It is reported that such chimneys were often slued round to a considerable degree but I am unable to confirm this personally, as no damaged chimneys were left standing when I visited Maymyo.

Motor House.—The walls of the motor house, a strongly built brick building, were shattered but none of them fell. The building was being dismantled at the time of my visit.

Boiler House.—The brick nogged panels in the walls running N.—S. tended to fall towards the W. The filling of the arches in the walls also tended to come out in the same direction. No damage was caused to walls running at right angles to this.

Foundations of New Church.—I was unable to detect any cracks in the foundations of the new church.

Maymyo Civil Hospital. Civil Surgeon's Room.—From the top of a wall running approximately E.—W., bricks close to the wooden roof were shaken off.

Mortuary.—Diagonal cracks in the E.—W. walls.

Paying Ward.—A long strip of plaster fell from a wall running in a W. N. W.—E. S. E. direction. The reinforced concrete roofs of the hospital wards were unhurt.

Various brick and mud buildings.—It was observed that in these cases the plaster covering brick and mud walls was often peeled off the ones coursing N.—S., while those running E.—W. were usually unhurt or contained minor cracks. Sometimes the brick and mud walls were cracked in every direction as if the whole building had been subjected to severe shaking.

Mosque.—The roof of the mosque was partly cracked away from the walls.

ACCOUNTS FROM MAYMYO AND DISTRICT.

Maymyo.

Mr. Chappel, Director of Telegraphs, Burma Circle.—Exact time, 8-55 A.M. Very severe shock. He left the house at once, but does not consider that the earthquake was equal in intensity to the Dharamsala shock of 1905 as felt in Umballa. There was a succession of shocks for days afterwards.

Superintendent of Telegraphs, Maymyo.—Time about 8-50 A.M., uncorrected. Very severe shock which came on suddenly without previous tremors and lasted over a minute. The house rocked about and he thought that parts of it would fall in. Damage however, was slight, with the exception of the chimney which was dangerously cracked. Numerous lesser shocks for two days afterwards.

Mr. B. Moses, Maymyo.—Time 8-55 A.M., correcting clock not stated. No preliminary tremors. The main shock lasted very nearly a minute and "played great havoc with Maymyo," bringing down chimneys, and cracking and bending walls.

Postmaster, Maymyo.—Immediately after the big shock of the 23rd May, he looked at the office clock and found the time to be between 8-56 and 8-57 A.M. The clock is regulated by the midday gun which is fired at local time (?). There is 9 minutes difference between standard time and local time (?). Neither the post office clock nor the one in his private quarters stopped. They were both in the same position, namely, with the pendulums swinging N. E.—S. W. He was in the compound when the main shock occurred. It appeared to come from the E. but he was too frightened to make any further observations.

Mr. J. Owen, Deputy Superintendent, Mandalay Signal Office.—He was at Maymyo when the earthquake took place at 8-55 A.M. by his watch. It is not stated whether this was compared with any standard time or not.

Dr. A. M. Finlayson, Geologist, The Indo-Burma Petroleum Co., Maymyo.—Time 8-57 A.M. on May 23rd, lasting over 1 minute. The first sensation to persons outside was the sudden sharp rattling of leaves on trees. Inside brick bungalows, closed windows commenced rattling, the rattle quickly increasing to a maximum in a little over 30 seconds. Walls and floors moved; during the maximum the ground was moving gently, and a slight rumbling occurred. After the sudden rise the shock died off more slowly. It was followed by minor tremors for the rest of the morning.

Unstable or top-heavy articles such as lamp-glasses, wine glasses (not inverted) were overturned. Some hanging lamps were thrown out of their supports. Brick chimneys were in some cases not visibly affected, in others cracked, and in several bungalows, crashed through the ceiling. Plaster was freely broken away at corners and along joints, and bricks were occasionally loosened. In a few bungalows, brick dividing walls were severely shaken and damaged. Outer walls were apparently less affected. In Messrs. Steel Bros. bungalow, "Churchill," windows facing E. and W. rattled backward and forwards in their settings, while windows facing N. and S. were much less affected. Hanging lamps swung E.—W. The W. wall was observed at the maximum to bulge out and recede several times. The E. wall also similarly moved. A heavy two-leaved folding table leaning against an E. wall at an angle of 12° from the vertical, was thrown to the floor. A few sudden vibrations would doubtless cause this and the movement indicated was probably a result of the sharp shock; it would scarcely be a measure of intensity or amplitude of wave motion. Dr. Finlayson also gives a valuable list of after-shocks which will be referred to later. He is of the opinion that the Rossi-Forel scale cannot be applied with much satisfaction to the effects at Maymyo. Most of the after tremors would fall in degrees I and II of the scale, two or three tremors in degree III. Probably for the main shock its intensity at Maymyo is best described under degrees VI and VII of the R.-F. scale, with the proviso that all persons indoors at the time ran out. Some of the effects, namely, fall of chimneys, come under degree VIII.

Sir W. F. Gates, Financial Commissioner, Maymyo.—Reported that at the time of the severe shock his house commenced to sway, and that the earth seemed to be in ripples as if disturbed by waves of great frequency. The shock was in two well-marked periods.

Thondaung.

Mr. Butcher, Public Works Engineer.—He was out on a hill side when the disturbance took place. It seemed to come from the E., or perhaps from a little to the S. of E.

Anisekan.

Mr. F. Hamilton Dale.—His bungalow is a wooden one with a tin roof, built on the side of a small hill and facing E. by S. The floor is about three feet from the ground. Time 8-50 or 8-55 A.M. Shock started quite easily but rapidly increased and lasted over 1½ minutes. He ran out and walked round two sides of the house expecting it to go crash every moment. "It didn't appear to sway much, not more than 3 inches—extreme to extreme—but the shocks were as rapid as a terrier shaking a rat, or as quickly as you could jerk your fist within a 4 inch shake from the elbow." There was but little damage done. A few bottles on the top of a meat safe were thrown down, some N. and the rest N. E. by E. A clock was jerked forward 1½ inches from the bottom towards the front of the house. A bookcase shot half its contents on to the floor, and many of the small ornaments in the bungalow were thrown down. He states that although it is a general idea that there have been no quakes since the shocks of 4 years ago, he has noticed several during the last 2 years while fishing in the pools in the local streams, which flow in deep limestone gorges.

Personal Observations in the Northern Shan States.

Thanks to the kindness of the railway authorities in Maymyo, I was enabled to travel by trolley over the line between Maymyo and Naunghkio and to inspect the damage done to it and to the country in the immediate vicinity. From

Maymyo the line crosses the limestone plateau to Wetwin where it descends a steep scarp facing the valley of the Ke-laung stream. From the crest of this ridge the view to the E. is closed by an even-topped scrap which follows the line of the great Kyaukkyan fault, and as the line proceeds on across the plateau through Hsum-hsai, the latter becomes more and more well defined. To the S. a long line of precipitous limestones cliffs marks the position of the crest, but at the gap where the railway and the cartroad cross, these are not conspicuous. Mr. La Touche was the first to point out how the rise at this point takes the form of a uniclinal flexure in the limestones rather than a fault scarp, and the ascent from the valley is only 400 feet, but there is a distinct fault along the crest with a down-throw to the W. Further to the S. the throw increases until the relative difference in level becomes about 3,000 feet. Between miles 450 and 451 (Hsum-hsai is situated at mile $443\frac{3}{4}$, and Nawnghkio at mile 456), the built up earth banks had cracked and slipped down towards the W. The Agent of the Burma Railways reported that 300 tons of earth slipped down and blocked the line at this point. A little further on, the pass cutting is situated. At this point the limestone is intensely crushed and traversed by slickensided planes in great numbers, owing to the proximity of the fault which appears at the crest. The sides of the cutting through this crushed limestone are between 30 and 40 feet high and a great deal of rock had fallen, mainly from the slickensided planes. A few yards from the cutting on the N., the line which used to run perfectly straight, was bent into a smooth curve which continued without any dislocation for some 80 or 90 yards. This had occurred close to the actual line of the fault, and if the thrust which caused the curve acted in a direction normal to it, it must have taken place from N. 15°—20° W. According to the report submitted by the Agent of the Railway, the bank in the neighbourhood of mile 451 had also slipped away towards the E. and sunk 5 feet for a distance of 150 yards. Small landslips are also reported to have taken place between miles 447-8 and 445-6. By these occurrences the line was blocked, but it was reopened for through traffic on May 25th. Bridge 190 between Hsum-hsai and Nawnghkio, built of massive stone-work, was badly cracked in both wing walls. I also noticed frequent small cracks in the "terra rossa" of the plateau bordering the line. The pagoda on the hill near the station at Hsum-hsai was broken down.

ACCOUNTS FROM THE NORTHERN SHAN STATES.

Hsum-hsai.

Station Master.—Time 9 A.M. Duration 2 minutes. The shock was preceded by a low rumbling noise. Most of the pagodas in Thonze were smashed down for $\frac{1}{2}$ or $\frac{1}{3}$ of their heights.

Gokteik Viaduct.

L. Ramaswamy, Station Master.—The station clock stopped at 9 A.M. Two landslips occurred near the tunnels just outside the station. The rest-houses were badly cracked and the chimneys tumbled down.

Agent, Burma Railways.—The south abutment wing of the Gokteik viaduct slightly cracked. Trestles 8 to 10 shifted $\frac{1}{4}$ inch on the foundation bearing plates.

Correspondent in the "Rangoon Gazette" of May27th, 1912.—He was one of a party of three exploring the interior of the cave under the viaduct in the bottom of the deep Gokteik ravine, when the shock commenced on the morning of the 23rd. A weird sound was heard which rapidly increased. At first they thought that a train was crossing the viaduct but the vault of the cave commenced to sway and the ground underfoot to give way. Huge rocks with trees growing on them tumbled down the mountain slopes and pieces of stone fell from the roof of the cave, which was filled with particles of earth blown in from outside. They fled to the top of the ravine and found the rest-house near the station shattered and unfit for occupation.

Nawnghkio.

A. Rahman, Station Master.—Station clock stopped at 9-4 A.M. The shock lasted for about 1 minute and appeared to travel N.—S.

Pyaunggaung.

Station Master.—Time 9 A.M., by the station clock which did not stop. Station buildings, signals, etc., shook from S. to N. A small bridge within the outer signal limit was cracked. Shan pagodas in the vicinity were broken.

Bawgyo.

Station Master.—Station clock stopped at 9-4 A.M. A brick pagoda 21 feet high was seen to have its upper 7 feet shaken down. 63 other pagodas varying in height from 10 to 50 feet are reported to have been damaged in a similar way in the neighbourhood. It is interesting to note that this witness like others, erroneously dates the time of commencement of the shock from the time shown by stopped clocks.

Kyaukme.

Maung San Win, Station Master.—Exact time given as 9 A.M., and station clock said to have stopped simultaneously. Half of the "Pyilonchantha" pagoda was broken down. It occupies a site on the top of a hill opposite the railway station and was 45 feet high before the earthquake.

Hsipaw State.

Mr. F. S. Grose, Assistant Superintendent, Northern Shan States.—The Möng Long Myosa reported that the shock came from the S. W. Time about 8-45 A.M. Almost all the pagodas and images in the western part of the State were either cracked or broken down. The principal disturbance took place at Myinpyu hill in Hsum-hsai. Here from a crack in the cliffs near Myinpyu village, a stream of sand and mud issued, overwhelming one house in a village below, called Hsaihkao, and partially destroying two others. From here the stream turned towards the S. and then to the W., breaking and carrying away trees, and finally subsiding into a bog 1 mile long, 800 yards wide and 4 to 5 feet deep. The whole of this area was turned into a quagmire and a large amount of paddy land destroyed. A man was overwhelmed and carried away in the stream of mud. A great crack of unknown length and depth, and with a width of about 2 yards, opened in the Myinpyu hill. Large rocks and boulders fell from the hillside on to the village below, compelling the inhabitants to abandon it. Landslips also took place in other places notably on the Yebyan Taung.

A crack was caused in the ground from Kyaukkyan in the Namma circle to the west of Seikpyu, where a hot spring dried up. The site of a deserted village went down 800 feet into paddy land, and landslips were continuing up to the 21st of June. In the same circle the Nam-pan-se stream was completely blocked for 10 days by landslips, through which the water eventually forced a way. In other places smaller streams were also blocked up by landslips.

Over 600 pagodas were damaged in the Möng Long substate.

In the rest of Hsipaw the shocks were not so violent, and little harm seems to have been done except to pagodas and brick houses. For the most part it was only the upper portion of the buildings which was thrown down, though cracks appeared everywhere.

Namhsan, Tawngpeng State.

Mr. R. D. Burne, Adviser to the Tawngpeng Sawbwa.—A very severe shock took place at 9-37 A.M., and lasted well over 1 minute. He was on the march and saw that the waves approached from the S. S.W.

to the N.N.E. A sound was distinctly audible before the shock was felt. There were numerous other slight shocks throughout the day, and for several days afterwards at varying periods. Practically all the large pagodas in the State were more or less demolished, the upper half of the masonry being in most cases thrown down. All the buildings in Namhsan are wooden ones, consequently no damage occurred, beyond that some of the houses appeared to be rather shaky afterwards. A feeling of nausea was experienced while standing in the open during the shock.

Hsipaw town.

Correspondent in the "Rangoon Gazette."—Reported that the shock was felt there and that the railway medical store and various business places at Hsipaw were badly damaged.

Sa-en, Hsipaw State.

Mr. Bell, District Engineer, Railways.—He was in a bogie carriage when the quake came on, and thought that some one was moving about rapidly in the next compartment. He jumped out and noticed that the station buildings, signals and trees were swaying. The shock lasted for about 30 seconds.

Lashio, North Hsenwi State.

Mr. Huge A. Thornton, Superintendent of the Northern Shan States.—"The shock was not noticed by me at the time as I was riding. My pony however and that of my wife who accompanied me, both staggered at one moment in a peculiar way about the time at which I learned afterwards an earthquake had occurred."

Lashio.

Mr. A. P. Warburton, Assistant Superintendent of Police.—Violent earthquake at 9 A.M., followed by several shocks afterwards.

Panglong.

Mr. D. W. Kiernander, Assistant Superintendent, Northern Shan States.—He was in the Engineer's house, Burma Mines, at Panglong on the 23rd May at 8 A.M. It began to rock but being a wooden one no damage was done. The shock came from the N.W. and lasted nearly 1 minute.

Kutkai, North Hsenwi State.

Mr. D. W. Kiernander, Assistant Superintendent, Northern Shan States.—Reported that the shock cracked the civil dispensary, military police store, godown and native officers' quarters at Kutkai.

South Hsenwi State.

Mr. A. Samuel, Assistant Superintendent, Northern Shan States.—A severe earthquake was felt throughout the South Hsenwi State on the morning of the 23rd May at 9-10 A.M. Time from an uncorrected watch. The duration was 53 seconds. The earth waves appear to travel N.—S. No damage was reported from any part of the State although there are various pagodas built on hills. All people who felt the shock complained of giddiness while it lasted. Lack of detailed information may doubtless have led to the report that no damage had been done.

Southern Shan States.

Taunggyi.

Captain H. S. Matson, I.M.S., Civil Surgeon.—Taunggyi is situated on a ledge among limestone hills which have a steep scarp facing W. and a gentle dip slope towards the E. Earthquakes are distinctly uncommon in the Southern Shan States and the last severe one happened in 1874; its effects were widespread in the States. Tremors are said to occur annually in various parts of Burma during the month of May. He gives an important list of fore and aftershocks which will be reproduced in a later paragraph.

The severe shock of the 23rd May occurred at 9 A.M. as nearly as can be determined. It lasted 64 seconds and was followed during the day by 4 small shocks, while 17 well-marked tremors were recorded during the night following the same day.

In Taunggyi not a single permanent building escaped undamaged. The direction was from N.—S., as evidenced by the oscillation of chimneys, the direction taken by bottles and ornaments which fell from shelves, and the severe damage to the N. walls of buildings, especially when the direction of the wall was due E.—W. Damage was occasioned by the tendency of the roofs of buildings to slide independently of their supports, by the oscillation of chimneys, and by the abundant fall of brick and plaster from the upper parts of buildings. No appreciable damage occurred until the 23rd May, but it was in some places accentuated by the repeated small shocks which took place later. The general effect of the shock was felt universally throughout the district, but with the exception of Taunggyi no damage to permanent buildings was caused. In the Yawnghwe valley which lies at the foot of the Taunggyi hill, damage was done to the rest-house at Sinhe, and to the pagodas near Yawnghwe.

Mr. A. R. J. Hope, Executive Engineer, Taunggyi Division.—Gives a list of fore-shocks but states that practically all the damage was caused by the shock which occurred at 9 A.M. on the morning of the 23rd May and lasted 64 seconds. It was followed by 4 lesser shocks during the day, and several well-marked tremors during the night. The general direction seemed to be N.—S. Every masonry building in Taunggyi was more or less damaged. The water level in the supply reservoir fell 1 foot and remained so for a few hours. During the night it regained the foot lost and 3 inches in addition. The damage done was shown mainly by collapsed or shattered chimney stacks, and cracks in the walls especially over door and window openings. The cracks followed the lines of least resistance through the mortar joints. In most cases they were slight and merely showed in the plaster, in others they were obvious and the bricks or stones adjoining were loosened. The N. and S. and cross partition walls of buildings were most affected, especially when the length of the building lay N.—S. In two-storeyed buildings the upper storey walls were damaged, while the ground floors were practically undamaged. Buildings with walls of brick nogging suffered little,— a panel or two falling out in one or two cases. Chimney stacks of all buildings were cracked and had to be dismantled at once to roof level as a precaution. In the Assistant Superintendent of Police's quarters, the lime plaster did not seem to have any grip on the mud walls and fell off in sheets, while the bricks were shattered. In several buildings the upper courses of walls suffered most, due evidently to the oscillation set up in the roofs. In the Civil Surgeon's quarters the N. bedroom suffered badly while the rest of the house, except for the chimneys, was not hurt. It was noticeable that in some of the smaller brick buildings, *e.g.*, the outhouses of the inspection bungalow, Government clerks' quarters, a followers' barrack in the military police lines, the damage was proportionally greater than in large buildings such as the record room, a stone building $42\frac{1}{2}' \times 39'$ with walls 22′ high, the Government Shan school buildings $224' \times 55'$ and $138' \times 37'$ with walls 16′ and 14′ high respectively. In the smaller buildings the walls were shattered or collapsed, while in the others there were only slight cracks or damaged chimney stacks. (Pl. No. 5.)

Buildings in Taunggyi are composed of :—

Stone masonry in lime.
Brick masonry in lime.
Brick in mud mortar.
Sun-dried brick in mud.
Brick nogging.

Where work and material have been good, brick buildings sufferred less than stone buildings. Bricks in mud, and sun-dried brick walls have not stood so well. Brick nogging has suffered little except that a few panels have fallen out. A 4-feet uncoursed stone rubble wall in lime mortar enclosing the cemetery, collapsed entirely on the E. boundary. The top 2 feet of the walls of buildings, arches and junctions of cross with main walls show the effects more than other parts of the structures. The shearing of the upper courses of the walls was clearly due to the oscillation of the roof.

Taunggyi.

The Assistant Superintendent of Police's quarters.—This has walls of unburned sun-dried bricks laid in mud, lime plastered and whitewashed. Most of the plaster came down with a crash and the walls though still standing were shattered. They had to be pulled down and replaced.

The Telegraph Office.—A double storeyed building with 18-inch brick walls. The ground floor showed little damage. The arches over doors and windows have cracked, but not seriously. Upstairs, the N. and S. walls were shattered and had to be rebuilt. The plaster needed renewal. Walls in linemen's quarters also damaged.

Civil Surgeon's quarters.—The walls were built of stone in lime mortar, except the S. bedroom, which had brick walls. This part was practically undamaged, but the stone walls of the N. bedroom were badly cracked.

Treasury Office.—A stone building. Inner face of N. gable wall fell in, and the cross walls were so badly cracked that they had to be pulled down. S. wall cracked and had to be partly rebuilt.

Military Police, Quarter Guard.—18-inch stone walls. N., S. and partition walls damaged and partly collapsed, top courses of side walls shaken down. Walls had to be partially dismantled and rebuilt.

Mounted Infantry Gear Store, and Guard Room.—A stone building of which all the walls were shaken and had to be pulled down and rebuilt.

P. W. D. Clerks' quarters.—These were originally mat-walled buildings. Subsequently the mat was replaced by brick in mud. The walls were shaken and the plaster shed off.

Military Police Buildings. Quarters for Sub-Assistant Surgeons.—Walls built of stone, lime plastered and cement pointed. They were cracked from the top through the arches over doors and windows.

Military Police Hospital.—A double storeyed building. Lower storey of stone and the upper one of brick. Cracked over the door and window openings but not seriously. Top courses of bricks on E. and W. walls shaken down for a length of 16 to 20 feet. Sundry cracks in the plaster.

Military Police Magazine.—Stone walls 1′ 10½″ thick with a concrete roof. Slight cracks in the N. and S. walls. Cracks in the roof which began to leak.

Military Police Office.—A stone building which was cracked over the doors and windows. A strip from the top of the E. wall fell in.

Ration Godown.—A stone building 150′ by 20′. Top courses of the walls shaken.

Barracks for Transport drivers.—A stone building. Top courses of the walls were badly shaken. E. wall cracked from top to bottom. Gables had to be rebuilt.

Strong Room.—A stone building with roof of concrete on steel beams and jack arches. Fine cracks in roof and two cracks in front wall.

Court House.—A stone building. The wall for about 6 feet over the 4 doors had to be pulled down and rebuilt. The chimney was cracked and had to be pulled down.

Record Room.—A stone building on the standard plan, 42′×39′ with walls 22′ high, showed only fine cracks over the arches. Walls slightly damaged where the angle iron from the iron racks entered them.

Residency.—A stone building downstairs with timber above. Undamaged except for the chimney stacks above the roof.

Quarters for the Treasury Officer.—Slight cracks in the main buildings and servants' quarters. A few bricks were also displaced.

Post Office.—A brick nogged building. Plaster sightly damaged.

Executive Engineer's Office.—A brick nogged building. Lime plaster shaken off.

P. W. D. Sub-divisional Officer's quarters.—A brick nogged building. Plaster damaged.

Executive Engineer's quarters.—A two-storeyed composite building, having walls of brick and brick nogging and plank partitions. It was undamaged except for the chimney stacks. Outhouses of brick showed some damage to the walls.

Assistant Political Officer's quarters.—A two-storeyed brick building. Fine cracks over the doors and windows. Chimney stacks dismantled. Servants' quarters slightly cracked.

Circuit House.—A brick building. Front portico gable badly cracked, had to be pulled down and replaced. Some plaster also fell.

P. W. D. Inspection Bungalow.—A brick building. Chimney stack cracked and separated from walls. Some cracks in the outhouses and stables with consequent damage to the plaster.

School for the sons of Shan chiefs.—All the buildings are of brick with corrugated iron roofs. They are well built.

School Building.—Fine cracks appeared over the door and window openings. About 2 feet of the cornice fell. Chimney stacks did not appear to have been damaged.

School kitchen.—Brickwork over the front door damaged.

South dormitory.—Two fine cracks appeared in the corners of one room. The filling between the lintel and the arches of the door was shaken loose. Kitchen was slightly cracked.

North dormitory.—All the walls in the masters' quarters, bath room, pantry and store-room showed cracks and the chimney stack was shaken.

Cemetery Wall.—A length of 50 feet collapsed.

Sinhe. Inspection bungalow.—This is a brick nogged bungalow with a shingle roof on a masonry plinth. Both the chimney tops fell and damaged the roof. Six panels of walls fell in and some of the plaster was damaged. In the servants' quarters 216 square feet of brick nogging fell out and damaged the plank sleeping platform.

Heho. Inspection bungalow.—Chimney stacks damaged. Part of the walls of the servants' quarters collapsed and those of the godown were damaged.

Loilem. Forest Officer's quarters.—A two-storeyed brick building. Cracks appeared in the walls of the upper storey over the windows.

Bricks along the top of the wall in the dressing room were displaced. Some plaster was damaged. On the lower floor, the arch over the door to the clerk's room had to be rebuilt.

Loilem. Assistant Superintendent's quarters.—A single storey brick building. Only slight cracks were caused in the main building but some damage was done to plaster. In the servants' quarters bricks from the tops of walls were displaced.

The Executive Engineer, Taunggyi, reported that while no proposals have been made in the past for making any of the buildings in his division earthquake proof, in future designing this point will have to be considered. The Shan States are not specially liable to severe earthquakes, and the last which can be compared with the present one is said to have occurred in 1874. A re-examination of the damaged structures showed that the effect of the repeated shocks was not so severe as appeared to be the case at first. It was expected that on both sides of a bad crack, the brick or stone work would be considerably loosened, and, that in consequence, sections of walls would have to be pulled down and rebuilt. But after stripping off plaster bordering cracks, and raking out mortar from joints, it was discovered that this was not generally the case. The stability of the wall not being endangered, all that needed to be done was to grout up the joints with cement and renew the damaged plaster.

Accounts from the Southern Shan States.

Mr. H. A. Sams, Postmaster-General, Burma.—Nampandet is a hamlet 63 miles 5 furlongs from Taunggyi, at the foot of the hills. Time 8-55 A.M., uncorrected. The shock was severe enough to cause all in the bungalow to flee from it, though being a wood and mat structure, it was not damaged. No preliminary tremors were observed. Mr. Sams writes that the shock was certainly intense and reminded him unpleasantly of the great Kangra valley quake which he felt at Lahore on April 4th, 1905.

Nampandet.

S. B. Dutta, Sub-Postmaster, and Nizamuddin, Signaller.—Time 9 A.M., observed from the time-piece used by the telegraph branch. Several shocks distinctly felt. Direction N.—S. A sound was noticed before the shock commenced. A record cupboard and a postal notice-board kept near the S. wall of the building fell towards the N. The N. side of the building

Yawnghwe.

was slightly cracked but the S.E. corner suffered more damage. Small shocks were noticed for several days afterwards.

Western Sub-division, Southern Shan States.

The Assistant Superintendent, Western Sub-division.—The shock which occurred on the 23rd was the worst of the series and caused most damage. Opinions differed as to whether it came from the E. or W. Some people thought from the N. also. In Yawnghwe and surrounding villages, the pagodas which were shaken down fell towards the N., elsewhere there did not seem to be any uniformity in the matter. Most of those in Kalaw were reported to have fallen to the S. On land, only brick buildings suffered. In the Yawnghwe lake some 15 houses at Zayatgyi and 6 or 7 at Kela are said to have fallen down. A large wave was formed on the lake.

North-Eastern Sub-division, Southern Shan States.

The Assistant Superintendent, North-Eastern Sub-division, Loilem.—In the sub-division generally no very serious damage appears to have been done. A number of pagodas suffered but they were mainly old and no doubt badly built. Time about 9-30 A.M. Duration about 10 to 12 seconds. The earthquake appeared to come from the E. and later from the W. The cracks in the damaged buildings of the station were mostly on the W. side. This latter information is given on the authority of Mr. H. C. Ackley, clerk in the P. W. D. Office, Loilem.

South-Eastern Sub-division, Southern Shan States.

Mr. J. Clague, Assistant Superintendent, Southern Shan States.—Time about 9 A.M. on the morning of the 23rd May. There was no means of ascertaining in what direction the earthquake was travelling. Numbers of pagodas were damaged, but the portions that fell did not come down in any uniform direction, and judging from the damage done to pagodas at Yawnghwe, the shock at Mongnai was probably less severe than at that place. The shocks were said to have caused little damage at Mongpan and Mawkmai. No damage whatever was done to the brick buildings at Bampon, nor is there any subsidence of earth or disappearance of water to record.

Keng Tung Sub-division, Southern Shan States.

Mr. S. St. R. Korper, Assistant Superintendent, Keng Tung Sub-division.—Time about 9 o'clock in the morning. The shock lasted quite 40 seconds, or one minute. All the trees in the compound began to shake as if their roots were being caught hold of, and the trees purposely shaken. This tree-dance kept on long after the earth vibrations ceased to be felt. Both this earthquake and the one of the 21st gave the impression of intense vibrations rather than distinct shocks. They came on and left off gradually, there was no jarring and no previous or subsequent sound, or any other physical phenomena. The direction appeared to be from N.E. or E. to S.W. or W. judged from the shaking of trees. No damage was done, no plaster from the roofs or walls fell, neither was any furniture overturned.

Karenni.

The Assistant Political Officer, Loikaw.—Earthquakes were felt all over the Karenni Sub-division. On the 23rd May one occurred at 9-11 A.M. Time not standardized. It was the worst of the series and was distinctly felt, lasting about one minute. It was preceded by a sound which one says resembled distant thunder, and another compares with the noise made by a shunting engine. After the sounds ceased, preliminary tremulous vibrations were felt. Then followed three prominent shocks which were followed by tremulous vibrations. The duration of these latter was not recorded. He is unable to state what the apparent direction of the shocks was, but happened to be standing near a canal and noticed that the water in the channel rolled from bank to bank in an E.—W. direction. The effects were very slight and only noticeable in masonry buildings as follows :—

Building 1.—E.—W. wall. Two cracks more or less parallel, inclining towards the W. at about 45°.

Building 2.—Two walls running E.—W. had slight cracks immediately above the doors. All these cracks were more or less vertical.

Building 3.—Wood above and brick below. The masonry is in blocks or sections as the bricks are between wooden frames. Many of these blocks of masonry were pushed outwards in all directions.

Ruby Mines District.

Mogok.

Mr. E. J. Colston, Deputy Commissioner.—The main shock occurred about 8-50 A.M. on the 23rd May. It was reported to have occurred in Momeik at 8-50 A.M. and in Mogok at 8-56 A.M. by telegraph time. The report from Thabeikkyin states that the shock occurred there rt about 10 A.M. (station time). To account for the discrepancy between the time for this latter place and that at which the shock was felt in Mogok, he writes that as there were a number of shocks during the day, it is probable that the first one was not noticed in Thabeikkyin. In Mogok, the shock at 8-56 A.M. was preceded by tremulous vibrations, and by a sound resembling distant thunder. Its duration is reported to have been 50 seconds, and its direction E.—W. The ground is described as rising and falling like the waves of the sea. All brick buildings suffered from the shock and the tops of pagodas collapsed, the ruins falling in a S.W. direction. The cracks in walls were more or less perpendicular. He was absent from the station on the day, but on his return made an examination and noticed that the pagodas had been affected in a peculiar way. They had crumbled down on one side almost as if they had been sliced with a knife, parallel to the side in question, and their "htis" had fallen over on the crumbled sides.

Besides the broken pagodas in the Mogok valley, the principal damage was done to the Government buildings of the station. In the houses of Government officers, which consist of wooden posts and frames with brick panels, the gable panels were shaken and could be seen rocking during the shocks. In one case a panel fell into the house, the direction of the fall being towards the N.W. The wall from which this fall occurred was along the line of what he took to be the general direction of the earthquake at this point. In the court-house which is two-storeyed and lies at an angle of 45° degrees to the general direction of the earthquake, a few of the top panels in the upper floor which had rocked were removed at once as they were considered unsafe. Compared with the damage done to the other houses, that caused to the court-house was inconsiderable, the reason for this being that the length of the court-house was at the given angle to the general direction of the earthquake. In various houses five brick chimneys were so badly damaged that they had to be dismantled, three from roof level and two from the base. In the jail, a two-storeyed masonry building, in addition to the cracks over the arches, most of the stones filled in between the top of the wall and the roof, came loose and had to be removed. It is said that this stone filling was probably inferior work. This building lies at an angle of 45° to the general direction of the earthquake, and the long jail walls at the back showed a horizontal crack at mid-height. In the Deputy Commissioner's house which faces S. E., most of the plaster was brought down from the walls running in a S.E. direction. The principal damage in this house was done upon the S.W. side, the rooms on the N.E. being scarcely affected. It was noticed later that shocks in the town, half a mile away in the valley, occurred there one or two seconds before they were felt in the Deputy Commissioner's house.

In Momeik an account was kept by two traders in the bazaar. They felt the chief shock of the day at about 9 A.M., or at about the same time as the chief shock seems to have been experienced in Mogok. In this case the sounds were heard coming from the S.W., and shortly afterwards the earthquake came moving towards the N.E. The pagoda in the centre of the town crumbled on its N.E. side and various other pagodas fell. The duration of the shock is said to have been about 8 minutes in Momeik and while it lasted about 100 cups and glasses in the bazaar were broken. During the day 14 shocks are said to have occurred here, and the lands near the Nammeik and Nammaung streams close to Momeik cracked in several places, the direction of the cracks being E.—W.

In Thabeikkyin as already stated, the time when the first shock was felt was 10 A.M. It was preceded by a tremor, and 3 distinct shocks at intervals of a minute or two are said to have occurred. The direction is believed to have been from S.W. to N.E., because the trees swayed to the N.E., and the pagodas crumbled on that side too. The same thunderous murmur was noticed before the shocks, and during their continuation hanging lamps swung S.W.—N.E. Pagodas at Thindaing and Kyahnyat are reported to have crumbled away from the N. E. side. The floor of both rooms of the Sub-divisional Officer's house cracked, the crack running in the direction of the tremor. In Thabeikkyin people suffered from giddiness for 5 or 6 days afterwards.

The Deputy Commissioner then goes on to give an account of a phenomenal rise in the Irrawaddy which he witnessed at Tagaung on May the 24th. The rain was torrential and in 24 hours the river rose 3 feet at this point, but he is unable to say whether this was merely an exaggeration of the normal state of affairs at the commencement of the rains. It was subsequently reported that during the earthquake the dry sand-banks in the river blew up and cracked, and that the same torrential rains and sudden rise had been noted on the Shweli, which runs through the Kodaung tracts from China. Being on the river in a launch he did not experience the shock of the 23rd personally.

It is noticeable that little or no damage was done to the Thabeikkyin—Mogok high road by the shocks of the 23rd, although on account of the way in which this road is overhung by precipices and overhangs them in turn, and also on account of the number of bridges, it was naturally expected that much damage would have ensued. The Myook of Mogok, who was travelling by motor car on this day on the road, reported that no shock was felt by any of those in the car, though the motor was moving through the severe shocks. He only became aware of the earthquakes on his arrival at Shweyaungbin at about 11-30 A.M., where he noticed that the top of a pagoda had fallen. Although the road was not damaged, six pagodas along the road between Shweyaungbin and Mogok were crumbled away, and four others were cracked.

In addition to the damage to buildings in Mogok itself, minor damage was caused to Government buildings throughout the district, and excluding the Kodaung hill tracts a total of some 200 pagodas have been more or less injured. The official account of the Government buildings in Mogok is given below :—

Deputy Commissioner's Quarters.—The plaster on the posts and many of the brick nogging frames in the building fell off.

Deputy Conservator of Forests' Quarters.—Both brick chimneys had to be dismantled to the roof level. One of the brick nogging panels fell and several others had to be taken down as unsafe.

Civil Surgeon's Quarters.—The gable portion of the brick nogging had to be removed as unsafe.

Deputy Superintendent of Police's Quarters.—Most of the top brick nogged panels had to be removed as unsafe. Several of the lower ones were also shaken quite loose.

Battalion Commandant's Quarters.—The gable portion of the brick nogging had to be removed. The kitchen range fell down.

Battalion Assistant Commandant's Quarters.—The gable portion of the brick nogging and one or two of the top panels had to be removed. The remaining portion of the front wall was shaken loose.

Assistant Commissioner's House.—Slight cracks in the chimney.

Treasury Officer's Quarters.—Many brick nogged panels were dismantled.

Court House.—Several of the panels at the top of the first floor were dismantled.

Jail.—At the junction of the roof and the stone wall of the guard house several stones worked loose and had to be removed. All the arches were slightly cracked. The greater portion of the outside of the jail wall contained a horizontal crack at half its height.

Opium Shop.—The walls of the opium cooking room were badly cracked.

Forest Office.—The chimney was dismantled at the roof level.

P. W. D. Inspection Bungalow.—Two out of the three chimneys fell and had to be dismantled.

Kodaung Hill Tracts.

The Assistant Superintendent, Kodaung Hill Tracts.—He experienced severe shocks in his camp on the 23rd, and subsequently found that most of the pagodas round the hills, including a number of very ancient ones, had crumbled.

Mogok.

Mr. L. James, Superintendent of Telegraphs, Sagaing Division.—Time about 8-55 A.M. It was not a sudden shock, and he continued breakfast for some seconds before it became obvious that the quake was more prolonged and severe than the minor ones which had preceded it. After leaving the bungalow he observed the surface of the ground in waves, the crest of which appeared to face W. As the shock continued the pagoda tops in and around the dâk bungalow compound gradually got up a swing,—there was ample time to speculate whether the top would fall or not, —and the very large amplitude attained before actual collapse took place was remarkable. The damage done was entirely due to the very long duration of the shock, and if it had continued a little longer the damage would have been very much greater than was actually the case. Most of the pagoda tops fell, and those which were observed went over in every case towards the W. All the bottles in the bungalow fell towards the W. and nearly all the coffee in the breakfast cups was slopped over on to the cloth on the same side.

There was a very sudden and severe shock about 11 A.M. of an entirely different character. It was more in the nature of a blow and was over in a second. In this case no damage was done. Minor shocks continued for two or three weeks after the 23rd.

Kyaukse District.

Kyaukse.

Lieutenant-Colonel J. J. Cronin, I.A., Deputy Commissioner.—His officers generally reported the chief shock of the 23rd at 9 A.M., which agrees with his personal experience. He had time to go downstairs and outside, and watched the finials on the roof of the house which were swaying from side to side. Almost immediately afterwards a pagoda in the vicinity came down with a crash and fell N.W. The tops of over a dozen pagodas in Kyaukse were thrown down, in most instances falling to the W. and N., while several more were similarly injured in Myittha. The iron stays holding the racks to the walls of the record room, were dragged out on both sides. In his house the cross beams of the ceilings running N.—S. moved out and showed about one inch of the unpainted portion at the ends. He also inspected the cracks which opened for a length of 150 feet approximately, about a mile S. of Kyaukse hill, within some 50 feet of the bank of the Zawgyi river, and noticed sand and water bubbling out.

Kyaukse.

Mr. Hampton, Sub-divisional Officer.—Time 9-10 A.M., by a watch adjusted to railway time a day or two previously. His house which is built on posts, swayed N.—S. The ground appeared to move N. A distinct rumbling was heard just before and during the shock.

Kyaukse.

Mr. W. A. Talbot, Station Master.—Time 8-57 A.M., "began by a crying wind running east and west which continued so and ended laterly from south to north, the full time this lasted was a minute and a half or may be some few seconds more." He was in the station office when the shock began and ran out on to the platform. He thought that the earth was shifting along E. and W. with a continued tremor. The station clock on the E. wall of the ground floor was not stopped, but a private clock upstairs in the centre of the N. wall stopped after it struck 9 A.M., just over a minute after the shock actually subsided. The pendulum on being examined was slanted W. The masonry walls of the building were disintegrated for a foot deep on the top along the roof, and five cracks about ¼ inch wide appeared over the arches of the doors and windows in the cases of 2 on the W., 2 on the N., and 1 on the S. Those on the E. were not damaged. Just a mile south of Kyaukse station and close to the Zawgyi river, a crack about 30 feet long appeared, from which fine sand and water bubbled forth until the evening. Many pagodas were cracked and had their upper portions smashed down.

Kyaukse.

Maung Po Shwe, Sub-divisional Officer.—Time 8-55 A.M. The direction was N.E.—S.W. Many old pagodas, zayats and brick-houses were damaged.

Singaing

Mr. Hampton, Sub-divisional Officer, P. W. D.—Reported that from an inspection made of cracks in the police station, he was certain that the direction of the shock was N.—S. The lower walls of this building, which has posts let into the ground at its corners, had vertical cracks in the N.—S. running walls, while those built in an E.—W. direction contained slight horizontal cracks. The vertical cracks were $\frac{1}{2}$ to $\frac{3}{4}$ inch wide. A distant rumbling, or "lower air vibration" was heard during, and just before, the severe shocks of the 21st and 23rd. On each occasion the sound appeared to be towards the S. Various aftershocks were felt, accounts of which are given later.

Myittha.

Maung Maung Tin, Sub-divisional Officer.—Three shocks in close succession were felt at 9 A.M. on the 23rd May. The direction was apparently from N. E. to S.W. The shocks were felt by everyone and were accompanied by loud rumbling noises. Most of the pagodas in the township had their tops lopped off by the earthquake, and others had their "htis" bent to the N. E. The W. side of the Sub-divisional Officer's court-house was slightly cracked and a few bricks were dislocated at the N.E. corner. The brick walling of the N. E. corner fell off in two places.

Myittha.

Mr. G. Craig, Executive Engineer.—In the civil police station at Myittha, two panels of brick nogged walls fell out and other panels were loosened. Plaster also fell off.

Myingyan District.

Natogyi.

Mr. G. Craig, Executive Engineer, Public Works Department.—The court-house at Natogyi was damaged. Four top and middle brick nogged panels of the N. wall and one middle panel of the S. wall dropped out. A few panels were displaced slightly.

Natogyi.

The Township Officer.—Time 9 A.M., from an uncorrected watch. Direction E.—W. Two distinct and severe shocks with no preliminary tremors. No sound was noticed before, during or after the shock, except that of the falling court-house wall. On the N. W. of the court-house 8 pagodas sustained damage or fell down. The direction of the shock was observed from the swinging of hanging objects.

Popa.

Mr. B. N. Tuck, I.C.S., Deputy Commissioner.—He was near the foot of Mount Popa on the 23rd, but only felt a slight shock.

Meiktila District.

The following damage was done to official buildings in Meiktila.

Meiktila.

Medical Officers' Quarters.—The panels in the brick nogged walls parted slightly from the frames, and some of them had a tendency to fall out.

Junior Married Officers' Quarters.—Same as Medical Officers' Quarters.

Servants' quarters, Native Infantry Mess.—Old cracks in the walls widened considerably and some new ones formed, endangering the structure.

Armourers' Shop, Native Infantry.—Old cracks widened considerably, endangering the structure.

Additional Judge's Quarters, Meiktila.—Old cracks in the brick walls of the lower storey widened, and some new cracks formed. Brick panels in the brick nogged wall in the upper storey parted from the frames, and some of them had a tendency to fall out.

District Superintendent of Police's Quarters, Meiktila.—Brick panels of brick nogged walls parted from the frames.

Deputy Commissioner's Quarters, Meiktila.—Brick panels of brick nogged walls parted slightly from the frames and some of them had a tendency to fall out.

Assistant Engineer's Quarters, and Superintendent of Land Records' Quarters, Meiktila.—Same damage as was caused to the Deputy Commissioner's quarters.

Jail Buildings, Meiktila.—Keystone of arch over main entrance fell out. Old cracks in enclosure walls widened and some new ones formed. Door bricks on enclosure wall fell out.

Thazi.

Mr. A. E. Floate, Station Master.—Exact time 8-55 A.M. The railway refreshment room clock stopped at 9 A.M. No damage was done.

Correspondent in "Rangoon Gazette."—The "hti" of the Shwe-hmaw-taw pagoda was hurled down in fragments.

Mayagon.

Mr. G. Craig, Executive Engineer, P. W. D.—Reported that no damage was done to any Government buildings in this sub-division.

Thazi Sub-division.

Yamethin District.

Major F. Bigg-Wither, I.A., Deputy Commissioner.—Direction N.—S. or N.E.—S.W. The back wall of the district office record room was badly cracked from top to bottom. The following damage was caused to official buildings in Yamethin.

Yamethin.

Jail Buildings.—Old cracks in the enclosure wall widened and new cracks formed. Plaster and loose bricks on the enclosure walls fell off.

Record Room.—This building suffered most, though the walls are of solid masonry. On examination it was found that in the series of arches on the N. side at the fifth from the W., the keystone of the fanlight arch had been thrown inward. The window arch below was in a similar condition. The cracks went to the foundations, and, as the building was in a dangerous condition, the cracked walls were dismantled and rebuilt. Cracks also formed in another arch and old cracks in the W. gable became widened. The W. gable (gable only) was thrown outward at least 2″ and the timbers of the roof are but poorly supported. With another severe shock the gable may fall out taking part of the roof with it. Plaster in various places also fell off.

Circuit House.—Brick panels of brick nogged walls parted slightly from frames and old cracks in the floor widened.

District Superintendent of Police's Quarters.

P. W. D. Sub-divisional Officer's Quarters.

Superintendent of the Land Records' Quarters.

Civil Sub-divisional Officer's Quarters.

In all these cases brick panels of the brick nogged walls parted slightly from their frames.

Treasury Strong Room.—One of the jack arches cracked at a corner and cracks formed in walls. Some plaster also fell off.

Civil Police Station Depôt.—Cracks appeared in floor and walls and some plaster fell off.

Military Police Armourer's Shop, and Ration Godown.—Some cracks appeared in walls and some plaster fell off.

I. B. Chakabutty, Civil Hospital.—Time 8-55 A.M. (railway time). Observer standing out of doors. Several continuous shocks lasting 90 seconds. Unusual sounds were heard from the S. before the occurrence. The shock was of sufficient intensity to crack the walls of buildings.

Yamethin.

Correspondent in the "Rangoon Gazette" of May 25th, 1912.—Reported that the Yamethin station building was slightly damaged.

Yamethin.

Correspondent in the "Rangoon Gazette" of June 5th, 1912.—"It comes to light that not only have the circuit house and the newly erected Roman Catholic Chapel been cracked, but the railway refreshment room has been damaged and the verandah condemned, so that its use is debarred until it can be rebuilt."

Maung Po Mye, Station Master.—Time 8-56 to 8-59 A.M. The only clock in the station was stopped. He was overpowered with giddiness which did not leave him completely for three days, and writes that many people in the town experienced the same feeling. Some 7 or 8 buildings in the town were cracked. The front face of one parted in the middle from top to bottom. The little cone which surmounts the top of the local Buddhist shrine, *i.e.*, the Lokamarayin pagoda, was detached from the rest of the structure.

Pyinmana.

Station Master.—Time 9-2 A.M., taken by a watch. Duration 1 minute 50 seconds. There were three shocks with intervals of about one second. The station clock was stopped but no damage was done, except to a brick house in the village which was cracked.

Pyawbwe.

Mr. A. Murray, Station Master.—Time 8-55 A.M. Duration about one minute. The station clock was stopped but no damage was caused as all the buildings are wooden ones.

Shwemyo.

CHAPTER II.

OTHER AREAS IN BURMA.

Bhamo District.

Bhamo.

Captain G. H. Medd, Irrawaddy Flotilla Company.—Time about 9 A.M. He was walking along the centre of a road but experienced an extraordinary inability to follow a straight line, and lost the sense of height in stepping. He found himself diverted to the left side of the road, into the centre again and thence to the edge once more. The movement lasted 1½ to 2 minutes and appeared to be from E. to W., the road running N.—S. He became intensely giddy and felt all the sensations associated with sea-sickness. Other wayfarers approaching from the opposite direction also staggered across the road in the same direction. At this observer's bungalow the servants were much alarmed, reported that the building which is an old wooden frame one had cracked and groaned during the shocks, and that the doors and windows swung open. High trees around swayed visibly at the tops, and four dogs kept in the house rushed out barking. Judging from previous experiences of earth tremors both in South America and in the East, Captain Medd considered the shock to be of considerable force, its short duration probably accounting for the absence of damage to brick buildings.

Bhamo.

Head Clerk, Irrawaddy Flotilla Company's Agency.—He was riding in China Street on a bicycle when the shock occurred, and found it impossible to keep his balance. He also felt severe giddiness. The population of the quarter rushed into the street in alarm.

Bhamo.

Mr. F. Lewisohn, I.C.S., Deputy Commissioner.—Summarising the reports which reached him, wrote that no one in the Bhamo district observed the earthquake with any accuracy. The time did not appear to have been checked. One observer stated the direction to be from W.N.W. to E.S.E., another within three miles of the former at the time of the occurrence, from E. to W. The former gave the length of duration as 1½ minutes, the latter from 1½ to 2 minutes, while a third person at Shwegu, a town 40 miles W. of Bhamo, felt 2 shocks from

E. to W., each lasting 20 seconds, with an interval of 5 seconds between them. The last shock was succeeded by a rumbling noise which lasted for about the same time, and approached and died away "as if a train were entering and leaving a railway station." All describe the shock as severe and one observer was knocked down by it.

The Superintending Engineer reported that the following damage was caused by the earthquake to Government buildings in the Bhamo district :—

Bhamo Town.—Slight damage to the Treasury strong room.

Warrabum.—Walls of the barracks and the Native Officers' quarters in the military police post were cracked in several places.

Myitkyina District.

Mr. J. T. O. Barnard, Extra Assistant Commissioner.—Time 9 A.M., guessed. It caused nausea at the time but he did not realise that it was an earthquake until afterwards.

Myitkyina.

Balkrishna, Chief Clerk.—Time 9 A.M., guessed. He felt the earthquake distinctly while sitting in the Deputy Commissioner's Office. It caused slight cracks in the brick nogging walls.

Myitkyina.

Mr. A. D. Gabriel, Meteorological Reporter.—Time 9-5 A.M. on the 23rd May 1912. Duration ½ second. Observer standing indoors at the time by the side of the Civil Surgeon in the office room. Two distinct shocks were felt unaccompanied by any unusual sounds.

Myitkyina.

Maung Po Thein, Township Officer.—Time 8-40 A.M. by clock set to railway time. The shock was distinctly felt and was preceded by a low roaring sound. From the swinging of hanging lamps its direction is given as from the S.W. No damage was caused.

Mogaung.

Station Master.—Time 8-56 to 9-2 A.M., the station clocks were not stopped. No damage was done, but the shaking was felt by the station staff, and the villagers in the neighbourhood were alarmed.

Mogaung.

A. P. Sundram, Sub-Assistant Surgeon, and S. M. Hedayatullah, Sub-Postmaster.—Time 8-45 A.M., by a time-piece not compared with standard time. Duration 15

Htagaw.

minutes. Three or four shocks, preceded by tremulous vibrations. Men standing had to steady their positions. Hanging lamps swung freely E.—W. As there are nothing but huts at this place no damage was caused.

Mr. W. A. Hertz, C.S.I., Deputy Commissioner, Myitkyina.—Reported that slight shocks are common in the Kamaing and Jade Mines tracts.

Kamaing.

Captain Batten, Sub-divisional Officer.—Time 9 A.M. by watch set to telegraph time. He was sitting at table and felt the shock distinctly. It lasted 30 seconds. Both the house and some big trees near rocked from E. to W. He experienced a feeling of nausea. No damage was caused.

Kamaing.

Mr. P. M. R. Leonard, Extra Assistant Commissioner.—Time 9 A.M., guessed. He was sitting at a table when the shock commenced and ran out of the house, as the table and chair commenced to rock from W. to E. The shock lasted from 1 to $1\frac{1}{4}$ minutes and caused nausea but did no damage.

Sima.

Mr. T. F. G. Wilson, Extra Assistant Commissioner.—Time 8 A.M., guessed. Two distinct shocks. No damage was caused.

Sadon.

Captain Fennel, I.A.—Time 9 A.M., guessed. The rock on which he was seated rocked from N.W. to S.E.

Sima-Nmaikrang Road.

Katha District.

The Sub-divisional Officer.—Two distinct shocks were felt about 9 A.M. Exact time not noted. Duration not more than 1 minute.

Katha.

Maung Po Tu, Advocate.—Time exactly 9 A.M., according to railway time. Apparent direction S.W.—N.E. No sounds of any kind were noticed before, during or after the earthquake.

Katha.

Station Master.—The station office clock stopped at 8-55 A.M. No damage was caused.

Naba.

The Sub-divisional Officer.—He was out walking and felt a shock a little after 9 A.M. (uncorrected time), but was informed by the villagers of Legyin that

Banmauk.

an earlier movement took place between 8-30 and 8-45 A.M. Direction of second shock from W.—E. Duration about 10 seconds. No sound phenomena were observed. The shock was very distinctly felt and the villagers experienced feelings of nausea. Banmauk sub-division is extremely hilly and sparsely populated. It contains only three masonry buildings, two police stations and a treasure vault, none of which were damaged.

Wuntho.

Maung Gale, Sub-divisional Officer, Maung Tha Byaw, Maung Tun, and Maung Khin, Traders.—Time 8-50 A.M., uncorrected. Three distinct shocks lasting 2 minutes. No preliminary tremors, but the subsequent vibrations lasted ½ minute. Direction S.W.—N.E., observed by hanging lamp which swung as much as 13 inches out of the perpendicular. There was a rumbling sound heard during the main occurrence. Two walls of the Wuntho township office, which is built of the usual brick nogging in wooden frames, were cracked and the plaster came off another wall in two places. Both cracked walls are parallel, coursing N.—S. In the E. wall the cracks occurred about 10 feet apart, on the S. side of the centre posts. Commencing from the edge of the posts they ran diagonally upwards at an angle of about 60°, to a height of about 5 feet from the ground, and right through the wall. A crack some 6 feet in length also appeared in the cement floor running in a S.W. direction.

Wuntho.

M. Molid Khalil, Sub-Postmaster.—A great shock occurred at 9 A.M., by telegraph time. Direction N.—S. Duration 1 minute. He thinks that the quake was divided into 3 or 4 separate shocks.

Pinlebu.

Maung Pyu, Myothugyi of Pinlebu Township, Maung Po Lu, Myothuggi of Pinlebu, Maung Lu Gyi, Ywasaye of Kauksin, Pinlebu Township.—Time 9 A.M., guessed. No preliminary or subsequent tremors and no sound phenomena. One shock distinctly felt from S. to N. Duration about 1 minute. Cooking pots and cups fell to the S., in Kauksin and Kyaukingon villages and hanging lamps swung as much as 18 inches from N. to S.

Kawlin.

U Ne Myo, Schoolmaster.—Time 9 A.M., by a watch compared with railway time. No previous or subsequent vibrations were felt but a rumbling sound was heard. Two distinct shocks lasting 2 minutes. Direction S. to N.

Shwebo District.

Mr. W. V. Wallace, Deputy Commissioner, Shwebo.—He felt a shock while writing in the office room of his house at almost exactly 9 A.M., on the morning of the 23rd May. He took out his watch to see how long the shock would last, but as he did so the violence of the earthquake greatly increased, with the result that a lot of plaster fell off the walls of a room upstairs, and the noise gave him the impression that the brick nogging was falling out, so he got up to leave the house. He then found that the earth was distinctly rocking from N. to S., as it caused a dinner waggon to sway in that direction to such an extent that some glass was flung on to the floor.

Shwebo.

Upstairs it was found that the plaster had fallen off the S. sides of the bathroom walls only, and that a door facing E. and W. had to be forced open, as the door frame had evidently been slightly pushed out of the perpendicular. The only noise detected was the creaking of the building itself. The duration was perhaps 40 seconds. Very little damage was done in Shwebo town, a few old and badly built brick buildings showed small cracks.

Upper Chindwin District.

The Sub-divisional Officer.—Distinctly felt a shock about 9 A.M. on May 23rd. Duration about 4 seconds.

Kindat.

The Sub-divisional Officer.—A distinct shock about 8-30 A.M. It began with a slight tremor lasting 30 seconds, followed by a very distinct shock lasting about 10 seconds, which was succeeded by after tremors for another 20 seconds. Direction N.—S. The children who were walking in the streets began to lose their balance. There was no damage to life or property.

Mingin.

The Sub-divisional Officer.—Distinctly felt shock at 9-30 A.M. Time merely guessed. About three distinct shocks were felt. No preliminary tremors and no sound phenomena. Direction S.E.—N.W. Mr. E. P. Dove, Executive Engineer, Public Works Department, did not feel the shock.

Kalewa.

Lower Chindwin District.

E. A. Passanha, Telegraph Master.—A continuous distinct shock started at 8-55 A.M., and lasted for 1 minute 55 seconds by telegraphic time. Judging

Monywa.

from the swaying of trees and the motion of water in fire buckets it moved from N. to S. No objects were overturned, neither was any damage caused to the building.

Maung Po Mya, Senior Sub-Assistant Surgeon.—Time 8-30 A.M. Duration $\frac{3}{4}$ of a minute. A very distinct shock from N. to S. Near the hospital the top of a pagoda, with its "hti," was broken off.

Monywa.

Mr. Francis, Storekeeper, Public Works Department.—Time 8-55 A.M. by telegraphic time. Direction N. to S. Duration about 2 minutes. This observer has lived in Monywa for 20 years but has never felt such a severe and continuous shock before. No damage was done to his house as it is a wooden one, but the clock was stopped and crockery fell down. Cracks 2 or 3 inches in width and extending over 15 feet in length, were noticed subsequently in a brick building in the town. A small crack about $\frac{1}{16}$th inch in width and 10 inches long appeared in the N. wall of the Roman Catholic Chapel. Old people were unable to stand without support.

Monywa.

J. Mahadala Moodlier, Station Master.—A severe shock occurred at 8-55 A.M. The station clock was stopped. Duration 1 minute 55 seconds. Direction N.—S., from the movement of trees and buildings. All the railway buildings are constructed of wood, therefore no damage was done. In a brick building a gaping crack 2 or 3 inches wide was caused. The Roman Catholic Church was cracked near the entrance. The station master has never felt such a severe shock in his life, and the inmates of his house "lost all confidence and they were very giddy."

Monywa.

Mr. Gordon W. Lepper, Geologist, The Burmah Oil Co., Ltd.—Time 9 A.M. by uncorrected watch. Intensity IV—V Rossi-Forel scale. The bungalow shook as if affected by a gale. He ran out and found his servants hastily getting from below the bungalow. The shocks lasted at least 30 seconds, and he instinctively held on to the compound fence, while the ground seemed to be moving to and fro in a horizontal plane. He then returned to the bungalow and placed a basin of water on the table. Extremely feeble shocks (intensity II, Rossi-Forel scale), continued for 5 minutes or more after 9 A.M., and again at intervals until about 10 A.M. These aftershocks were extremely feeble, hardly noticeable.

Kani.

Sagaing District.

Ywataung.

The Station Master.—Time 8-50 A.M. Duration about 2 minutes. The station clock was not stopped. The station buildings and the wagons in the yard could be clearly seen shaking. As most of the quarters in this station are built of wood they sustained no damage, but brick buildings suffered slightly. These latter comprise the locomotive workshops, the engine shed and the divisional offices. The brick walls broke here and there, some partitions fell down and large cracks were caused in several places.

Natyekan.

Maung Bah, Station Master.—Time 8-55 A.M. Station clock stopped. Duration 2 minutes and 5 seconds.

Sagaing.

Mr. C. S. Pennel, Deputy Commissioner.—Time exactly 8-57 A.M. on May 23rd. Several clocks with pendulums stopped at the hour mentioned. These clocks were regulated with that of the telegraph office. At outstations in this district the timing was more or less guess work and variously reported as 9 and 9-30 A.M. A loud rumbling sound resembling that of heavy carriages driven quickly on a metalled road preceded the shock, which lasted for 1½ to 2 minutes, and was followed by 7 or more shocks during the course of the day. Apparent direction from N.E. to S.W. judged from the fall of loose objects and the swing of hanging lamps. Brick buildings and pagodas suffered throughout the whole district. Walls running E. to W. were cracked towards the perpendicular. Several pagoda tops were knocked off and the "htis" of others were bent. Ornaments on tables and brackets were knocked down, and water jars containing water overturned. A Jost fan was thrown from its pedestal, the direction of its fall being N.—S. In the towns of Sagaing and Myinmu all these effects were noticed, also free swinging objects swung considerably from N.E. to S.W. Houses swung in an alarming manner and stucco ornaments on the top of brick buildings were dislodged. Mr. G. F. S. Christie was in a moving train and felt nothing.

Minbu District.

Minbu.

Mr. Soloman, Sub-Assistant Surgeon.—Time between 9 and 9-30 A.M. Chimney of a hanging lamp fell and smashed. Duration 5 seconds.

Minbu.

Mr. Grey, Headmaster, Government High School.—Time between 8-30 and 9 A.M. He did not notice the shock personally but the teachers in the school experienced it. Apparent direction N.—S.

Minbu.

The Sub-divisional Officer.—Reported that various people in the town felt the shock very slightly.

Minbu.

Mr. Morris, The British Burma Petroleum Co.—He was seated at his desk about 9 A.M., when the chair moved gently backwards and forwards and he experienced a feeling of nausea.

Minbu.

Mr. Francis, Head Clerk, Deputy Commissioner's Office.—Noticed that one of the Duthagon pagodas was cracked by the shock.

Salin.

The Sub-divisional Officer.—Reported that various people in the town felt the shock "very slightly."

Salin.

Township Officer.—Time about 9 A.M. (guessed). Two or three distinctly felt shocks from S.W. to N.E., which disturbed hanging objects but caused no damage.

Salin.

Head Clerk, Sub-divisional Officer's Office.—Time 9-15 A.M. by watch compared with the post office clock three days previously. A distinct shock with previous vibrations and aftershocks. No damage was caused.

Salin.

The Assistant Township Officer and Maung Pe, Zema Quarter.—Time 9-15 A.M. by a watch compared with the post office clock. Distinct shock, which lasted 1 minute. Direction N.W. to S.E. Hanging objects moved but no damage was done. After the shock was over a great noise, something like the firing of a cannon, was heard. No aftershocks were noticed.

Sagu and neighbouring villages.

Maung Tha Do, Advocate, Sagu; Ywathit Headman, Kyauksan; Maung Zan Pe, Advocate, Sagu; Kumaruppa Chetty, Sagu; Maung Tun Mya, Sagu; Maung Po Twin, Sagu.—Time at Sagu, 8-47 A.M. by a clock compared with that of the telegraph office. Two distinct shocks were felt each of which lasted 5 minutes (!) with an interval of 1 minute between. They "appeared to go first from north-east to south-west and then from south-west to north-east." Plates on a table fell away towards the S.W., and suspended lamps swung in the same direction. Some people felt dizzy owing to the shock. When the earthquake was over a great noise like a cannon being fired was heard three times from the N.E.

Ngape.

Maung Ba Nyun.—Time about 8-10 A.M. Three distinct shocks, which lasted about 5 minutes. No preliminary tremors. Direction observed from the motion of hanging objects, was E.—W.

Pwinbyu.

The Township Officer.—Time about 9-12 A.M., by a watch compared with post office time. A second shock took place at 9-14 A.M., and lasted until 9-17 A.M. Vibrations felt for a minute after this latter shock. The first one appeared to come from the N., and the second from the W. Nothing was overturned and no damage was done.

Sadoktaya.

Maung San Hlaing, Head Clerk; Maung Thet Nan, Burmese Medical Practitioner.—Time about 9 A.M. (guessed). Duration about 5 minutes. The shock appeared to move from W. to E. Hanging objects continued to move for about 10 minutes. No preliminary tremors, sound phenomena or aftershocks.

Magwe District.

Magwe.

Mr. W. Robson, Chief Clerk, Deputy Commissioner's Office.—Time 8-55 A.M. according to telegraph office time. Duration 2 minutes. He was seated in a chair in an upper room reading, when the floor began to rock and he became giddy and sick. He rushed downstairs, found the house rocking and children holding on to posts for support. His house is 100 yards from the telegraph office and opposite it. Ten minutes after the shock the signallers came over and enquired whether he had felt it, as they themselves had not done so. They only knew of it by the telegraph master of Taungdwingyi asking whether they felt it or not, and also by the Rangoon telegraph office making the same enquiries. No damage was done to the house, nor were any things upset.

Magwe.

Head Accountant, Deputy Commissioner's Office.—Time 8-55 A.M. He noticed that his house was shaking and hanging lamps were swinging to and fro.

Magwe.

Mahomed Esoof, Head Revenue Clerk, Deputy Commissioner's Office.—Time 8-50 A.M., according to telegraph time. He felt two distinct shocks. The first lasted about 15 seconds with tremors for some 20 seconds afterwards. The second lasted longer than the first and took place some 10 or 15 seconds afterwards. Apparent direction from E. to W., judging from the motion of water in a wide-mouthed jar filled to the brim. Both he and his wife suffered afterwards from giddiness. Nothing was upset in the house and no damage was caused.

Magwe.

Mr. de Facieu.—Time about 8-45 or 8-50 A.M. He was on the veranda of the Deputy Commissioner's court-house, and distinctly felt the building sway several times in about 2 minutes. There was no accompanying sound, neither were any objects in the building displaced or overturned. He thinks that what he felt were more like tremors than distinct shocks, and very unlike any earthquake he has experienced before. Not a building in the town was damaged or cracked. The effect of the shock was to induce in several persons a feeling of slight nausea.

Magwe.

Hospital cook, and Sub-Assistant Surgeon, Military Police Hospital.—Both felt a slight shock about 9 A.M. Direction from E. to W. It was not experienced by the Civil Surgeon who was in a launch on the river.

Thekemyaung. Yabo forest reserve.

Mr. W. Ripley, Sub-divisional Officer.—A distinct shock at 9-30 A.M. on the 23rd May. No preliminary tremors were felt, but several smaller tremulous vibrations were distinctly felt after the main-shocks. Time of duration from 10 to 20 seconds. Direction S. E. —N. W., judged by water, by the movements of objects and shadows of trees, etc., at the time of the shock. Water bottles and hats said to have fallen and overturned. No particular sounds were noticed before or afterwards. On the 16th, very peculiar sounds were heard towards the N., by villagers and himself, at a place called Inywagyi in the Myothit township, in the morning and afternoon. When the villagers were questioned they said they had never heard such peculiar rumblings before, and could not understand them. They were of long duration and not very loud.

Between Myothit and Natmauk.

Mr. H. Marsland, Public Works Department.—He was riding on a pony between these two places and did not feel anything. No buildings, Government or private, in the Magwe district were damaged. The shock must have been very slight in Magwe, as a masonry building, which had partially collapsed a month or so before, whilst it was under construction and which he had condemned as dangerous to human life, some of the walls being at angle to the vertical, was not affected in any way.

Mr. Ray, District Superintendent of Police.—Time soon after 9 A.M. Duration about 2 minutes. He was seated in a chair on the ground floor of a house. He felt the concrete floor move in waves, and the swaying was so severe that another officer who was standing had to sit down. They both experienced a sensation of nausea. Two very distinct periods were noticed.

Taungdwingyi.

Maung Ba Pe, Head Clerk, Sub-divisional Office.—Time about 9 A.M., by a watch compared with telegraph office time. Duration about ½ minute. Direction from N.E. to S.W. as estimated from the swaying of pagodas. Not noticed by people on the move. Hanging objects were set swinging. No aftershocks.

Taungdwingyi.

I made numerous enquiries amongst the European and American officers of various oil companies in Yenangyaung. Most of those who were on the oil-field felt a slight shock and saw the derricks moving, whilst others who were in office felt nothing.

Yenangyaung.

Captain A. P. Sandeman, I.A., Warden.—Time about 9 A.M. He was in office at the time when it began to rock as in a high wind. He rushed out, but no damage was caused. Experienced nasuea.

Yenangyaung.

Mr. W. E. Smith, Agent, The Nath Singh Oil Co.—Time about 9-20 A.M. Distinct shock felt by all the office staff. Duration about 5 seconds. No articles were moved or dismantled and no damage was caused.

Yenangyaung.

Mr. Fred. W. Spicer, Field Accountant, The Burmah Oil Co., Ltd.—Time 8-56 A.M. by local time (standard time unknown). He was sitting at his desk in a large single-roomed bungalow raised from 1 to 3 feet from the ground on piles, when the house swayed twice. The motions had an interval of 1 or 2 seconds and were sufficiently violent to give him a momentary qualm of sickness.

Yenangyaung.

Mr. Basil E. Macrorie, Geologist, The Burmah Oil Co., Ltd.—He looked at his watch when the shock was over. It indicated 8-55 A.M. It is difficult to say

Nyaunghla.

how long the shock lasted. Possibly he only felt it for 5 seconds, but it may have been as long as 10 seconds at a maximum.

Pakokku District.

Yenangyat.

Mr. H. H. Young, Refinery Manager, The Burmah Oil Co., Ltd.—The shock was felt at 8-52 A.M. He noted the time immediately by his watch, but unfortunately he has no standard time to go by. There was one distinct shock which lasted about 55 seconds, preceded by a slight wind and followed by complete stillness. It was distinctly felt and appeared to come in waves, its apparent direction being from W. to E., judged from the agitation of water in a tank set in the ground, and also from the swinging of balance weights set to flue doors. One slight crack, running nearly straight up and down, was caused in the brickwork of an oil still. Earthquake tremors are almost weekly occurrences at this place.

Toungoo District.

Toungoo.

Mr. Walter. C. Sherman, Government Telegraph Office.—Time 9-3 A.M. by the telegraph office clock, which is said to be fairly accurate, but "of course there may have been a difference of a minute or two each way." Duration a good 6 or 7 seconds, accompanied by a peculiar droning sound. He was in the telegraph office which is a wooden building 15 feet off the ground. It shook and swayed a good deal. Direction N.—S., judging from water spilt from fire buckets kept on the veranda floor. It was rather distinctly felt by people in upstairs buildings. Others on the roads at the time said they felt a peculiar sensation and some experienced a feeling of nausea. Only one building to his personal knowledge suffered slightly, a masonry wall facing N. cracked from the ceiling downwards. No aftershocks were experienced.

Toungoo.

Mr. W. R. Fry, Municipal Engineer.—Time 9-5 A.M., by an uncorrected watch. No preliminary vibrations or unusual sounds. Duration a little over a minute. Direction E.—W., judged from the movement of water in a small tub near his office table, part of the liquid from which was spilled. He did not hear of any buildings being cracked in Toungoo. According to Mr. A. H. Geyer, Deputy Commissioner, no damage was done in Toungoo or the district.

Pyu.

Maung Po Tin, Sub-divisional Officer.—A severe shock was felt at 9 A.M., lasting a full minute. With his family he went downstairs and when on the ground they continued to feel the shock. A brick wall of the house in which the township judge, Maung Gale, lives, was slightly cracked from top to bottom. The water in the Sittang river was disturbed, the waves moving from E. to W.

Kyaukkyi.

Mr. A. Williamson, Sub-divisional Officer.—Time 9 A.M., not accurately observed. Duration 2 minutes, a rough guess. To an unscientific observer the whole phenomenon appeared a wave-like motion, gradually increasing to a period of highest intensity and then dying away again. Direction mainly N. and S., as estimated from the swaying of a punkah. The only sounds noticed were the rattling of doors and windows and the creaking of joists. He was writing at the time, and the preliminary tremors were quite sufficient to make it impossible to continue.

Shwegyin.

The clerk to the Sub-divisional Officer.—The cupboard in the office threatened to fall over on to him. From its position, this indicates a more or less N.—S. direction for the shock. Some joists fell from a house in the bazar but they were very rotten. Two long cracks were caused in the plaster of the Sub-divisional Officer's house, which is a comparatively new laterite building. They run straight up and down in the E. and W. walls of one of the rooms.

Thayetmyo District.

Thayetmyo.

Mr. R. C. W. Symms, Deputy Commissioner.—He did not feel the shock on the ground floor of his house. People on the first storey noticed it about 8-45 A.M. Glasses on tables shook and doors rattled. The direction was from N. to S. apparently. No damage of any kind was done in the Thayetmyo District.

Thayetmyo.

The Civil Surgeon.—Time 9-5 A.M. Duration 30 seconds. Observer sitting indoors at the time. One slight quake was felt, strong enough to move his seat a little. No unusual sound phenomena were heard.

Allanmyo. *The Sub-divisional Officer.*—Time 9 A.M. uncorrected. No preliminary vibrations. Duration 1 minute, and direction W.—E.

Tawmun. *Mr. R. C. Rogers.*—Time 8-30 A.M. He was sitting in a one-storied house and felt a continuous shock from E. to W. It lasted for quite a minute and felt as if a large animal was rubbing itself against the posts of the house. It caused the writer and the policemen, who were with him, to feel giddy.

Sinbaungwe. *U. Asaya, Pongyi.*—Time 8-47 A.M. No preliminary vibrations. Continuous shock, lasting about 1 minute.

Minhla. *A belated report from a Burmese official.*—Time 8-15 A.M. Duration 5 seconds. Direction N.—S.

Mindon. *A belated report from a Burmese official.*—Time 9 A.M. Duration 3 minutes. No preliminary tremors. Apparent direction N. W.—S. E.

Northern Arakan District.

Paletwa. *Mr. W. H. Thom, Deputy Commissioner.*—He did not feel the earthquake personally, but the clerk of the police station recorded a slight shock lasting 2 seconds at 10 A.M. This time is said to be taken from a clock compared with the one in the telegraph office. Other people said that they felt the shocks at about 2-30 P.M., but when asked some weeks afterwards could not state the exact date. With regard to these time observations, the following pertinent remark of the Deputy Commissioner is worth quoting :—"The latter time is merely guess-work as most of the people in these parts have not even seen a clock and have no idea of time." No damage was done in Paletwa or district.

Akyab District.

Akyab. *Mr. J. D. deVine, Meteorological Observer.*—Time 8-55 to 9 A.M. Duration 23 seconds. Writer was standing on a staircase and felt two distinct shocks from N. to S. Doors and windows rattled and hanging objects swung. There were no other sound phenomena.

Akyab.

The Sub-divisional Officer.—A slight shock was felt in the town and in parts of the sub-division. "There were no effects."

Minbya.

Maung Saw U. Kaing, Sub-divisional Officer.—He noticed a slight shock which lasted for about a second.

Naungdaw.

The Sub-divisional Officer.—No shock experienced.

Buthidaung.

Saw Ban U., Advocate, and Tha Tun U., Head Clerk.—Time 9 A.M., by unchecked watch. About 7 distinct shocks were felt, lasting from 40 seconds to 1 minute and followed by a few vibrations.

Kyauktan.

Maung San Aung.—Time about 9 A.M., unchecked. Direction and duration not noted. No damage of any kind was caused.

Poonagyun.

Mr. A. R. Morris, Sub-divisional Officer, and the Township Officer.—Both reported that the shock was not felt.

Rathedaung.

The Sub-divisional Officer.—Two distinct shocks were felt, one at 9 A.M., and the other at 9 P.M.

Kyaukpyu District.

Kyaukpyu.

Maung Myat Tun Aung, Deputy Commissioner.—Reported that the earthquake of May 23rd, was hardly felt in Kyaukpyu. "Someone said that a slight shock was felt in the afternoon." No damage of any kind was caused.

Kyaukpyu.

The Sub-divisional Officer, Public Works Department.—He did not feel the shock himself, but reported that a gang of men employed at Pyade noticed it.

Sandoway District.

Sandoway.

The Civil Surgeon.—Time betwen 8 A.M., and 10 A.M. He was working in the Jail office, and felt the shock travelling from S.S.W. to N.N.E. Both the jailor who was standing near, and the deputy jailor seated at another table in the same room, felt the movements, which the writer regarded as a series of small shocks lasting 6 or 8 seconds. Five prisoners sitting on the ground just outside the office did not notice anything. The shock was not felt in the hospital or in the Civil Surgeon's house. Mr. J. D. Hamilton, Sub-divisional Forest Officer, reported that he did not feel the earthquake.

Sandoway.

Mr. P. Vajravelu, Accountant, Public Works Department.—Time about 8-30 A.M. He was seated in a chair facing S. and felt a slight shock lasting for a few seconds, running from W. to E. Both the chair and a table moved, the former in a lateral direction. He was informed a few minutes later by an outsider that an earthquake had been felt in the town.

Sandoway.

Maung Po Thwai, Tracer, Public Works Department.—Time between 8 and 9 o'clock in the morning of May 23rd. He was sitting on an easy chair and noticed that the direction of the movement was from W.—E. A few seconds later he thought the direction was reversed and then the former motion was resumed again.

Kyeintali.

Mr. J. A. de Rozario, Supervisor, Public Works Department.—Did not feel the earthquake of the 23rd May.

Taungup.

Mr. N. A. Times, District Superintendent of Police.—He felt a shock, but it was so slight that he did not take any particular notice of it.

Taungup.

Mr. J. C. Brown, Telegraph Master.—He did not notice any shock on the 23rd May, and failed to elicit any definite information regarding the earthquake in the town. It was not felt by anyone residing on the telegraph station premises and no damage of any kind was caused.

Prome District.

Prome.

Post Master.—Time about 9 A.M., two slight shocks were felt in quick succession on May 23rd, 1913. No further particulars are available.

Tharrawaddy District.

Tharrawaddy.

Major F. R. Nethersole, I.A., Deputy Commissioner.—He was seated at 8-30 A.M. (time guessed), in the upper storey of a wooden building which faces N., when the oscillation appeared to be from side to side, *i.e.*, E.—W. Duration about 15 seconds. No sound phenomena were observed.

Zigon.

The Sub-divisional Officer.—Zigon is 48 miles to the north of Tharrawaddy. Time 8-45 A.M. Duration 20 seconds.

Henzada District.

Henzada.

Mr. C. W. Allen, Divisional Forest Officer.—Time 8-53 A.M., by a clock set to railway time. One shock which lasted for about 30 seconds. Direction seemed to be W.—E.. No sound was noticed. It was distinctly felt by the Forest Officer, by his wife and by the Extra Assistant Conservator of Forests who were all sitting upstairs at the time. The whole house moved with a swinging motion, and water in a basin in the room was disturbed.

Pegu District.

Pegu.

Mr. W. Howell, Station Master.—The station clock stopped at 8-52 A.M. A very severe shock and two of a lesser nature were felt. They succeeded one another without a break and lasted for about 50 seconds. From the swinging of lamps and hanging flower-pots, the direction appeared to be from N.—S. No damage was done.

Pegu.

Mr. Ormiston, Deputy Commissioner.—He was informed that the earthquake took place about 9 A.M., but was out riding near the town and felt nothing. Mr. T. Lister, Assistant Commissioner, was talking in the road at the time to Sheikh Safdar Hussain, Extra Assistant Commissioner. The latter sat down in the road, while Mr. Lister said he felt trembling in the knees as one does on landing after a long sea voyage. He heard no accounts of objects being displaced. As regards injury, he mentions that his own house is extensively cracked, being built on made soil (the banquette of the old town wall), but it showed no fresh cracks after the earthquake.

Myitkya.

The Sub-Postmaster.—Time 8-47-56 A.M. on May 23rd, lasting about 3 minutes. No damage was caused.

Hanthawaddy District.

Rangoon.

Lieut.-Col. S. L. Aplin, I. A., Deputy Commissioner.—He felt a very slight shock which was only just perceptible at his house in Leeds Road, Cantonments, Rangoon, at 8-55 A.M. on the 23rd May. The time is from a watch which was lying before him on the table at which he was seated at the time, and which was within 2 or 3 minutes of the correct time according to the clock on the Chief Court, Rangoon, which he believes is usually correct. The electric lamp above his table swung from side to side but nothing else appeared to have moved. There were no cracks in the building nor was any object overthrown.

Insein.

Mr. H. Thompson, C.S.I., I.C.S., Deputy Commissioner.—He was a mile or two from Insein in the open and noticed nothing. The shock is reported to have been felt in different parts of the district at or shortly before 9 A.M. No accurate observations were recorded, but hanging lamps and other suspended objects were noticed to swing E.—W. No sounds were heard, and no damage of any kind was caused.

Kyauktan.

Capt. E. Butterfield, I.A., Sub-divisional Officer.—The shock was noticed at places all over the sub-division, and appeared to be a long slow wave. In no case was any noise observed and nothing was thrown down except balanced instruments at Seikkyi. No damage was done. In Sittan village, one Maung Kyaw, son of the headman, reported that he was writing letters at the time, seated facing N. and felt himself impelled forward and almost overbalanced. The shock lasted 2 minutes.

Syriam.

Various European employees of the Burmah Oil Co., Ltd., reported that the oil was observed distinctly swinging in the tanks at the time of the earthquake.

Thilwa.

The Manager, British Burmah Petroleum Co.'s Refinery.—reported that nothing was noticed at Thilwa.

Kayan.

The Township Officer.—Time 9-10 A.M., by a clock compared with the telegraph office time. No damage was done.

Thongwa.

The Township Officer, and Maung San Yon, Pleader.—Time 8-50 A.M., by a watch compared with telegraph time a week before. There were 3 shocks, the first being distinctly felt and lasting a minute. At intervals of about a minute two other shocks were felt. Hanging lamps moved or shook slightly and a few persons got giddy. There was no sound.

Seikkyi.

Mr. James Turley, Chemist, Indo-Burma Petroleum Co., Ltd.—Time 8-58 A.M., by the candle-house clock. Time not verified. One distinct shock. Direction N.N.W.—S.S.E.. Duration about 10 seconds. The candle machine weights, the lamps and the pans of a chemical balance were set swinging in the above mentioned direction. The swinging of the weights and lamps was approximately 2 inches. The pendants supporting the pans of a chemical balance were shaken off the knife-edges, but falling in a confined space, nothing was to be learned from the direction of fall. No aftershocks.

Seikkyi. *Mr. J. Thompson.*—Clock stopped, and water in the river was seen to move in waves from a few points to the E. of N. towards the S.

Maubin District.

Maubin. *Capt. A. B. Roberts, I.A., Deputy Commissioner.*—He felt no shock personally, but reported that it was felt slightly in Danubyu and Yandoon about 9 A.M. on May 23rd. No damage was done and very few people noticed it. In the S. of the district it was so slight that only one or two people felt it. Standard time is not kept, and 9 A.M., the time quoted, is a rough guess. No particulars were noted by anyone and nothing was overturned.

Bassein District.

Bassein. *Mr. W. F. Grahame, Deputy Commissioner.*—None of the people consulted by the Deputy Commissioner felt any earthquake shock during the month of May. He did not experience any himself, nor did he hear of anyone in the district who did. It is interesting to note that the Sub-divisional Officer of Bassein reported that an earthquake shock was felt there on the night of 22nd February 1912, at 8-10 P.M., the duration of which was 2-3 seconds. The Deputy Commissioner is very sceptical regarding the occurrence of this alleged shock.

Myaungmya District.

Myaungmya. *Mr. F. L. J. Williamson, Deputy Commissioner.*—Reported that no earthquakes were felt in the Myaungmya district in May 1912, so far as he could ascertain.

Pyapon District.

Pyapon.

Major H. V. M. Langtry, I.A., Deputy Commissioner.—Reported that no earthquake was felt in the Pyapon district on May 23rd, 1912.

Amherst District.

Moulmein.

Mr. J. D. Frazer, I.C.S., Deputy Commissioner.—Time 9 A.M., Slight shocks were experienced in Moulmein and Kawkareik.

Moulmein.

The Civil Surgeon.—Time 8-50 A.M., on May 23rd, 1912. A slight shock was felt by observer while working in his office.

Mergui District.

Mergui.

Mr. G. P. Andrew, Deputy Commissioner.—The shocks were not felt elsewhere than in Mergui town and no damage was caused.

Mergui.

Mr. J. F. Leslie, Secretary, Municipality, and U. Paduma, Head Upazin of Taw Kyaung, Alegyun, Mergui.—Time, just about 9 A.M., followed almost immediately by a second shock. Both were slight and their duration was not noted. Direction thought to be N.—S. Hanging lamps commenced to swing about, but nothing fell or broke. No sound was heard. Only people who were at rest felt the shock.

Chin Hills.

Falam.

The Assistant Superintendent, Chin Hills.—The shock was so slight that it was almost imperceptible, so much so that very few noticed it.

Tiddim.

The Assistant Superintendent.—Reported that no shocks were felt in his sub-division.

Haka.

The Assistant Superintendent.—Reported that no shocks were felt in his sub-division.

CHAPTER III.

OTHER AREAS OUTSIDE BURMA.

Yünnan Province, China.

Têng-yüeh.

Mr. C. D. Smith, H.B.M.'s Consul.—Reported that the earthquake was felt in Têng-yüeh, a few minutes before 9 A.M., as noted by the Commissioner of Customs shortly after the shock. Two separate shocks were distinctly felt, occupying perhaps a minute and a half from the beginning of the first to the end of the second. This is, however, a mere guess. The shocks appeared to move in an approximately N. and S. direction judging from the motion imparted to water in a bath tub. The first seemed to be the shorter in duration and the lesser in intensity. No sound phenomena were noted, and the Consul was unable to obtain any information as to the effects of the quakes, though no damage appeared to have been done.

Ssumao.

Mr. Roshigliosi, Assistant in Charge of Customs, Chinese Customs Service.—He did not feel the shock personally as he was out of doors at the time, but it was noticed by various other people. It was divided into 3 parts, the first was the most distinct and lasted 2 or 3 seconds. The apparent direction was N.—S., as judged by the pendulum-like swinging of hanging lamps. No unusual sounds were noticed. The time is given as 4-45 P.M., but as this is stated to be a mere guess, and it was not until the middle of August that Mr. Roshigliosi wrote his account, furthermore, obtaining his information from Chinese sources, I am of the opinion that this may be definitely stated to be a mistake.

Bengal.

Chittagong.

Mr. A. H. Clayton, Deputy Commissioner.—No earthquake was perceived in the Chittagong district on May 23rd, 1912.(1)

[1]Earthquake shocks were reported at the following Indian stations on May 23rd, 1912 :—

Rawalpindi	4-53 A.M. (Indian Standard Time.)
Drosh	{ 4-45 ,,
	2-0 ,,
Chitral	4-43 ,,
Gulmarg (Kashmir)	4-46 ,,

The intensity of these shocks does not seem to have been greater than IV—V on the Rossi-Forel scale. They appear to have been quite local in origin and to belong to the series of small shocks which are continually being felt in the Himalayan region.

Siam.

The following account appeared in the "Bangkok Times" of May 23rd, 1912:—

"Bangkok experienced a slight earthquake shock this morning which lasted for three or four seconds. The very slight duration of the shock notwithstanding, it was noticed over quite a large area. At Bankolem the electric lamps were all swinging, and from different business houses situated along the east bank of the river we have received the same report of lamps and electric fans swinging. At the Royal Railway Department the shock was distinctly noticed and two of the clocks stopped, the time being 9-10 A.M. At the Post and Telegraph office the time of the disturbance is given as 9-9 A.M. The sorting staff in Post Office No. 2 at work on the English mail, noticed the disturbance, and it is evident the tremors were not confined to one particular spot, as reports from the west side of the river, Bangsue military quarters, the Ordnance Department at Bang Nga and the Police School at Sapatum all report having experienced the tremors. At the police station near Wat Buparam the earthquake was noticed by people in the streets. At Messrs. Harry A. Badman's city store the lamps in that part of the building nearest the Chakkri Palace were all set swinging, while those in the other half of the building were stationary. The last earthquake recorded in this country as far as our knowledge goes was on the 1st January 1887.

Paknam.—It was at first thought that possibly an explosion had taken place at Paknam, but a telephone message to that place brought news that everything was all right and no tremors whatever were noticed there.

Petriu.—A telephonic enquiry to Petriu has elicited the fact that nothing untoward was noted in that district this morning.

Chiengmai.—A telegram received this morning states that a slight shock was experienced in that city on the 21st May. The tremors this morning were more severe and lasted longer. The time of the shock is given at 9-5 A.M.

Bangkok, later.—The boys in school as well as some members of the teaching staff noticed the earth movements, which produced a feeling of giddiness. One of the shipping firms state that the fans in their office swung nearly a foot out of the perpendicular. At the Railway works at Makasan a number of workmen complained of giddiness and sickness."

The following account appeared in "The Siam Observer" of May 23rd, 1912 :—

"An earthquake of some force was experienced here (Bangkok) this morning, the first shock being felt at 9-8 A.M. It lasted for just on three minutes. In the *Observer* building the shock was felt with considerable definiteness. Pictures swung on the walls and hanging lamps gyrated. In other houses full water jars shook so that some of their contents was spilled, while the telegraph and telephone wires above the streets swung several inches. A feeling of giddiness was the first indication of the quake experienced by most. This passed off as the tremor became more definite. During the first minute wooden buildings swayed distinctly, and even in stone buildings such as the Chartered Bank and Post Office No. 2, the shock was strongly felt. We learn that the direction was from the south-east. An old resident informs us that the last shock felt here was on either November 17th or 18th, 1886, when tiles fell from the roofs of houses in old Raheng, while in Bangkok the wood work of the houses strained and creaked. This quake occurred about 11 A.M., and was much more severe than this morning's quake. A local lady informs us that the tables and chairs in her house moved across the floor at the height of the shock this morning. The tremor was less noticeable on the river, although it was distinctly felt on one or two ships at anchor."

Concerning the effects of the earthquake at Tachin the following report appeared in the "Bangkok Times" of May 24th, 1912, dated Mahachai, May 23rd :—

"The shock was of a very deliberate nature, severe enough to set the trees swaying, every hanging object swinging violently, and to stop my clock. The duration of the shock must have been at least one to one and a half minutes as I had time, first to realize what was going on, then to cross the room and to note the time (9-5 A.M.), steady a hanging lamp, rest myself and watch the lamp resume its oscillations. It was a curiously nauseating sensation and caused one occupant of my house to vomit.''

In the "Bangkok Times" of the 25th May 1912, the following further reports appeared:—

"As the reports come in from the outlying Monthons it appears that the seismic disturbances of Thursday morning occurred practically all over the country. We have received telegrams or letters from correspondents in Monthon Bayat (Chiengmai, Chiengrai and Nakon Lampang), Monthon Ratburi (Petchaburi), Monthon Nakon Sri Thammaraj, Monthon Nakon Chaisi (Mahachai) and Monthon Krung Thepe. The reports from Chiengmai and Tachin have already appeared. Apparently, two distinct shocks were felt in the far north. Our correspondent in Chiengmai reported a slight shock on Tuesday morning as well as on Thursday. Chiengrai also experienced two shocks. No telegram has come to hand from our Puket correspondent, and presumably the shock was not felt there. The later telegrams to hand are given below.

Lakon Lampang.—The earthshock was distinctly felt here. Clocks were stopped in a number of houses. No damage is reported.

Nakon Sri Thammaraj.—We only experienced a cyclonic thunderstorm here. There was no earthquake. A number of roofs were slightly damaged.

Petchaburi.—No earthquake shock was noted here on Thursday.

Chiengrai.—There was an earthquake shock here yesterday (Thursday) morning and another, and minor one, this (Friday) morning.''

His Britannic Majesty's Consul in Chiengmai in a letter to the Assistant Superintendent, Southern Shan States, Keng Tung Subdivision, reported that shocks were felt there on May 21st and 23rd.

Correspondent in the "Rangoon Gazette."—Time 8-45 A.M. on May 23rd, 1912. The shock lasted some seconds. The bungalow rocked and creaked to such an extent that the writer thought it safer to get outside. It also caused a good sized wave, very similar to that caused by a steamer going up a narrow river, to run along the banks of the creek on which the house is built. Mongpai is situated in Lat. 19°30′: Long 98°30′, approx.

Mongpai, Siam.

PART II.

CHAPTER IV.

THE TIME OF THE EARTHQUAKE AND RATE OF PROPAGATION OF THE SHOCK.

It has not been an easy matter to obtain reliable time observations of the earthquake, in fact the difficulties met with have been greater than those usually encountered in such enquiries. The epicentral area itself is situated in a sparsely populated portion of the Northern Shan States, and although crossed by a branch of the Burma Railways, has furnished but little trustworthy evidence. Both for the adjoining, and for more distant regions, I have received various time data exhibiting different degrees of accuracy, and the sources from which they have come may be divided as follows :—

1. Letters from district officials and others.
2. Reports from station masters and from post and telegraph offices.
3. Automatic records of self-registering instruments in India.

The records from the first category are the most variable. In a few cases, it is definitely stated that the watch or clock from which the observation was made, had been compared with that of the nearest telegraph office or railway station, but in others, the time is merely guessed, or no details of any kind are given. It might be supposed that in telegraph offices which receive a daily signal, or in railway stations where the constant running of trains demands due attention to a time-table, some considerable measure of accuracy would be approached. Such a supposition is erroneous, the causes being errors in the clocks themselves, and failure on the part of recorders to appreciate that *exact* time was required of them.

Standard Time.

Standard Time is generally used in Burma. According to information supplied to me by the Commissioners for the Port of Rangoon, it is 5 minutes

20 seconds ahead of Rangoon Mean Time, which is 6 hours 24 minutes 40 seconds (96° 10′) in advance of Greenwich Mean Time, whereas Burma Standard Time is 6 hours 30 minutes (97° 30′) in advance of Greenwich Mean Time.

Railway Time.

The official guide book of the Burma Railways states that Standard Time is kept at all the stations on the line. An enquiry addressed to the Traffic Manager of the railway in Rangoon confirmed this, and elicited the further information that the railway administration receives a daily time signal from the Rangoon telegraph office.

Telegraph Time.

The Indian Telegraph Guide states that all telegrams are timed by Standard Time which in India is 5½ hours, and in Burma 6½ hours, in advance of Greenwich Time. I have been informed by the Deputy Superintendent of Telegraphs in Rangoon that this Standard Time is kept at all Burma telegraph stations, and that the time signal is obtained daily from Calcutta.

Great irregularity of recorded times.

The present investigation only adds confirmation to the opinions expressed by Oldham in 1899 and Middlemiss in 1910, that in the outlying provincial districts in India, "uniformly co-ordinated time is not yet recognised as a necessity, and therefore in spite of the well-meant daily signal it is not as a matter of fact, kept."([1]), ([2])

Time which can be used in calculations.

After making a thorough examination of the times given in the descriptive part of this report, I have come to the conclusion that for the purpose of seismological calculations, the great majority of them from scattered places in the province are worthless, as the differences even in times which are said to have been compared with Standard Railway or Telegraph Time in the same towns, are often very apparent and mutually irreconcilable.

Fortunately, in Mandalay, the chief city of Upper Burma, and in Maymyo, which is the summer headquarters of the Government

[1] R. D. Oldham: Report on the Great Earthquake of 12th June 1897. *Mem., Geol. Surv., Ind., Vol. XXIX*, p. 53, *et seq.*

[2] C. S. Middlemiss: The Kangra Earthquake of 4th April 1905. *Mem., Geol. Surv., Ind., Vol. XXXVIII*, p. 285.

of the province, a closer approximation is visible, as can be seen from the following list :—

Mandalay Time.	Standard.	Observer.
8-57	No standard stated . .	Meteorological Reporter.
8-55	No standard stated . .	Secretary to Municipality.
8-56	Clocks stopped	Deputy Superintendent, Signal Office.
8-55	Railway Time	Sub-Postmaster, Police lines.
8-55	Post Office Clock	,, ,, , Hospital.
8-55	Station Time	Station Master, Myohaung.
8-55	Mandalay Clock Tower . .	Mr. Eades, Zigon.

From this list other times which are uncorrected or which are obvious guesses, are omitted. The time given by the Meteorological Reporter cannot be correct, for the clocks in the Mandalay telegraph office had stopped at 8-56 A.M., which was doubtless some time after the first violent movement had affected them.

Turning now to Maymyo, the following list gives the more exact times which have been gathered together :—

Time.	Observer.
8-55 " exact "	Director of Telegraphs.
between 8-56 and 8-57	Postmaster.
8-55	Deputy Superintendent, Mandalay, Signal Office.

The Postmaster in Maymyo informed me that his clock is regulated by "gun time." I thereupon communicated with Capt. A. Thorp, the officer under whose orders the daily gun was fired in Maymyo and who replied as follows :—

"The gun is supposed to be fired in accordance with the time kept by the railway station clock and I send a watch to be checked by it every morning, but as the station clock is a very indifferent one, the amount that the watch (a very good timekeeper) differs from it varies 4 or 5 minutes every day. I do *not* alter the watchr daily so can only say that gun time is approximately railway station time. I have no record now (July 7th, 1912) how much difference there was on 23rd May........, so that I am in a position to say that by gun time the earthquake on May 23rd took place a few minutes before 9 A.M."

Under these circumstances no reliance whatever can be placed on the times quoted by the Postmaster in Maymyo or on any others based on "gun" or railway time there. There remain the times given by the Director and the Deputy Superintendent of Telegraphs, and it need only be pointed out that they are in agreement with similar data from Mandalay.

Most of the station masters in or near the epicentral tract sent the times at which the station clocks stopped, or approximate guesses, evidently to the nearest five minutes. As examples Hsumhsai, Nawnghkio, Gokteik, Pyaunggaung, Kyaukme, and Bawgyo may be quoted. The time records from the Southern Shan States and the Ruby Mines District are rejected for the same reasons.

Time of commencement of shock.

As far as can be ascertained from the data at my disposal therefore, the earthquake was felt in Mandalay at 8-55 A.M., Burma Standard Time, on the morning of May 23rd, 1912, in Maymyo a few seconds earlier, and in the epicentral area a few miles to the east of this, slightly earlier still. The probable time of commencement of the shock therefore as accurately as can be determined, lies between say 8-54 and 8-55 B.S.T.

Instrumental Records.

Burma possesses one seismograph which is of the Omori type and is installed in Rangoon College. Other instrumental records were derived from the seismographs of the Milne type in the meteorological observatories of Calcutta (Alipore), Kodaikanal in the Palni Hills and Bombay (Colaba), and from the Omori-Ewing seismographs in the same stations at Bombay and Simla.

According to Middlemiss :—

"If recent criticism of seismographic records is to be trusted (as to which specialists in this branch of science can alone speak with particular knowledge), the Milne seismograph trace, which is very small and often blurred, cannot be trusted to show all those minute sub-divisions of regularly recurring period and amplitude which the larger forms working with a large natural period of swing, register by means of a needle point on smoked paper, and which give an open or large scale diagram.

The so-called preliminary tremors as seen in long-distance seismograms written by the Milne instrument, are, however, fairly well differentiated from the large movement which follows. The splitting of the preliminary tremors into two groups, first and second, is also believed by many to be sufficiently recognisable. However that may be, the beginning of the large movement is the only definite point that can be reasonably correlated with the sensible earthquake wave or shock as felt in its progression from place to place over the surface of the affected area."(1)

The data obtained from the Indian seismographic records are as follows :—

Rangoon.—The Omori seismograph installed in the Rangoon College.—The shock commenced on the morning of the 23rd May at 8 hours 54 minutes 10 seconds, and lasted till 10 hours 3 minutes 30 seconds (B.S.T.). The shock was severe from 8 hours 54 minutes 10 seconds till 9 hours 13 minutes 30 seconds. The clock whose pendulum swings from east to west stopped as soon as the shock commenced.

Through the courtesy of the Principal of the Rangoon College, I have been allowed to examine the original record taken by this instrument, but I do not think that any further evidence can be safely deduced from it, owing to the violence of the motion consequent upon the short distance of the station from the epicentre, and the unsatisfactory condition of the clock.

Kodaikanal.—A good record was obtained from the instrument of the Milne type in this observatory (Pl. No. 10).

(All times given in this and subsequent data are referred to Greenwich Mean Time.)

Time of commencement of Preliminary Tremors, 2 hours 29·0 minutes.
,, ,, ,, ,, Long Wave, 2 hours 29·5 minutes.
,, ,, Maxima, 2 hours 39·9 minutes. Maximum Amplitude, 13·5=5·4 mm.
,, ,, ,, 2 ,, 42·0 ,, ,, ,, 14·5=5·8 mm.
,, ,, ,, 2 ,, 47·9 ,, ,, ,, 16·0=6·0 mm.
End, 6 hours 15·2 minutes. Duration, 3 hours 46·2 minutes.

Alipore (Calcutta).—The record from the Milne instrument in this observatory was not satisfactory. Owing to air tremors the time of the commencement of the preliminary tremors cannot be given. The large movement is stated by the meteorological reporter to commence at 2 hours 26·1 minutes (?), but I think that this is very much open to question, after an inspection of a copy of the record. Owing to the boom moving throughout the trace, the time of maximum and the amplitude cannot be deduced.

The movement ended at 6 hours 1·9 minutes (?).

Sensibility, 1 mm=0·38 of tilt.

1 C. S. Middlemiss : *Loc. cit.*, pp. 290 and 291.
See also Publications of the Earthquake Investigation Committee in Foreign Languages No. 24, p. 26.
La Science Séismologique, by Le Comte de Montessus de Ballore, p. 40.

Simla.—The following data were obtained from the two instruments of the Omori-Ewing type in Simla (Pl. No. 8) :—

A = East and West component.
B = North and South component.

Time of commencement of 1st Preliminary Tremor,	A=2 hours	28·4	minutes.
,, ,, ,, ,, ,, ,, ,,	B=2 ,,	28·5	,,
,, ,, ,, ,, 2nd ,, ,,	A=2 ,,	31·3	,,
,, ,, ,, ,, ,, ,, ,,	B=2 ,,	32·3	,,
,, ,, ,, ,, Long Wave,	A=2 ,,	35·6	,,
,, ,, ,, ,, ,, ,,	B=2 ,,	35·7	,,

Owing to the style touching the stops, the time and displacements of the maximum amplitude cannot be given.

Time of approximate end of movement,	A=4 hours	36	minutes.
,, ,, ,, ,, ,,	B=4 ,,	37	,,
,, ,, duration,	A=2 ,,	7·6	,,
,, ,, ,, ,, ,,	B=2 ,,	8·5	,,

On the seismograph trace (Pl. No. 8), the following corrections to the minute marks are necessary to find Indian Standard Time :—

Instrument with boom, E.—W.	—2·7	minutes.
,, ,, ,, N.—S.	—2·2	,,

Bombay.—The following data were obtained from the Omori-Ewing instrument in Bombay (Pl. No. 11) :—

Time of commencement of the Preliminary Tremors,	2 hours	28·9	minutes.
,, ,, ,, ,, ,, 2nd Phase ,,	2 ,,	33·1	,,
,, ,, ,, ,, ,, Large Waves,	2 ,,	38·4	,,

The maximum was lost as the zero shifted and the pen lay against the W. stop.
Approximate end of the movement, 4 hours 42·7 minutes.

On the seismogram a smaller disturbance is noted which took place on the previous day, commencing at 23 hours 14·7 minutes.

The Milne instrument in Bombay gave the following figures (Pl. No. 9) :—

Time of commencement of the Preliminary Tremors, 2 hours 28·9 minutes.
,, ,, ,, ,, ,, 2nd Phase Preliminary Tremors, 2 hours 33·6 minutes.
,, ,, ,, ,, ,, Large Waves, 2 hours 38·6 minutes.
The Maximum (1st) is timed at 2 hours 42·5 minutes.
,, ,, (2nd) ,, between 2 hours 43·3 minutes and 2 hours 44·1 minutes.

For hours prior to the quake the trace is disturbed by small tremors and hence the previous quake is masked. Two thickenings showing maxima, however, can be indicated at 22 days 23 hours 18·6 minutes and at 23 days 0 hours 3·9 minutes.

The vertical motion and tilt record from Bombay is as follows :—

The commencement of the Burma quake is timed at 2 hours 29·1 minutes.
,, ,, ,, ,, of the previous day at 23 hours 12·3 minutes.

The times of commencement as recorded by this instrument are almost always earlier, but in a few cases they are either simultaneous or slightly later than the commencements recorded by the horizontal pendulum seismographs (Pl. No. 9).

Rate of Propagation of the Shock.

For the purposes of this calculation I take 8 hours 54 minutes 15 seconds, as the probable time for the beginning of the shock at the epicentre.

The times of commencement of the large movement in the Indian seismographic records of the earthquake are as follows :—

	Hours.	Minutes.	Seconds.
Bombay	9	8	24
Simla	9	5	39

We therefore have :—

——	Distance in miles from epicentre.	Seconds during transit.	Deduced rate in miles per second.
Bombay	1,561	849	1·83
Simla	1,350	684	1·97
....	....	Mean .	1·90

The times given are all reduced to Burma Standard Time. I am indebted to my colleague Mr. C. S. Fox for the calculation of the distances given above.

THE ISOSEISTS. DISTRIBUTION OF INTENSITY AND CHARACTER OF THE SHOCK.

The intensity of an earthquake is best inferred from the records of instruments designed for the purpose, and stationed in the districts over which the shock is felt. Owing to the absence of such instruments in Upper Burma we have to fall back upon the more general method, by estimating intensities from the effects of the quake upon mankind in general, upon structures of all sorts, and upon movable objects which they contain.

The plotting of the isoseismal curves upon the map has been carried out almost entirely from the collated reports of various individuals who experienced the shock in different parts of Burma, and, following the custom hitherto adopted in similar investigations in this country, use has been made of the modified Rossi-Forel scale. The curves of course enclose zones of equal intensity, and in passing from one to the next we proceed through belts of greater intensity until the pleistoseismic area, or that portion of the earth's crust which is immediately above the seat of the disturbance, is reached. Indeed, one of the many reasons for delineating intensity systematically is to locate this position and to make known any fault with which the earthquake may be connected. The study of the distribution of intensity may lead to the recognition of deep-seated portions of a fault not recognisable at the surface, or reveal other dislocations which happened at the time of the shock, by the sudden release of molecular strain in neighbouring portions of the region, or, again, auxiliary faults which bear some relationship to the main system.

The Rossi-Forel scale.

I.—*Microseismic Shock*—recorded by a single seismograph, or by some seismographs of the same pattern but not by several seismographs of different kinds; the shock felt by an experienced observer. (This number of the scale is now obsolete owing to improvements in seismographs.)

II.—*Extremely Feeble Shock*—recorded by seismographs of different kinds; felt by a small number of persons at rest.

III.—*Very Feeble Shock*—felt by several persons at rest; strong enough for the duration or the direction to be appreciable.

IV.—*Feeble Shock*—felt by persons in motion; disturbance of movable objects, doors, or windows; cracking of ceilings.

V.—*Shock of Moderate Intensity*—felt generally by everyone; disturbance of furniture and beds; ringing of some bells.

VI.—*Fairly Strong Shock*—general awakening of those asleep; general ringing of bells; oscillation of chandeliers; stopping of clocks; visible disturbance of trees and shrubs. Some startled persons leave their dwellings.

VII.—*Strong Shock*—overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings. (Owing to poor material and construction in India damage to buildings is considered to begin here.)

VIII.—*Very Strong Shock*—fall of chimneys, cracks in walls of buildings.

IX.—*Extremely Strong Shock*—partial or total destruction of some buildings.

X.—*Shock of Extreme Intensity*—great disasters, ruins, disturbance of strata, fissures in the earth's crust, rock falls from mountains.

Scale adopted by the Californian Commission.

A revised and simplified scale was adopted by the Commission appointed to investigate the California Earthquake of April 18th, 1906. Degrees VIII, IX and X agree with the above. The first seven are as follows :—

I.—*Perceptible*—only by delicate instruments.

II.—*Very Slight Shock*—noticed by a few persons at rest.

III.—*Slight Shock*—of which direction and duration were noted by a number of persons.

IV.—*Moderate Shock*—reported by persons in motion ; shaking of movable objects ; cracking of ceilings.

V.—*Smart Shock*—generally felt ; furniture shaken ; some clocks stopped ; some sleepers awakened.

VI.—*Severe Shock*—general awakening of sleepers ; stopping of clocks, some window glass broken.

VII.—*Violent Shock*—overturning of loose objects ; falling of plaster ; striking of church bells ; some chimneys fall.

Disadvantages of the scale.

There are many uncertain features about both schemes. The personal factor of course enters very largely, for different observers interpret the same event in different ways. The Commission point out that the stopping of clocks is a very uncertain criterion of intensity, a statement well substantiated in the present case too. Again, with regard to degrees VI, VII, VIII and IX of the Rossi-Forel scale, in which damage to buildings is relied upon for an estimate, two important factors are given which tend to vitiate the conclusions arrived at as to comparative intensity. These are, the great variability of the structures themselves, and the nature of the ground upon which they are built. The scale was probably designed originally for regions where brick and masonry structures prevail ; in California wooden structures are by far the most common. The same is true for Burma probably to a greater degree still.

"Wooden houses by reason of their greater elasticity, are usually much better adapted to withstand the wracking movement of an earthquake shock than are brick and masonry walls. The intensity as inferred from a region of wooden buildings, would therefore, in general appear to be less than that for a region of brick or masonry structures. Even among the latter, and among the brick chimneys of wooden houses, which are so generally used as indicators of intensity, there is a great variation in strength due to the variation chiefly in the character of the mortar used in their construction."[1]

The prevailing custom in the district towns of Burma is to build houses with wooden frames, the panels of which are filled in with brick-work. This adheres to the wooden framing with greater or lesser cohesion depending upon the character of the original structure and the age of the work. Now although intensity inferred from damage to wooden buildings appears to be less than that computed from the partial destruction of brick structures, it must not be forgotten that panels of fairly loose brick nogging, especially those filling in the frames of high parts of end or partition walls, do not require much shaking to bring them down.

Fissures in the ground as a measure of intensity.

Another point to which the Californian Commission draws attention and which is of interest to us in Burma, deals with the question of fissures in the ground, taken as a criterion of the highest grade of intensity and placed in grade X of the Rossi-Forel scale. As a matter of fact the value of such a criterion entirely depends on the circumstances under which such a fissure is formed. Those which are due to actual rupture on a fault-plane are significant of the highest degree of disturbance, but cracks which occur in the bottoms of alluvium-filled valleys, or near a stream, or cracks which are associated with earth or rock-slides, when the slide was imminent and merely precipitated by the shock, are superficial phenomena and do not actually indicate so high a degree of intensity as X on the Rossi-Forel scale. The subject will be referred to in a later paragraph in connection with fissures caused by the Burma quake near Kyaukse. Again,

[1] The California Earthquake of 18th April 1906. Report of the State Earthquake Investigation Commission. Vol. I, Pt. I, p. 161.

the detailed study of numerous earthquakes has made it abundantly clear that on river bottoms and valley floors, especially when the latter are water-logged, buildings are more susceptible to damage than similar structures built on solid rock.

A grouped scale adopted.

The regions affected by this earthquake comprise some of the most thinly populated country in the Indian Empire, indeed everywhere in Burma the population is under 100 persons per square mile. In addition to this, the most severely shaken area lies within the wildest and most thinly populated portion of Burma, that is to say in the western regions of the Northern Shan States, and about their borders with Mandalay and the Ruby Mines Districts and with the Southern Shan States, etc. It has for this reason been found necessary to group together the lower members of the Rossi-Forel scale as shown below, a practice already established by Oldham([1]) and Middlemiss([2]) in the accounts of the great shocks of 1897 and 1905. For the same reason I am unable to draw the curve which encloses the small area over which an intensity of IX was reached.

Grouped members of the Rossi-Forel scale.	Definition taken here.
II and III	Felt by a few sensitive people lying down or favourably situated.
IV and V	Generally noticed, no damage. Shaking of beds, etc.
VI and VII	Universally felt. Upsetting of small loose objects. No damage except in rare instances, to burnt brick structures. Small cracks and damage to sun-dried brick and mud buildings.

Curves only approximate.

The resulting curves are shown on the map. It is not contended that they are highly satisfactory, or comparable with the elaborate delineations given on recent maps of the great earthquake-shaken regions of

[1] Oldham : *Loc. cit.*, p. 42.
[2] Middlemiss : *Loc. cit.*, p. 303.

the world. From the northern and eastern portions which lie about or across the frontier and are inhabited by wild tribes, I have obtained no information. Moreover, had facilities existed for visiting these areas or obtaining information from them, it is doubtful if anything of much value would have been obtained, owing to the flimsy nature of the bamboo houses in which the greater part of the population exists. As it happened, I had to abandon any attempt to tour through the regions in question, owing to pressure of work elsewhere, but I am convinced that very little has been lost. The curves have been drawn in accordance with what little is recorded and only an equal amount of value can be attached to them.

Isoseists VIII and IX.

(1)—Description and General Intensity.

Area and boundaries.

The innermost isoseismal line shown on the map (Pl. No. 7) encloses an area of approximately 36,000 square miles, over the greater portion of which the shock reached an intensity of VIII on the Rossi-Forel scale. (As mentioned in a previous paragraph, sufficient information does not exist to permit of the delineation of the line enclosing the area over which an intensity of IX was reached, but it must be a small area lying mainly about the Kyaukkyan fault and roughly coinciding with the central portion of the oval enclosed by line VIII.)

The longer axis of this oval runs in a general north and south direction, and the area includes the whole or greater part of the districts of Mandalay, Sagaing, Kyaukse, Meiktila, Yamethin, Shwebo and the Ruby Mines, small portions of the districts of Bhamo, Lower Chindwin and Myingyan: practically the whole of the Northern Shan States of Hsipaw (with Tawngpeng and Monglong) and Mongmit: parts of North and South Hsenwi, Lawk Sawk, Mongkung and the group of smaller States in the south-west corner of Southern Shan States overlooking the Burmese plains. It embraces the city of Mandalay, the towns of Maymyo, Mogok, Sagaing, Shwebo, Mongmit, Lashio, Hsipaw, Kyaukse, Thazi, Meiktila, Yamethin and Taunggyi, and numerous smaller places. Maymyo itself probably lies just outside the borders of the area of intensity IX, all the other places experienced the lower degree of intensity, namely VIII.

Parts of the area where an Intensity of IX was reached.

Two railway lines traverse the area: (1) The main line of the Burma Railways from Rangoon to Mandalay, and its continuation on the other side of the Irrawaddy from Sagaing to Myitkyina. Entering to the south of Yamethin and leaving just to the north of Shwebo, the line cuts across the western part of the oval, more or less parallel to its long axis. This line and the telegraph which runs alongside it were entirely undamaged. (2) The other line is the Shan States branch of the Burma Railways which runs from Mandalay to Lashio over the upper part of the oval from south-west to north-east. Although it rises from the plains in a series of zigzags overhung by precipices of very folded strata, and crosses several well known faults, the line was only damaged to the east of Maymyo on the "plateau" itself, where it crosses the great Kyaukkyan fault. This fact adds confirmation to the view already arrived at from a study of the distribution of the intensity, namely that the earthquake was connected in some way with this fault. The railway lines were bent into a smooth curve close to the actual line of the fault, while cuttings and earth banks in the vicinity had slipped and blocked the line.

To the north and south of this point and in the neighbourhood around, the greatest intensity of the quake was experienced. Cracks in the cliffs near Myinpyu gave out streams of mud and water which were voluminous enough to overwhelm and partially destroy Shan houses. Fresh cracks opened in the ground on the Myinpyu hill, and from Kyaukkyan in the Namma circle to Seikpyu. At the latter place a hot spring dried up. Near the northern end of the fault, land and rock slips took place and completely blocked up the Nam-pan-se stream for a time, after which the water forced its way through the barrier. This stream flows along the course of the northern end of the Kyaukkyan fault for some 4 or 5 miles before crossing it. Other landslips happened in various places; indeed, I was informed that the dust from them was visible for days along the Kyaukkyan fault, and gave rise to the belief amongst the Shans that a volcanic eruption had taken place.

Variety of Architecture.

The great diversity of architecture within this region tends to complicate deductions regarding the intensity. Throughout the most shaken area, practically no stone or brick edifices exist outside the towns, with the exception of those of a religious character,—the Buddhist pagodas of varying ages and styles.

In towns like Maymyo buildings are composed of:—

Brick nogging.
Brick in lime mortar.
Brick in mud mortar.
Sun-dried brick in mud.
Bamboo mat and thatch.

On the whole, it seems best to characterise the damage here as moderate, with the proviso, gained from a careful study of the results of the shock, that the damage would undoubtedly have been very much greater if more houses had been built of stone and brickwork in lime of the ordinary type.

Practically every pagoda which I saw had crumbled or been shaken down for the greater part of its height.

Damage to buildings in Maymyo.

Every fair-sized brick building in Maymyo suffered more or less damage. Good examples of solid brick and masonry structures existed in the kitchens of the British Infantry barracks; many of these were very badly cracked and shattered, and most were injured to some extent, affording an illustration of the probable result if the station as a whole had been built after the same fashion. The garage of Government House which was also a strongly built brick building was completely shattered. Brick nogging buildings fared much better. Lower panels sometimes cracked and high gable panels rocked out of their frames, causing considerable damage as they fell. Plaster from walls and ceilings was shaken off, and bricks, especially along the tops of walls, were often loosened. Complete destruction was conspicuous by its absence, and this I believe is to be put down to the elasticity of the wooden frames of the brick nogged bungalows.

The brick chimneys which are a feature of the bungalows in Maymyo suffered greatly. In most cases they fell or were so badly cracked that dismantling was imperative. Considerable damage was caused to roofs and ceilings by falling chimneys. As was only to be expected from its lack of cohesion and strength, work composed of brick in mud mortar, and sun-dried brick in mud was badly shattered and cracked by the shock.

Damage at Gokteik.

The bungalow used as a rest-house near the Gokteik railway station was shattered and rendered uninhabitable. Landslips took place in the gorge itself, and large rocks fell from the roof of the cave through which the stream in the bottom of the gorge flows. Two landslips occurred near the tunnels beyond the station, while the viaduct itself was very slightly displaced.

Damage in Mandalay.

From a perusal of the detailed accounts of the damage in Mandalay, it might be thought that the shock reached a higher intensity there than in Maymyo, but two considerations have led me to the opposite conclusion.

Mandalay is built on a thick cushion of alluvium which fills in the bottom of the Irrawaddy valley, and it is well known that actual sinking of the ground in such situations, can wreck and injure buildings independently of any elastic vibration communicated to them from the ground, and on the motion of which the intensity of the shock itself depends.

Again, the age and construction of the buildings which collapsed in Mandalay compare very unfavourably with those of the newer and better built ones in Maymyo, situated as they are on the plateau of the Shan States. Witnesses declare that it was very difficult to stand during the shock in Mandalay. The ground between the fort wall and the moat was cracked in places. Three quarters of the brick structures in the city were more or less cracked, and nearly every pagoda and brick monastery was damaged.

Damage at other places.

At Hsipaw the railway medical store and various places of business were badly damaged. In Mogok and Taunggyi brick nogging buildings suffered in the same way as in Maymyo. In both these towns every masonry structure seems to have been more or less damaged. Collapsed and shattered chimney stacks were common, and cracks in walls over doors and windows, especially in north and south and in cross partition walls, were very generally caused. Considerable damage of a similar kind was caused to the Government buildings in Meiktila. Cracks opened in alluvium for a length of 150 feet, and gave forth sand and water near the Zawgyi river to the south of Kyaukse railway station. Throughout the area enclosed by isoseismal VIII the majority of the Burmese and Shan pagodas were wholly or partially broken down.

Accounts of the damage in other places can be found in the first part of this report.

(2) Character of the Shock.

The preliminary tremors which precede a great earthquake seem to have been absent or of unusually short duration. The shock itself is described as very severe by most observers, and the duration is given generally as 1—1½ minutes. Some witnesses state that the shock was divided into three distinct periods, but others do not mention this peculiarity.

The following are among the more characteristic descriptions of the shock:—

(1) Appeared to be a shaking underfoot rather than a distinct wave motion.

(2) Like the sensation experienced in a big building in which a high speed engine is running.

(3) Like a child's cradle being roughly pushed backwards and forwards.

(4) Like a ship at sea.

(5) The earth seemed to be in ripples as if disturbed by waves of great frequency.

(6) It required a considerable muscular effort to stand: women were thrown to the ground.

(7) Saw the earth moving towards him in waves about 1 foot high and 2 feet distant from each other.

(8) Unstable articles like lamp-glasses and wine glasses overturned; hanging lamps thrown out of their supports; brick chimneys crashed through ceilings. Windows rattled backwards and forwards.

(9) Clocks jerked forwards; bottles and ornaments thrown down; books shot out of book cases.

(10) Ground rose and fell like the waves of the sea; pagodas crumbled as though sliced with a knife; trees swayed and ground cracked.

Sounds were very generally heard throughout the area both before and during the shock, and are compared to low rumblings and to distant thunder.

Conclusion.

Although there is much contradiction, general opinion places the direction of the shock in Mandalay and Taunggyi as approximately north and south. In Maymyo there is evidence of motion at right angles to this.

The shock certainly appears to have been split up into 3 or 4 separate periods, each with a maximum intensity of its own, but diverse surface conditions, and, perhaps, subconscious personal idiosyncracy, have obscured this in some places.

Isoseists VI and VII.

Area and boundaries.

The area circumscribed within the grouped isoseists VI and VII amounts to approximately 82,900 square miles, and like the later grouped areas IV and V, and II and III, it is bounded by a smooth curve joining up the somewhat isolated places from which accounts were received (Pl. No. 7). The detailed accounts of the shock have already been given, and it only remains to summarise them briefly here. As a glance at the map will show, these grouped isoseists contain the headquarter towns of Monywa, Katha, Bhamo, Myingyan, Pakokku, Toungoo, the southern part of the State of Karenni, and a belt of country comprising the eastern portions of the Northern Shan States and the central portions of the Southern Shan States.

Cracking of buildings.

Unusual sounds were still heard in some places, and many buildings were cracked, but not sufficiently to cause even partial destruction or the widespread fissuring of all brick structures as found in the area of higher intensity. Cracking of walls though common in some places, is by no means universal and has generally taken place near doors or windows. An occasional brick nogged panel has dropped out, plaster has often fallen, and old pagodas have had part of their tops carried away.

Description of the shock.

The shock seems now to have lost a good deal of its suddenness and to have become more even and prolonged. It is described as follows :—

(1) The observer could not follow a straight line in walking and lost the sense of height in stepping. He became intensely giddy and experienced the sensations associated with sea sickness. High trees swayed. A wooden bungalow creaked and groaned and dogs rushed out and barked.

(2) Cooking pots and cups were thrown over, hanging lamps swung.

(3) The earth distinctly rocked. Plaster fell and glass was thrown to the floor.

(4) Trees swayed, water in fire buckets moved. Pagoda tops broken off. General panic.

(5) House rocked, inmates rushed out in alarm. Children could not stand unsupported.

The jerky motion of the central area was converted into more undulose waves, which seem to have been responsible for the widespread nausea, sickness and giddiness, which is an ever recurring statement in the reports from the districts where an intensity of VI—VII was experienced.

Isoseists IV and V.

Incompleteness of area.

The area enclosed within this isoseist is only shown on the north, west and south-west of the epicentral tract, for in the other directions it comprises the frontier regions of Burma with the Chinese province of Yünnan, and the Kingdom of Siam. These regions are very difficult of access, sparsely inhabited and devoid of postal communications except along one or two widely separated routes. Towards the north it embraces parts of the Myitkyina and Katha districts, on the west and south-west the greater portion of the central basin of Burma including parts of the Pakokku, Minbu, Magwe and Thayetmyo districts, running down into the districts of Prome and Tharrawaddy, into Pegu and the Irrawaddy and Sittang deltas.

An area of no damage.

This is the area where the shock appears to have been felt by the majority of the people, but where no damage was caused, except in one or two cases where it is expressly stated that the structure in question was old and rotten. A rolling motion of the ground was reported in a few instances but not comparable with that felt in the VI—VII area. Tremulous vibrations were experienced before the main shock, and the whole movement though softened and modified could still occasionally be differentiated into three parts.

Extends to far east of the Southern Shan States to Yünnan and Siam.

Although this isoseist cannot be completely drawn on the east, it is known that an intensity of IV—V was experienced in Kengtung, the most easterly station of the Indian Empire, and from Têng-yüeh to the far north-east, a letter from His Britannic Majesty's Consul leads me to the same conclusion there. Over the greater part of north-western Siam a similar intensity appears to have been felt.

As a general rule no damage was caused, nor were objects overturned, though suspended bodies appear to have freely swung.

Descriptions of the shock.

Observers have described the shock as follows :—

(1) Like a wave motion gradually increasing to a period of highest intensity and then dying away again.
(2) Like a large animal rubbing itself against the posts of the house.
(3) The bungalow shook as if affected by a gale.
(4) Slight tremor followed by distinct shock and then slight aftershock ; windows rattled.
(5) Table and chairs rocked, hanging lamps swung ; no unusual sounds were noticed.

Effect on the Yenangyaung Oil Field.

It is interesting to note that the Yenangyaung Oil Field lies within this area, and although the derricks were seen to get up a slight swing, no damage whatsoever was caused to any of the wells, the lining casings of which in some cases extend to depths of almost 2,000 feet. In strata such as these, any violent movement of the ground would have resulted in bending or flattening of the pipes and consequent stoppage of the well.

Isoseists II and III.

Line wanting on east and north.

The region included in the outermost isoseismal only partly lies in Burma, and I have only been able to draw the line on the west and south. To the north it enters the little-known country between Burma and Assam, from which it was quite impossible to obtain any information ; on the north-east and east it crosses into the transfrontier prefectures of Yünnan, and on the south-east it must cut across south-western Siam.

Effects in Burma.

In the extreme south of the Irrawaddy delta, the officers in charge of the districts of Bassein, Myaungmya and Pyapon reported that no earthquake disturbances were experienced in any part of their charges. From the Chin Hills came the news that the shock was so slight as to be almost imperceptible. In Rangoon it was very slight and only just perceptible, yet withal strong enough to swing hanging lamps, and to stop the delicate sidereal and local mean time clocks in the Port Commissioners' Time Ball observatory. These clocks were both in such a position that their pendulums swung normally between north and south, and their movements were probably stopped through their having struck the back inside casings. These observations tend to prove that the direction of the shock was from east to west, for another pendulum clock in the observatory, which faced south with its pendulum swinging east and west, did not stop and was not affected. Nevertheless other observers in Rangoon assert with equal confidence that the direction was from north to south.

Absence of detailed accounts.

There are not many details given in the reports from this area. The shock is generally referred to as a long slow wave which was only felt by certain people. Lamps and other hanging objects like suspended weights freely swung, doors and windows occasionally creaked. Water in a river was seen to sway slightly, and oil in the tanks of the Seikkyi refineries was observed to move. No damage of any kind was caused and no unusual sounds were heard.

From Ssumao in Southern Yünnan we learn that three portions of an undulatory movement from north to south were still recognisable, and that a pendulum-like swing was communicated to hanging lamps.

Over the greater part of Lower Siam the shock seems to have been of much the same intensity. In Bangkok clocks were stopped and electric lights and fans set swinging.

The north-western corner of the Akyab district marks the limit of the felt shock in that direction, as nothing was noticed in the Chittagong district of Bengal.

I believe that in spite of its sketchy character, this outer isoseismal line approximates very closely to the actual outer limits of the shock, so far as it was perceptible to the unaided senses. The area between it and the next line was remarkably free from the phenomena which indicate a higher scale, *i.e.*, general notice by everyone, disturbance of furniture and movable objects.

General Deductions from the Isoseismals.

A consideration of the isoseismal lines as a whole, leads to the recognition of the following peculiar features :—

(1) The elongated central tract enclosed by isoseist VIII. (Isoseist IX probably occupies a very much smaller region towards the centre of this.)

(2) The close approximation of the curves towards the north-west.

(3) The wider separation of the curves towards the south.

(4) A line joining the southernmost portions of the curves, follows approximately the strike of the main mountain ranges of Lower Burma.

Considerations based on the disposition of the isoseists.

With regard to (1); the elongated nature of the area points to the fact that the original earthquake impulse proceeded from a line or plane following somehow the long direction of this oval tract.

With regard to (2); the narrowing in of the curves towards the north and north-west is believed to indicate a comparatively shallow depth for the portion of the fault which lies in this direction.

With regard to (3); the opposite conclusion is indicated, and in travelling south from the epicentral area into Lower Burma or into Siam great distances of slowly diminishing intensity are crossed, pointing to greater depth towards the south.

With regard to (4); it is suggested for consideration, but without any claim to finality, that the extraordinary conditions of Burmese orography as exemplified by the folding of the great chains running down into the Malay States and Siam, may not be without their special influence upon the transmission of impulses.

In seismological text-books and in theoretical discussions concerning the variation of intensity, it is usually assumed that the pulsations of earthquakes are transmitted through a perfectly solid and continuous medium, homogeneous in its properties of density and elasticity. But soils and subsoils to a certain extent, and rocks and strata, especially near the surface in those parts of the crust through which the impulses we are here considering travel, possibly to a greater extent, are neither homogeneous, nor evenly distributed in all directions, nor continuous. It is suggested that these defects change both the direction and intensities of the impulses to a greater or lesser degree.(1)

DEPTH OF FOCUS.

Unknown but probably shallow.

Owing to my conviction that the angles made by cracks in the walls of buildings with the surface of the ground, are in Burma at any rate, dependent mainly on the variations in the type and character of construction, and on the site chosen for the foundations, I have made no attempt to calculate the depth of focus by the old method of drawing perpendiculars to the direction of the cracks.

The newer method adopted by Major C. E. Dutton cannot be applied owing to the absence of detailed information from the epicentral tract, and the consequent impossibility of recognising that portion where the intensity declines or varies most rapidly. This lack of information is due to the sparsely populated nature of the region, and to the absence of brick or masonry structures.

We are left therefore with the following conclusion drawn from the isoseismal lines—the great extent of country covered by isoseist VIII, and the closeness with which the other isoseists are grouped around it. The depth of the focal line was probably shallow all through, approaching nearer the surface towards the north, and pitching or dipping towards the south, where it attained a somewhat greater though still shallow depth. Judging from the cases of the well-known Indian quakes, a shock of intensity IX in the Shan States should have been felt over a much greater area than was actually the case, had it been proportionately deep-seated.(2)

ELEMENTS OF THE WAVE MOTION.

Unfortunately I have not been able to make any estimates of the acceleration, amplitude, velocity or period of the wave particle. Calculations based on overthrown or projected bodies were out of the question owing to the absence of suitable objects. It was anticipated that much might be gleaned from the broken and thrown down pagodas, but their unusual shape, intricate construction, varying age and composition tended to extreme complexity, and in most cases they had simply shaken down into loose fragments or heaps of broken bricks, scattered in general

[1] In this connection see Montessus de Ballore: "La Science Seismologique," p. 92.
[2] See Middlemiss: *Loc. cit.*, p. 334.

confusion anywhere over the surrounding ground. Some days intervened between the shock and the time of my visit to the disturbed area, and the fallen pinnacles of mosques, overturned walls and broken chimneys had all been cleared away. From Mandalay I obtained data which I thought might be useful. These I submitted to Mr. R. D. Oldham but on his advice I am not making use of the figures as they are open to various objections.

EXTRA-INDIAN SEISMOGRAPHIC RECORDS.

The shock of May 23rd seems to have affected most of the long distance seismographs in the world. Records obtained in England, Scotland, Germany, Italy and America have already been published and the details of time and place worked out from some of them. Doubtless other reports have appeared which I have not seen, for no attempt has been made to collect the seismographic records from countries outside India. Although of great interest to students of seismology,—who can readily obtain them from the publications of foreign countries devoted to the purpose,—the collection and discussion of the mass of detailed figures involved is "a specialist's work in the domain of geophysics," (1) and is moreover outside the scope of this account, which is intended to describe only those results which belong to India proper.

[1] Middlemiss; *Loc. cit.*, p. 341.

CHAPTER V.

GEOLOGICAL CONDITIONS IN RELATION TO THE EARTHQUAKE.

Importance of such a study.

In his account of the Kangra earthquake, Mr. C. S. Middlemiss has shown how important the study of the geological structure of the shaken area may be.(1) This is primarily on account of the generally accepted theory that great earthquakes are due to strains set up in the earth's crust by geotectonic movements, and to their sudden relief by slipping along a fault. Yet another aspect of the subject is to be found in the superficial and secondary effects of the earthquake, consequent upon the nature and disposition of the rocks at the surface.

It has already been shown that the great Kyaukkyan fault was probably in some way connected with the shock, and in the following pages it is proposed to discuss the geological structure of the country more especially from the tectonic point of view, and to adduce the remaining evidence in support of this view.

Structural Geology of the affected portions of the Northern Shan States.

The interpretation of the geological structure of the Northern Shan States is mainly due to the researches of Mr. La Touche, though other contributions have been made by earlier workers. The account which follows here is based almost entirely upon the work of the former geologist, from whom I had the good fortune to learn my early lessons in Indo-Chinese geology.

The severely shaken area lies partly in the Northern Shan States, the Ruby Mines, Mandalay and Kyaukse districts and partly in the Southern Shan States. By far the greater portion is comprised within the "plateau" of the Shan States. Other portions form part of the plains of the Irrawaddy basin which is filled up with strata of Tertiary age and alluvium, and from which the hills at the western edge of the plateau-like country rise boldly in an unbroken wall of jungle-covered scarps, extending far to the north and south, and reaching in the neighbourhood of Maymyo, that is in a distance of some 23 miles as the crow flies, an ele-

[1] C. S. Middlemiss: Preliminary Account of the Kangra Earthquake of 4th April 1905. *Rec., Geol. Surv., Ind.* Vol. XXXII, Pt. 4, p. 281.

vation of about 4,000 feet above the level of the sea, whereas the approximate elevation of Mandalay itself is only 315 feet. South of Lat. 22°, the geology of the interior is practically unknown.

Ascent to the Shan Plateau from the Plains.

The ascent to the plateau from the plains does not proceed in one long steep line, but in a series of step-like formations, separated by fairly level expanses of country. La Touche has demonstrated that these are merely portions of the main plateau let down by a succession of parallel faults, running in a north and south direction, the position of each being regularly marked by the steeper rises (see Pl. 6).

Character of the country towards the north and north-west.

Towards the north and north-west, the gneisses and associated crystalline rocks of the Ruby Mines and Mandalay districts form the foundation upon which all the later strata have been laid. They build a succession of roughly parallel ranges which extend from north-east to south-west. To the north, these ranges increase in elevation, their crests rising to an average height of from 4,000 to 6,000 feet above sea-level. There is no doubt that this crystalline mass is continuous with the gneisses and crystalline limestones which are found about the Burma-China frontier in the Bhamo district, though the intervening region has still to be geologically surveyed.(1)

To the south of the Ruby Mines district, the gneisses occupy the whole of the country between the Chaung Magyi and the Irrawaddy. The long range of hills which runs parallel to the river opposite Mandalay, in the Sagaing district, is composed of the same rocks, and although the Palæozoic rocks of the Shan plateau come right down to the edge of the plain, the Archæans themselves pierce the alluvial floor occasionally, and are found in places like Sagyin and Mandalay Hill rising in small abrupt outliers. The gneisses appear again at the foot of the plateau scarp near Kyaukse, and from this point they are believed to form a continuous band, extending along the edge of the Shan plateau to the sea near Moulmein.(2)

[1] C. L. Griesbach: Geological Sketch of the Country North of Bhamo. *Rec. Geol. Surv., Ind.*, Vol. XXV, p. 127.

L. Von Loczy in Graf. Bela Szechenyi's "Reise in Ostasien," Vol. I, p. 776.

J. Coggin Brown: Contributions to the Geology of Yunnan. I. The country between Bhamo and Teng-yueh. *Rec., Geol. Surv., Ind.*, Vol., XLIII. pp. 174-205.

[2] C. S. Middlemiss: Report on a Geological Reconnaissance in parts of the Southern Shan States and Karenni. *General Report, Geol. Surv., Ind.*, 1899-1900, p128.

Tawngpeng System.

To the south of the crystalline area but still outside the plateau, a broad area of deeply dissected hilly country intervenes. Its most important member consists of a series of metamorphosed, unfossiliferous, sandy or argillaceous beds, to which the name Chaung Magyi series has been given, owing to their great development in the valley of the river of the same name. Here they occupy a narrow zone below the precipitous scraps of limestone along the western edge of the plateau overlooking the Irrawaddy plains. The western boundary of this zone is marked by a fault, which brings them into contact with the gneiss towards the north, and with the Palæozoic rocks to the south. Throughout this zone the strike of the quartzites and slates is north and south, that is to say parallel to that of the gneisses of the western bank of the Irrawaddy.

Rocks of the Plateau.

Practically the whole of the area which is termed "plateau" is occupied by one formation, a dolomitic limestone of Palæozoic age, and the chief orographical features are due to the peculiar weathering and disintegration of this rock. On the north it is bounded by the hilly country described above, but on the east its limits are not so well defined, for in this direction the limestones are thrown into more or less regular folds, and in succession with the older Palæozoic rocks form high hill ranges. To the south the plateau merges into that of the Southern Shan States, the geology of which is practically unknown, with the exception of the small area traversed by Mr. C. S. Middlemiss and described in the paper previously quoted. In association with the Plateau Limestone, and usually outcropping at its junction with the Archæan or Tawnpeng systems, or brought to the surface in other places by faults, are various older Palæozoic formations belonging to the Ordovician and Silurian systems, while above the limestones, strata of Rhætic and Jurassic age are sometimes found.

Fluviatile and Lacustrine valley deposits.

The valleys of the Shan States are as a rule filled with fluviatile and lacustrine deposits of sands, silts and sand rock of late Tertiary Pleistocene age.

Crushing of the Plateau Limestone.

A very remarkable and constant feature of the Plateau Limestone is the extraordinary manner in which it has been crushed. To such an extent have differential movements taken place that it is difficult to find even small pieces which have not been broken in all directions, and which are not traversed by veins and fissures filled with secondary calcite or dolomite. This pulverization and brecciation is put down to the effects of the enormous stresses set up by the great earth movements, which took place at the close of the Mesozoic period, and to the removal in solution by carbonated waters of immense quantities of the rock. Large as the quantities of limestone removed in this manner must be, and far-reaching in effect as this agency doubtless has been, I regard it as a secondary process, which has accentuated the universal brecciation to which the formation has a whole has been subjected by tectonic stresses.

Faulting of the Northern Shan States.

The account which follows here is based entirely on the work of La Touche[1] (see Pl. 6).

Outer Boundary Fault.

The western edge of the Shan plateau is a fault scrap, bounded by a great fault which breaks into two branches, one following the edge of the alluvium east of the Irrawaddy, and the other crossing the river below Mandalay and dividing the Sagaing hills from the plains of Sagaing and Shwebo. The period at which the folding and faulting of these rocks took place is uncertain. Suess has remarked that the Burmese arc of folding preceded that of the Himalaya. La Touche is of the opinion that it was anterior to that of the Himalaya for a time, though for the most part the great thrust movements, the one acting from the north and the other from the east, must have proceeded simultaneously. He has also drawn attention to the analogy between the results of the movements which produced the Burmese and Himalayan arcs respectively. The Shan plateau is held to correspond with the Tibetan plateau, both of them being elevated floors of ancient oceans now undergoing abrasion and reduction to peneplains. The outer edge of each is bounded by what is virtually a scarp, and in both cases there exists a zone of Archæan and Palæozoic rocks, composed generally speaking of strata of greater age than those of the plateau beyond. In each case the zone is bounded by a great fault forming the inner edge

[1] T. D La Touche: Geology of the Northern Shan States. *Mem., Geol. Surv., Ind.*, Vol. XXXIX.

of the "fore-deep" that separates them from the foreland of the continent beyond. In front of these again there occurs a zone of faulted and folded Tertiary strata, in the one case represented by the Tertiary series of the Irrawaddy valley, and in the other by the Siwalik and associated strata of the Sub-Himalayan zone.

Results of the compressive Tertiary movements.

The results of the compressive Tertiary forces which have effected the Shan plateau can be divided into two groups :—

(1) Regular folds, accompanied by overthrusts and reversed faults parallel to their strike.

(2) Vertical faults, due to the sagging down of the underlying Archæan floor. These bear no relation to the strike of the rocks, follow more or less straight lines for long distances, are often at right angles to each other, and sometimes still form conspicuous surface features in the form of precipitous scarps of limestone extending directly for many miles. There is evidence which tends to prove that the first type of dislocation preceded the second.

Parallel faults.

The following are the members of the series of parallel faults which have been recognised up to the present time. Their locations can be perceived from Pl. No 6.

1. The outer bounding fault which has brought up the Archæan rocks opposite Mandalay.

2. The Tonbo fault, probably a branch of the former which cuts off the Plateau Limestone at the foot-hills to the east of Mandalay, and brings it up against the Archæan.

3. The Sedaw fault, which runs due north and south, and brings the Ordovician beds into contact with the Plateau Limestone. It extends north into the Kyetmaok valley and south into the Myitnge gorge.

4. The Zebingyi fault, running into the gorge of the Myitnge, and bringing the Nyaungbaw (Silurian) beds against the Plateau Limestone.

5. The Chaung Magyi fault, probably continuous up the valley of the same name, and bringing the Chaung Magyi strata into contact with the Mogok gneiss.

6. The Pyintha flexure, marked by a folded zone of Nyaungbaw limestones, which form the final step up to the main plateau east of Zebingyi, and which is almost certainly faulted along the crest of the ascent.

7. The Kyaukkyan fault, which shows at the surface as a great scarp forming a conspicuous feature of the landscape, as seen from the railway between Maymyo and Hsum-hsai. It closes up the view towards the east, rising like a wall beyond the broad valley of the Kelaung and Hpawng-aw streams, surmounted by precipitous cliffs of limestone.

At the point where it is crossed by the railway it takes the form of a uniclinal flexure in the limestone, rather than a fault scarp, and the ascent from the valley is only about 400 feet, but there is a distinct fault along the crest, with a down-throw towards the west. Further north the line of dislocation is not easily perceived, but it probably continues some distance further into the Chaung Magyi and Mica Schist series than is shown on the map. For a few miles the Nam-pan-hse stream flows along it, and in this region the down-throw is on the eastern side. "Further to the south the crest remains perfectly level backed by a plateau rising very gradually towards the edge of the Gokteik gorge, but the flexure increases in importance, while at the same time the fault itself appears as a line of vertical cliffs just below the crest, until the differential movement becomes so great that the older Palæozoic rocks beneath the limestone are exposed along the face of the scarp, which by this time has reached a height relative to the plateau below, of some 3,000 feet. Along the base the edges of the Plateau Limestone are seen inclined at a high angle or even vertical, but the strata are quickly bent into an almost horizontal position, and between the base of the scarp and Wetwin are found everywhere with a moderate inclination towards the east." ([1])

South of Lat. 22°, the direction and throw of this great displacement are unknown, but it is thought that it continues for some considerable distance.

The origin of these vertical subsidences is obscure. La Touche has pointed out that in the manner in which they are represented at times by a monoclinal flexure, they recall the vertical fault systems of the Colorado plateau described by Gilbert and Dutton,([2]) and that they are apparently due to local and deep-seated subsidences

[1] La Touche: *Loc. cit.*, p. 363.

[2] Geology of portions of Nevada, etc., *U. S. Geol. Surveys; W. of 100° Meridian.* Vol. III, pp. 48-57. See also Geology of the High Plateaus of Utah. *U. S. Geol. Surveys*, 1880, pp. 25-54.

of the rocks below the surface. "The fact that they follow the maximum degree of tangential folding in point of time seems to me to suggest that the cause of the subsidences may have been an easing off of the compressive forces, when the reaction might have resulted in the production of a certain amount of tensional stress, and consequently a slight opening out, as it were, of the folded strata.([1])

CAUSE OF THE EARTHQUAKE.

Connection of the disturbances with the Kyaukkyan fault.

Whether we accept the theory that the majority of tectonic earthquakes are to be ascribed to vibrations originating in movements along fault planes, which may or may not reach the surface, or whether we believe with Oldham "that the growth of our knowledge of earthquakes is making it more and more evident that, whether great or small, they have little or no connexion with the faults which reach the surface of the earth,"([2]) makes little difference to the conclusions which it is desired to draw attention to here.

[1] La Touche: *Loc. cit.*, p. 362.

See also Suess: Das Antlitz der Erde, Vol. 1, pp. 164-187.

[2] R. D. Oldham: The Geological Interpretation of the Earth-Movements associated with the Californian Earthquake of April 18th, 1908. *Q. J. G. S.*, Vol. LXV, pp. 1-20.

In this connection see also—

Sir T. H. Holland: The origin of the Himalayan folding. *Geol. Mag.*, April 1913, p. 169.

This view only refers to the great world-shaking seisms, and not to earthquakes originating in the outer crust, characterised by their localization and by producing no impression on the most delicate instruments at small distances outside the seismic area.

The following paragraph from Oldham's paper seems to summarise his views regarding intense seismic disturbances.

"In the case of great earthquakes, like the Californian one of 1906, the surface-disturbance is still the immediate result of fracture and yielding of the outer skin, but these are the result and accompaniment of an abrupt yielding of the underlying crust. It is difficult to believe that this yielding can be precisely similar to the fractures which may be and are produced in the surface rocks; but it is probably analogous in the sense that the ultimate result is the same, and that there is a sudden yielding and displacement of adjoining masses of matter relative to each other. On this hypothesis we have, in great earthquakes, two closely connected and yet distinct disturbances: there is first the dislocation of the outer skin, which gives rise to the surface-shock, and secondly the deep-seated displacement, or bathyseism, which gives rise to the wave motion, which, propagated to great distances, impresses itself on suitable instruments all over the world and constitutes the teleseism, or world-shaking earthquake." *Loc. cit.*, p 14.

For another view of the causes of the Californian Earthquake see—

Harry Fielding Reid: On Mass Movements in Tectonic Earthquakes and the depth of the Focus. *Beiträge zur Geophysik*, X Band, 1910, pp. 318-350.

These are as follows :—

1. The major axis of the elongated oval enclosed by the innermost isoseismal line coincides very nearly with the Kyaukkyan fault.
2. A relationship is evident between the places where the maximum intensities were experienced and the greatest damage done, and the known course and probable continuation of that fault.
3. The railway was bent close to that point where it crosses the Kyaukkyan fracture, but quite undamaged at the places where it traverses the other faults of the plateau.

It is not known that any fresh surface displacement took place as a result of the shocks, though it is improbable that such was the case.

SOUNDS CONNECTED WITH THE EARTHQUAKE.

Some information has been gathered together with reference to the manifestation of sounds in connection with the earthquake.

Unusual sounds were heard before the shock itself in :—

Maymyo.
Mandalay and district.
Hsum-hsai, Northern Shan States.
Namhsan, Northern Shan States.
Yawnghwe, Southern Shan States.
Loikaw, Karenni.
Mogok, Ruby Mines District.
Mogaung, Myitkyina District.
Sagaing.
Kyaukse and District.
Yamethin.

Accompanying the shock in —

Maymyo.
Wuntho, Katha District.
Toungoo.

Following the shock in :—

Shwegu, Bhamo District.
Salin, Minbu District.
Sagu, Minbu District.

Sounds were heard but no details were supplied in the case of :—

Pinlebu, Katha District.

The evidence of persons who heard the sound during the shock does not contravene that of the greater number who heard it before. It is well known that such sounds possess an extraordinary depth, and that they are too low to be heard by many persons. Part of the vibrations which produced the sounds in question may have been below the range of audibility of some people, while well within the compass of others. Again, low preceding sounds may have escaped the attention of persons who were not alert enough to perceive them until they were disturbed by the shock itself.

Agreement as to the character of the sound.

There is a uniform agreement amongst observers as to the character of the sound, and it is variously described as being like low thunder, the rumbling of a string of carts loaded with loose iron sheets, a running railway train, a cavalry charge riding past a saluting base, low rumbling noise, low roaring noise, thunderous murmur, lower air vibration, heavy carriages driven quickly on a metalled road, etc.

Locations of preparatory sounds.

Most of the places where preparatory sounds were heard are situated within isoseists VIII and IX; as exceptions, however, there are four places which lie in isoseists IV—V. It is concluded that the sound was heard in most cases an appreciable time before the shock commenced.

Aftersounds.

In the town of Shwegu, Bhamo District, the last shock was succeeded by a rumbling noise which lasted for about 20 seconds, and which approached and died away as if a train were entering or leaving a railway station. After the shock was over in Salin, Minbu District, a great noise something like the firing of a cannon was heard, while from Sagu in the same district comes the confirmatory and independent evidence that a similar noise was repeated three times from the north-east after the earthquake.

The sounds heard in Salin and Sagu belong to the type of explosive sounds, coming after the passage of the shock which have been recorded in the cases of three former Indian earthquakes,—those of 1869, 1881, and 1897.(1)

1 Oldham: *Loc. cit.*, pp. 194-195.

The sounds referred to here, like those associated with the former earthquakes, were local in their distribution, the areas over which they were heard were a long way from the epicentral tract, and the explosions followed the shock.

Noises heard in the Magwe District on May 16th, 1912.

Mr. Ripley, Sub-divisional Officer of Magwe, reported that on May 16th he was at a place called Inywagyi in the Myothit township, when peculiar, though not very loud sounds of long duration were heard from the north. The inhabitants of the neighbourhood could not understand the noises and had never heard them before. Such mysterious noises known under the general name of "brontides" and locally as "Barisal guns", "mist-poeffeurs", "marinas", etc., may possibly be earthsounds following in the wake, but after a prolonged interval of time, of some past and almost forgotton shock.(1)

Origin of earthquake sounds.

The questions may be asked—how do such sound vibrations originate, and how do they reach any particular locality in advance of the shock itself?

A view which appears to find some favour is that earthquakes and earthsounds are manifestations, differing only in degree and in the mode in which mankind perceives them, of one and the same phenomenon. The excentricity of the sound areas when referred to the isoseismal lines, in the cases of those earthquakes concerning which sufficient data exist to enable such comparative studies to be made, together with the general precedence of the sound, is held to be explained by assuming the generation of two sets of vibrations in different regions of the focus. The portion from which the sound vibrations proceed lies outside the other, and principally in the upper and lateral margins of the seismic focus.(2)

Seismic waves traverse the earth's crust very much faster than sound waves are transmitted in air. It is therefore impossible for sounds produced in the latter medium, above the seat of the the disturbance, to reach distant points in advance of the seismic vibrations themselves. United testimony of witnesses is too strong for the fact to be doubted that the sounds are really generally heard in advance of the felt shock. The sounds, therefore, must be made by vibrations communicated to the atmosphere by

1 C. Davison: The Origin of Earthquakes, p. 121.
2 Davison: *Loc. cit.*, p. 123.

tremors of the surrounding ground preceding the large waves, and which are not otherwise perceptible to the unaided senses. They may correspond to the "preliminary tremors" recorded by seismographs.

VISIBLE UNDULATIONS OF THE GROUND.

Places where visible undulations of the ground were observed.

The rate of travel of the earthquake has been shown in an earlier paragraph to have been about 2 miles per second. Surface undulations due to the passage of such waves would not be visible. Yet, as in the case of the Californian earthquake, there is positive testimony that much slower undulations were observed.[1]

The following examples may be cited :—

Mandalay.—(Mr. Swinhoe). He noticed the road heaving in gentle undulations.

Mandalay.—(Mr. Armitage). He distinctly felt the rise and fall in the ground similar to the sensations felt in a lift, but the alterations were very rapid.

Mandalay.—(Mr. E. C. Beresford-Parnell). He saw the earth moving towards him in waves about 1 foot high and about 2 feet distant fom each other.

Myohaung.—(Mr. T. Johannes). The platform felt like a ship at sea.

Namhsan.—(Mr. Burne). He saw the waves approaching from the south-south-west.

Maymyo.—(Sir W. F. Gates). The earth seemed to be in ripples, as if disturbed by waves of high frequency.

Mogok.—(Mr. Colston). The ground is described as rising and falling like the waves of the sea.

Mogok.—(Mr. James). He observed the surface of the ground in waves, the crest of which appeared to face towards the west.

Other less positive statements of the same kind will be found in the descriptive part of the report.

[1] *Loc. cit.*, Vol. I, Pt. II, p. 380.

Explanation advanced in the case of the Californian earthquake.

These types of ground waves occur in regions where high intensities are experienced but do not appear to have been generally recognised as yet. Their origin is obscure, though the following explanation has been advanced in the case of the Californian earthquake, where they were observed on alluvial tracts, although some of the reports, as in the present case, came from places where there is but a thin veneer of alluvium or soil upon the rocks.

"If it should prove, on the basis of more abundant evidence, that these waves are peculiar to alluvial basins, they may be explained as reflections from the rocky slopes of such basins. If a bowl of liquid be tapt smartly, vibrations are inaugurated in the rigid bowl which have a speed so great that the secondary waves generated in the liquid pass out from all parts of the walls of the vessels sensibly at the same instant. But the secondary waves thus generated in the liquid have so slow a rate of propagation that they are quite apparent to the eye, and in the central part of the surface of the liquid, where the waves meet, there is a violent commotion. If, instead of a bowl of liquid, we have a rock basin filled with water-saturated alluvium it seems probable that a similar effect would be produced in a modified degree; and the visible waves at the surface may have had such an origin. But whatever be their origin, it is apparent that they must be a large factor in damaging structures situated upon the ground in which they occur, and so raising the apparent intensity on any scale based on destructive effects."([1])

EFFECT ON SPRINGS AND WATER-SUPPLY.

In the descriptive part of this report there are references to the effect of the earthquakes on various springs and water-supplies, such as the hot spring which dried up at Seikpyu as a result of the shocks, and the remarkable changes in the level of the water in the reservoir at Taunggyi in the Southern Shan States. Similar phenomena were reported from Kyaukse and from Shwemyo.

Springs produced at Kyaukse.

In the former instance cracks appeared in the ground as a result of the quake, for a length of some 150 feet, about a mile south of Kyaukse hill, and within 50 feet of the bank of the Zawgyi

[1] *Loc. cit.*, p. 380

river. Water and sand bubbled forth from them. On July 15th 1912, Tun Min, Deputy Superintendent of Police, reported to the Deputy Commissioner in Kyaukse that the fissure had been covered up by cultivators ploughing over it, and that only an irregular crack was then visible. He thought that the proximity of the Zawgyi river accounted for the expulsion of the sand and water owing to "a waterway under the earth connected with the river being closed up, by a mass of earth falling on it." The formation of earth fissures, sand vents and allied phenomena has been very fully discussed by Oldham in the case of the Assam earthquake of 1897.[1]

Changes in water-level at Shwemyo.

At Shwemyo in the Pyinmana District the water-level rose some 15 feet during May and June. The previous year wells had to be sunk about 30 feet before water was reached, but in 1912 water was available from 10 to 15 feet down. As the rains of 1912 and 1911 were both scanty and early, it has been suggested that the earthquake may have affected the water-level in this neighbourhood.

[1] Oldham: *Loc. cit.*, pp. 85-111

CHAPTER VI.

EARLIER SHOCKS.

The earthquake of May 18th, 1912.

First shock felt in Maymyo and Taunggyi.

The first earthquake of the series appears to have been felt in Maymyo and in Taunggyi on May 18th in the early hours of the morning. According to Dr. Finlayson of Maymyo it took place about 2-45 or 3 A.M., and consisted of a single tremor, but other persons state that two shocks were felt with an interval of 10 minutes between them. The shock was afterwards reported in the "Rangoon Gazette" and described as quite slight and causing little alarm.

In Taunggyi, according to Mr. A. R. J. Hope, Executive Engineer, the quake occurred at 3 A.M. and lasted 15 seconds. Capt. H. S. Matson, I.M.S., of the same place gives the same time and duration, and states in addition that a second tremor occurred half an hour later. Its intensity does not appear to have been more than IV—V on the Rossi-Forel scale.

The Assistant Superintendent of the western sub-division of the Southern Shan States also reported a slight shock in the early hours of the morning of the same date.

The earthquake of May 21st, 1912.

Mandalay.

A widely felt shock occurred on the afternoon of May 21st, 1912, concerning which the following information has been gathered together :—

Mandalay.

The Meteorological Reporter.

The following shocks were observed :—

Time.	Duration
3 P.M.	50 seconds.
3-20 P.M.	15 ,,
3-25 P.M.	5 ,,
3-55 P.M.	30 ,,

He was seated in office at the time, and during the shocks heard sounds which are compared with those made by a heavy engine moving over the road close by. The first three were strong enough to cause a slight crack in the ceiling of the eye ward of the hospital. The fourth moved his seat, made doors and windows rattle, and caused hanging objects to swing.

Mandalay. *Mr. M. Paul, 1st Assistant, St. Xavier's School.*—Time 3-30 P.M. (guessed). Duration 15 secs. It was followed by two aftershocks and was accompanied by rumbling noises.

Mandalay. *Mr. Armitage.*—Time 9 A.M. (?). Quite an uncomfortable shock.

Northern Shan States.

Maymyo. *Dr. Finlayson.*—A tremor occurred about 2-55 P.M. It rattled windows freely. Other slight shocks occurred the same afternoon and night. According to a correspondent in the "Rangoon Gazette," it occurred at 3 P.M. Duration 40 seconds. A fairly severe shock.

Anisekan. *Mr. F. Hamilton Dale.*—On the 21st at about 3-30 P.M., he was near the edge of the very deep cliff on the north of the railway line near Anisekan, when the shock commenced. It seemed as if huge rocks were being heaved up from below against the earth's crust accompanied by a deep booming sound. He did not notice any rocking movement only an "upward kicking." He hastened away as he feared that the place might slip bodily into the depths of the gorge. On reaching home he was informed that two shocks had been felt, one at 3-30 P.M. and the other at 4 P.M. Between the 21st and the 23rd several slight shocks were experienced.

Lashio. *Mr. A. P. Warburton, Assistant Superintendent of Police.*—He felt 3 shocks on May 21st, and made the following notes in his diary:—

3-24 P.M. Severe earthquake which lasted for fully 1½ minutes.

4-8 P.M. Very short.

4-20 P.M. Very short.

Namhsan, Tawngpeng.

Mr. R. D. Burne.—He felt three shocks at the following times :—

3-9 P.M.
3-53 P.M.
4-5 P.M.

Each lasted from 10 to 20 seconds. No damage of any kind was caused.

Monglong.

Mr. Grose and the Monglong Myosa.—The shock was felt about 3 P.M. coming from the W.

Southern Shan States.

Taunggyi.

Mr. A. J. R. Hope, Executive Engineer.—May 21st at 3 P.M. Duration 17 seconds.

Taunggyi.

Capt. H. S. Matson, I.M.S.—At 3 P.M., on May 21st, 1912, a sudden severe shock occurred, lasting 17 seconds, and continuous small shocks were felt during the remainder of the day. Particularly well marked tremors occurred at 3-30, 4-15, 5, 5-30, 5-35, 6, 6-15 and 6-34 P.M. There was also a severe shock at 11 P.M. No damage was done.

Western Sub-division.

The Assistant Superintendent.—The shock of the 21st was severe and felt throughout the sub-division.

South-eastern Sub-division.

The Assistant Superintendent.—The shock of May 21st was felt about 3 P.M.

North-eastern Sub-division.

The Assistant Superintendent.—Time 3-45 P.M. Seven slight shocks followed from that time until the morning of the 22nd.

Kengtung Sub-division.

The Assistant Superintendent, Mr. S. St. R. Korper.—May 21st, 1912. Time about 3 P.M. Duration 10 seconds. Both the writer and Lieutenant Childers experienced the sensations of sea-sickness.

Thamakan.

Mr. Sams.—He felt an unpleasant but not severe shock on the 21st.

Karenni.

Loikaw.

The Assistant Superintendent.—A distinct shock about 3 P.M.

Ruby Mines District.

Mr. Colston, I.C.S., Deputy Commissioner.—The shock felt about 5 P.M. on the 21st May lasted for a second or two and no particular damage was done.

Mogok.

In Momeik, according to the same writer, a shock was felt about 3 P.M.

Momeik.

Shwebo District.

The Deputy Commissioner.—Time about 2-30 P.M. A slight but very distinct shock. Duration 5 seconds. Apparent direction N. to S.

Shwebo.

Sagaing District.

Mr. Pennell, I.C.S., Deputy Commissioner.—The shock was felt at 3 P.M. on May 21st, 1912. Direction N. E.—S. W.

Sagaing.

Lower Chindwin District.

Mr. Gordon W. Lepper, Geologist, Burmah Oil Co., Ltd.—On May 21st, at 3-8 P.M. by an uncorrected watch, he was drawing at a table in the Kani dâk bungalow and felt it shaking. At first he thought that the wind was shaking the bungalow, but soon saw than this was not the case. He rushed oustide, followed by the Deputy Commissioner who was also staying there at the time, and noticed the shock. It is described as feeble and estimated at II—III on the Rossi-Forel scale.

Kani.

Kyaukse District.

Lt.-Col. Cronin, Deputy Commissioner.—A distinct shock was felt on May 21st. It appeared to move N.E.—S.W., and was accompanied by loud rumbling noises.

Kyaukse.

Maung Po Shwe, Sub-divisional Officer.—On the 21st May at 3-2 P.M. by railway time. Direction S.W.—N.E. In the evening of the same day about 3 more shocks were felt.

Kyaukse.

Maung Maung Tin, Sub-divisional Officer.—Three shocks in quick succession were felt about 3 P.M. on May 21st.

Myittha.

Mr. Hampton, Sub-divisional Officer.—A "lower air vibration," was heard just before and during the severe shock of May 21st. The sound appeared to be towards the south.

Singaing.

Myingyan District.

Natogyi.

The Township Officer.—Time 3-8 P.M., by uncorrected watches. Direction S. W.—N. E.

Mr. H. N. Tuck, I.C.S.—He was on Mount Popa on May the 21st, 1912, and felt a slight shock.

Popa.

Meiktila District.

Correspondent in the "Rangoon Gazette."—At 2-55 P.M. on May 21st a violent earthquake shock was experienced. It lasted quite a minute, set dogs howling, and brought the people in a panic from their houses into the streets. Many fell ill with nausea without comprehending the cause.

Meiktila.

Magwe District.

The Sub-divisional Officer.—A very slight shock was felt about 3-5 P.M. on May 21st, 1912. It lasted about $\frac{1}{3}$ of a minute.

Taungdwingyi.

Mr. Ripley.—Time 3-30 P.M. (guessed). Duration about 10 seconds. Direction N. to S. as free swinging objects were caused to move in that direction.

Nyaunghmaw.

Yamethin District.

The Meteorological Reporter.—May 21st at 3 P.M. by railway time. Observer standing indoors. After a moment's trembling 2 shocks were felt, of sufficient intensity to crack the walls of buildings and throw down loose objects. Duration 3 seconds. No unusual sounds were heard.

Yamethin.

Toungoo District.

Correspondent in the "Rangoon Gazette."—On May 21st at 3 P.M., a distinct shock lasting 15 seconds was experienced. The same writer reported that a shock was also felt in the early morning a week or so earlier.

Toungoo.

Mr. Walter C. Sherman.—A distinct shock a very little after 3 P.M. on the afternoon of May 21st, 1912.

Toungoo.

Mr. W. R. Fry.—A distinct shock was experienced at 3 P.M. on May 21st. It lasted nearly a minute.

Toungoo.

The Sub-divisional Officer.—A shock was felt on May 21st about 3 or 4 P.M. Duration, about 2 minutes. Direction N. to S. He was writing at the time and the preliminary tremors were quite sufficient to make it impossible to continue.

Kyaukkyi.

Maung Po Tin, Sub-divisional Officer.—A rather severe earthquake, lasting a full minute, was felt at 3-5 P.M. on May 21st. At the time a local advocate named Maung Su advised his people to quit the house as he feared the roof would fall in.

Pyu.

Pegu District.

Mr. Ormiston, I.C.S., Deputy Commissioner.—On the 21st May a shock was felt at 3-2 P.M. Time taken by a watch regulated by Standard Time. The earthquake was perceptible for about 3 minutes as a series of vibrations rising and falling in intensity. These vibrations were only just visible on the surface of the ink in a large ink-pot on the writer's office table at Pegu.

Pegu.

Siam.

Correspondent in the "Rangoon Gazette."—Time about 3 P.M. on May 21st. A short sharp shock preceded by a trembling of the earth which was distinctly felt for some seconds.

Mongpai.—(Lat. 19°-30'; Long. 98°-30' approx.)

Correspondent in the "Bangkok Times."—A slight shock was experienced on May 21st.

Chiengmai.

Correspondent in the "Bangkok Times."—A slight shock was experienced on May 21st.

Chiengrai.

EARTHQUAKES OF MAY 22ND 1912.

As the following accounts show, a series of shocks was felt on May 22nd in places close to the epicentral tracts shaken by the big shock of May 23rd.

Maymyo. *Dr. Finlayson.*—Slight tremors were felt during the night of the 22nd.

Mr. M. Paul.—Six shocks were felt at intervals during the day on May 22nd. Some were but slightly felt.

Mandalay.

Taunggyi. *Mr. A. J. R. Hope.*—On May 22nd there were two small shocks.

Capt. H. S. Matson, I.M.S.—Two small shocks were felt during the morning of the 22nd, of an average duration of 10 seconds.

Taunggyi.

The Assistant Superintendent, North-eastern Sub-division.—One slight shock lasting 2 or 3 seconds was felt at 11-20 A.M on the morning of May 22nd.

Loilem.

Myittha, Kyaukse District. *The Sub-divisional Officer.*—A slight shock was felt about 3 P.M. on May 22nd.

Kyaukse. *The Sub-divisional Officer.*—A slight shock was noticed in Kyaukse town on May 22nd at 2 P.M.

Records of Rangoon seismographs.

The shock of May 22nd was recorded by the seismograph at Rangoon College. It commenced at 14 hours 49 minutes 30 seconds and lasted till 15 hours 23 minutes 30 seconds (B. S. T.). It was severe from 14 hours 50 minutes 30 seconds till 14 hours 57 minutes 30 seconds (B. S. T.).

A second shock on the same day commenced at 15 hours 34 minutes 35 seconds (B. S. T.) and lasted till 15 hours 38 minutes 45 seconds. This shock was described as a slight one by the officer in charge of the instrument.

Indian Records.

The first of these two shocks appears also to have been recorded by the instruments in the Meteorological Observatories in Kodaikanal, Calcutta, Bombay, and Simla but owing to the unsatisfactory nature of the time observations in Burma I am unable to make use of the figures, which can be found in the Government of India, Meteorological Department, Monthly Weather Review for May 1912.

Probable identical origin.

A study of the distribution of the intensity of these earlier shocks, from such scanty data as are available, leads me to the conclusion that their origin is probably identical with that of the great shock of May 23rd, and is to be sought for in or about the Kyaukkyan fault.

AFTERSHOCKS.

Distribution of aftershocks.

For some days after the main shock the earth in the immediate neighbourhood of Maymyo, Mandalay, Taunggyi and other places seems to have been in an almost continual state of tremor. I was informed by residents in Maymyo that it was impossible to chronicle all the aftershocks which were felt, and when I visited the station, almost imperceptible tremblings of the ground were a repeated occurrence. The list given below is very incomplete and can only show a small percentage of the actual number of aftershocks. Many were slight enough to be hardly felt at all, while others attained a fair degree of strength. Yet although admittedly incomplete, the list shows how the shocks gradually became less frequent, of lower intensity, and more localised in the Northern and Southern Shan States, and in the Mandalay and Ruby Mines districts around Maymyo, Taunggyi and Mogok.

Seismograph records of aftershocks.

Four slight shocks were recorded on the Rangoon seismograph after the great shock on May 23rd.

		H.	M.	S.		H.	M.	S.	
1. May 23rd . . .	from	12	56	5	till	13	2	45	B.S.T.
2. Do. . . .	,,	15	20	0	,,	15	23	0	,,
3. May 24th (morning) .	,,	5	34	45	,,	5	44	30	,,
4. Do. . . .	,,	10	37	30	,,	10	45	20	,,

Recrudescence of Burma Earthquakes in 1913.

The following extract is taken from the Calcutta "Statesman" and is dated Rangoon, January 21st, 1913. "There was quite a severe earthquake shock at Maymyo during the early hours of Saturday morning last (*i.e.*, January 18th, 1913), quite the most severe one experienced since the bad shock of last May. The actual shock was preceded by a low rumbling sound which increased in volume as it approached and finally died away."

Another earthquake of a severe nature was felt in Mandalay about 9 A.M. on September 1st, 1913, according to the "Statesman" of September 3rd, 1913.

LIST OF AFTERSHOCKS.

Date.	Time and details of shocks.	Place.
1912, May 23rd .	Every few minutes for some hours after the principal shock. 12 shocks between 9 A.M. and 10 A.M.	Mandalay.
Do. do. .	The main shock was followed by minor tremors at short intervals during the morning. One at 9-28 A.M., visibly shook the walls of houses. They gradually became fainter and less frequent during the afternoon. In the late afternoon there were tremors at 3-33, 5-3, 5-14, 5-19, 5-22, 5-32, 2 or 3 tremors between 7 and 8 and one at 9-8 P.M. Further tremors occurred during the night.	Maymyo.
Do. do. .	The severe shock was followed by 4 others during the day, and by 17 well marked tremors during the following night.	Taunggyi.
Do. do. .	Strong shock at 9-30 A.M., lasted about 10 to 12 seconds. 2 more slight shocks in the afternoon.	Loilem.
Do. do. .	Throughout the day constant shocks were felt. At night there were shocks also.	Mogok.
Do. do. .	14 shocks beginning from 9 A.M. . .	Momeik.
Do. do. .	1 shock at 3 P.M.	Myittha.
Do. do. .	10-30 A.M., very slight tremor, followed a short time afterwards by another. Others at about 4 P.M. and 12-30 night.	Shwebo.
Do. do. .	There were 7 or more aftershocks . .	Sagaing.
Do. do. .	A slight tremor lasting 30 seconds at about 10 A.M.	Mingin.
Do. do. .	Slight shock at 4 P.M. Duration 2 seconds.	Sadon.

LIST OF AFTERSHOCKS—*contd.*

Date.	Time and details of shocks.	Place.
1912, May 24th .	Slight tremors during the day at 6 A.M., 8-28 A.M., 9-14 A.M., 9-28 A.M., 12-42 P.M., 3-41 P.M., 3-48 P.M., and during the night.	Maymyo.
Do. do. .	3 slight shocks felt during the day . .	Mandalay.
Do. do. .	Slight shock about 10-30 A.M. . . .	Lashio.
Do. do. .	A distinct tremor lasting 15 seconds at 3 P.M.	Taunggyi.
Do. do. .	Slight shock at 6-10 A.M. . . . . Do. do. 9-25 A.M. Do. do. 3 P.M.	Loilem.
Do. do. .	Rather severe shock at 3 A.M. and 5-10 A.M. Other numerous small ones during the day.	Mogok.
Do. do. .	2 A.M. and 6-30 P.M.	Momeik.
Do. do. .	A minor shock in the morning . . .	Chiengrai, Siam.
Do. 25th .	5 slight shocks during the day . . .	Mandalay.
Do. do. .	A sharp tremor at 9-30 A.M. . . . Other slight ones later.	Maymyo.
Do. do. .	6 tremors during the night, of short duration. Others during the day at 11 A.M. 1 P.M. 2 P.M. 5 P.M.	Taunggyi.
Do. do. .	One slight shock at 11 A.M. and another at 1 P.M.	Loilem.
Do. do. .	2 or 3 slight ones between 10 and 11 A.M. .	Mogok.
Do. do. .	9 A.M.	Momeik.
Do. 26th .	6 slight shocks were felt during the day .	Mandalay.
Do. do. .	Slight tremors in the afternoon. . . A sharper one at 4-29 P.M. Another about midnight.	Maymyo.

LIST OF AFTERSHOCKS—*contd.*

Date.	Time and details of shocks.	Place.
1912, May 26th .	Slight shock at 8-30 A.M. . . . . Do. do. 12 noon. Average duration 10-12 seconds.	Taunggyi.
Do. do. .	9 A.M. . . . . 4 P.M. 10 P.M. 12 P.M.	Momeik.
Do. 27th .	8 slight shocks from 5 A.M. to 10 P.M. .	Mandalay.
Do. do. .	Slight tremors during the morning and afternoon.	Maymyo.
Do. do. .	A slight tremor at 9-20 A.M., duration 7 seconds, 2 tremors during the night.	Taunggyi.
Do. do. .	Shock at night about 10-30 P.M. . . Fairly strong.	Loilem.
Do. do. .	2 P.M.	Momeik.
Do. 28th .	11-51 A.M. sharp tremor . . . . 8-20 P.M. do. 10-20 P.M. do.	Maymyo.
Do. do. .	3 tremors during the night and one at 4-30 P.M., lasting 8 seconds.	Taunggyi.
Do. do. .	12 noon	Momeik.
Do. 30th .	2-30 P.M.	Maymyo.
Do. do. .	2 slight shocks during the night and one at 6 A.M.	Taunggyi.
Do. do. .	7 A.M.	Momeik.
Do. 31st .	7-30 A.M.	Taunggyi.
Do. do. .	6-30 A.M.	Momeik.
Do. June 1st .	Small tremors during the night . .	Taunggyi.
Do. 2nd .	4-30 P.M. (approx.)	Maymyo.
Do. do. .	10-30 P.M. do.	Mandalay.

LIST OF AFTERSHOCKS—*contd.*

Date.		Time and details of shocks.	Place.
1912, June	3rd	2 A.M. (approx.)	Maymyo.
Do.	do.	6-30 P.M. do.	Do.
Do.	do.	1 A.M.	Momeik.
Do.	do.	5-30 A.M.	Do.
Do.	4th	Slight tremors in the morning 5-58 P.M.	Maymyo.
Do.	do.	2 tremors in the afternoon	Taunggyi.
Do.	6th	4-30 P.M.	Taungyyi.
Do.	do.	7 P.M.	Momeik.
Do.	7th	12-30 A.M. (approx.) 3-30 A.M. A sharp tremor.	Maymyo.
Do.	do.	Two during the afternoon	Taunggyi.
Do.	8th	11 P.M. (approx.)	Mandalay.
Do.	do.	1 A.M.	Momeik.
Do.	9th	A slight but smart double shock was felt between 8 and 9 o'clock.	Mandalay.
Do.	do.	11-30 P.M.	Myittha.
Do.	13th	During the night	Maymyo.
Do.	16th	11-30 A.M. Duration 15 seconds. Severely felt. Plaster fell from walls. Followed by tremors off and on for about ½ hour.	Mandalay.
Do.	do.	11-40 P.M. Sharp shock lasting 3 to 5 seconds. Apparent direction N.-S.	Loilem.
Do.	18th	3-30 A.M.	Anisakan.
Do.	do.	3 A.M.	Mandalay.
Do.	19th	4 A.M. (severe)	Momeik.

LIST OF AFTERSHOCKS—*concld.*

Date.	Time and details of shocks.	Place.
1912, June 21st .	8-40 P.M. Duration 10 seconds . . Direction N.-S.	Anisekan.
Do. do. .	8-30 P.M. One shock followed by small tremors. Duration 3 seconds. Strong enough to move observer's seat, and to cause doors and windows to rattle slightly.	Mandalay.
Do. July 8th .	3-30 P.M. Duration about 3 minutes. Direction E.-W.	Momeik.
Do. 19th .	4 P.M.	Do.
Do. 14th .	1-25 A.M. Duration 3 seconds. One shock followed by small tremors. trong enough to move observer's seat and to make hanging objects swing.	Mandalay.
Do. do. .	3 shocks during the night. Th first was very sharp, and brought down a lot of plaster which had been used to patch up the damage done by the great shock.	Maymyo.
Do. 15th .	Midnight	Loikaw.
Do. 16th .	12-5 (Midnight) . . . . . . 3 shocks. Duration 6 seconds. Strong enough to throw down loose objects. Awakened observer from a deep sleep. 12-10. Duration 3 seconds, 2 shocks. Slight. 12-15. Duration 3 seconds. 1 shock. Slight.	Mandalay.
Do. do.	12-11 A.M.	Momeik.
Do. do. .	Midnight	Mogok.
Do. 18th .	4 A.M. Quite severe but caused no serious damage.	Do.
Do. 26th .	9-25 A.M.	Momeik.

In addition to the list of shocks given above, more general reports were received from other places and are given on the next page.

Mandalay, May 27th, 1912.—"There is scarcely an hour, day or night, without its slight shock or tremor. Since I started writing this letter I have felt 3 distinct tremors, and it is not imagination for mortar dust has at the same time been falling from the cracks in the plaster."—("Burma Critic.")

Mandalay, June 10th, 1912.—"We are daily having slight earthquake tremors here since the severe shock experienced a fortnight ago, and those living in pucca [brick] houses are having an anxious time."—("Rangoon Gazette.")

Maymyo, June 4th, 1912.—"Earthquake shocks of very slight intensity, but some of curiously long duration, considering their weakness, continue to recur once or twice during the 24 hours and people still consider it wise to sleep under canvas fearing lest another severe one may follow."—("Rangoon Gazette.")

Maymyo, June 1st, 1912.—"Earthquakes still continue at regular intervals, but none of the shocks are very bad ones and no further damage has been done. A general exodus from the station is taking place as a result of the continuance of the trouble."—("Rangoon Gazette.")

Maymyo, June 11th, 1912.—"We still have an earthquake shock now and then, chiefly at night, but none are very violent and no one takes much notice of them."—("Rangoon Gazette.")

Nawnghkio (North Shan States).—Slight shocks were being felt up to July 4th (date of the letter), and were sometimes accompanied by a low rumbling noise.

Taunggyi.—"Since then (the main shock of the 23rd May 1912), there have been shocks, mostly slight, with occasional severe ones every day, and although the disturbance would seem to be over earth tremors are still felt."

Southern Shan States, South-Eastern Sub-division.—"After this (May 21st 1912) shocks were experienced for about 20 days."

Southern Shan States, Western Sub-division.—"For the succeeding 20 days or so there were other shocks, usually slight."

Southern Shan States, Yawnghwe.—"For several days after May 23rd, 1912, small shocks were noticed."

Ruby Mines District, Mogok.—"No record has been kept of the subsequent shocks in Mogok and Thabeikkyin, but for about a month afterwards shocks of different intensities were experienced from time to time."

Sagaing District, Sagaing.—" No detailed record of aftershocks was kept but they continued nearly every day for a month."

Shwebo District, Shwebo.—" During the next few days there were almost imperceptible tremors at intervals."

Maymyo, August 12th, 1912.—" The earthquakes are very slight, so slight that many people do not even notice them."—(" Rangoon Gazette.")

Aftershocks in Maymyo.

For data regarding most of the aftershocks in Maymyo I am indebted to Dr. Finlayson, Geologist to the Indo-Burma Petroleum Co., Ltd. Unfortunately he left the station on June 8th and I was unable to find anyone ready to complete the list which he had started. He wrote that the times were taken from a watch correct with the 12 o'clock (midday) gun. As regards aftershocks during the night, the fainter ones, which must have been frequent, would not arouse sleeping persons. The stronger ones were sufficient to awake and disturb light sleepers. All the effects were noted and recorded in Messrs. Steel Bros. brick bungalow. Most of the after tremors would fall in degrees I and II of the Rossi-Forel scale and two or three of the tremors in degree III.

The Bassein Earthquake of July 26th, 1912.

Reports appeared in the Burma press of July 27th, 1912, concerning two slight earthquake shocks felt in Bassein on the previous day, one at 1-54 A.M. and the other at 3-20 A.M.

Later, the Meteorological Observer in Bassein reported that an earthquake took place at 1-59-58 A.M., and lasted for one second. He was awakened by the shock which had a shaking movement and caused hanging objects to swing slightly. No unusual sounds were noticed.

I do not think that these shocks were in any way connected with the movements taking place in Upper Burma. They are regarded as purely local and originating either in the Irrawaddy delta or the rocks below it. They belong to the same category as the two Calcutta earthquakes of 1906 described by Middlemiss.[1]

[1] Two Calcutta Earthquakes of 1906, C. S. Middlemiss. *Rec., Geol. Surv., Ind.*, Vol. XXXVI (1907-08), pp. 214-232.

CHAPTER VII.

THE EARTHQUAKE AND BUILDING CONSTRUCTION.

Brick and masonry work.

The damage caused to brick and stone buildings was far more severe than to those of wood, or of wood and brick nogging. Although as a rule left standing, most of the injured brick and stone walls contained numerous large and small cracks (Pl. No. 5). In a few very bad cases walls collapsed or the top parts near the roofs were shaken away. Cracking was most prevalent near lines of weakness caused by the presence of windows, doors and arches, but did not as a rule cross the bricks themselves, following rather the mortar binding them together.

Wooden houses.

Wooden structures suffered much less than those of brick and stone, though judging by the damage to loose objects contained in them, they felt the shock to much the same extent. The indigenous Shan and Burmese houses were hardly injured at all. They are practically earthquake proof.

Brick nogged houses.

The high panels in brick nogging walls, and the gables in similar positions were frequently shaken out and the lower ones cracked, but where the keying of the frames was well done and in good condition, with the exception of minor damage to plaster ceilings and to chimneys, little further injury was caused.

Brick chimneys.

It may be taken for granted that nearly all the brick chimneys of houses in the severely shaken areas were damaged. Some seemed to have been lashed off whole at their junctions with the roof. Others appear to have crumbled away, and cases were observed in which chimneys although standing had been twisted around through quite large angles, while others were shattered or cracked in all directions. Not only was such cracking found in those portions of the chimneys projecting above the roof level, but it often extended down into the flues, which were also occasionally broken away from the walls of the house. The situation of the site and the character of the mortar used in construction probably account for these bewildering variations.

CONCLUSIONS.

Although the modern type of bungalow in Maymyo (Pls. Nos. 3 and 4), stood the shock remarkably well, it is perfectly evident that much of the damage which was caused, both here and in other towns, could have been avoided by judicious construction, if the liability of the district to disastrous earthquakes could have been foreseen.

Slightly modified birck nogged bungalow necessary.

That such a danger exists is now only too apparent. It is a comparatively easy matter to build houses at a reasonable cost which are to all intents and purposes earthquake proof, yet I do not consider it expedient to advocate any considerable departure from the broad lines of the general type of brick nogged bungalow a sketch of which is appended (Pls. Nos. 3 and 4). In the first place it is useless to urge the construction of earthquake-proof buildings while earthquakes are isolated occurrences, hardly remembered a few months after they have taken place. The prejudices of custom, helped out by the more immediate demands of economy and convenience, have already proved themselves powerful enough to override considerations of absolute safety in districts which have experienced the most appalling results of the strongest earthquakes. Furthermore, the ordinary type of brick nogged bungalow with a few modifications seems to me fitted to withstand shocks of the intensities described in these pages.

I shall therefore content myself by bringing forward the results which the present investigation has revealed in this connection, by means of which I believe a further margin of safety may be added to the peculiar type of house, which the special local conditions in Upper Burma have brought into existence.

Californian earthquake-proof bungalow.

Perhaps the best description of a resistant type of wooden structure, which might be combined with the designs of the bungalows of towns like Maymyo and Taunggyi, is that which the Californian Earthquake Commission put forward as a result of their researches. It is as follows :—

"The building should be of wood, and a wooden sill should be bolted to a deep-laid concrete foundation, the top of which should be but little above the level of the ground. It should be ceiled with wood within. Shelves for dishes should be closed in with doors, or should at least have strips along the front edges. The chimneys should be laid with cement mortar and boxed from a foot or two below the roof to the top, and the parts above the roof should be braced with iron rods. The lower the structure the less strain it will be subjected to. Such a building would be practically proof against earthquakes having an intensity below X on the Rossi-Forel scale."[1]

Reinforced concrete.

It is also pointed out that steel frames and reinforced concrete structures are eminently well adapted to resist earthquake shocks of high intensity.

The reinforced concrete roofs of the military hospital in Maymyo did not fall or crack. Some of the girders moved and crushed the walls under them, but this would have been avoided if bed plates had been provided.

Construction of modified bungalow.

The frames of brick nogged houses then should be as low, solid and strongly keyed together as possible. The upper panels of walls and gables should be filled in with wooden boards. The brick work of lower panels runs less chance of being rocked out during a shock, but it should be firmly bound together, and some means devised of clamping it to the woodwork in a better way than is the custom at present. Plaster on inside walls, and ceilings, and plaster or stucco on the outside of houses, should be avoided as far as possible. Attention should be paid to the foundations on the lines indicated above. Any break between the foundations and the upper structure of a house, as in the case of a wooden building erected on brick or masonry pillars is dangerous. On the other hand, foundations like the long teak post, let deeply into the ground as is often done in the construction of bungalows in Burma, ensures a considerable element of safety.[2]

Present chimneys a source of danger.

The present method of constructing chimneys must be a perpetual menace in a situation liable to earthquake shocks. It is recommended that chimneys be built as light and low as possible, that the brick courses be braced together with iron rods used as clamps, and that they should be, as far as practicable, provided with casing boxes or a coating of cement.

[1] *Loc. cit.*, Vol. 1, Pt. II, p. 358.
[2] See Montessus de Ballore: La Science Seismologique, p. 485.

Chimney pots, galvanized iron pipes and stove pipes are to be preferred to brick structures. During the Californian earthquake their efficiency was conclusively demonstrated, for in the San Mateo county where a survey was made, 90 to 95 per cent. of such chimneys passed through the earthquake without harm, whereas no less than 88 per cent. of the brick chimneys fell.

To avoid the great damage caused by the pitching of solid masses of masonry on to roofs, or to the cracking of chimney flues both above and below roof level, some modification of the patterns in use at the present time is highly desirable.([1])

Mud mortar and sun-dried brick work.

That houses built of burnt bricks in mud mortar or of unburnt sun-dried bricks in lime or mud mortar, are totally unsuited to withstand earthquake shocks of high intensities, is a self-evident fact which needs no emphasis here.

BURMESE ARCHITECTURE.

The following notes on Burmese architecture are taken almost entirely from the report of Mr. F. O. Oertel reproduced in the "Upper Burma Gazetteer."([2])

They will explain how it is that no native buildings, except those connected with the religion of the country, suffered any severe damage.

Types of native buildings.

Sumptuary laws have in Burma, from very ancient times, restricted the use of all durable building materials such as brick and stone masonry, and all architectural adornments to religious and royal edifices. The people live now, as probably they always did, in single-storied huts, raised a few feet above the ground and constructed of bamboo frame-work with split bamboo floors and and mat partitions. The richer people use teak posts and boarded partitions instead of bamboo. The roof is thatched, tiled or in some cases covered with wooden shingles (Pl. No. 1).

There are three distinct types of religious buildings in Burma which may be classified as follows :—

1. Solid pagodas, or topes enshrining relics, such as the Shwe Dagon Pagoda, Rangoon.

[1] Since these lines were written I have seen the designs of a good type of earthquake-proof chimney which is now built in Maymyo by the Public Works Department.
[2] The Upper Burma Gazetteer, Vol. II, Pt. 1, pp. 168-175

2. Carved and ornamented wooden monasteries (*pongyi kyaungs*) including the royal palace at Mandalay, rest-houses (*zayats*), wooden shrines, *theins*, *tazaungs*, and the like.
3. Masonry temples, such as the Ananda and others, peculiar to Pagan and other old sites in Upper Burma.

Pagan temples uninjured.

We are only concerned here with buildings of the first class, the wooden structures of class 2, escaped with very little injury, while an examination of the ancient Pagan temples which I made two months after the earthquake, proved that they suffered little or no damage.

Classification of pagodas.

The common classification of solid pagodas (which are unquestionably the direct lineal descendants of the ancient Indian Buddhist stupas), or *zedis*, is as follows :—

1. Dat-daw Zedi, those containing relics of a Buddha or Rahanda.
2. Paribawga Zedi, those containing implements or garments which have belonged to the Buddhas or sacred personages.
3. Dhamma Zedi, those containing books or texts.
4. Udeiksa Zedi, those built from motives of piety, and containing statues of the Buddha or models of sacred buildings.

The last two classes are by far the most numerous, and the devastation which the earthquake caused to such buildings in the Shan States and Upper Burma was confined to these groups.

Construction of Burmese pagodas.

Most of the Burmese pagodas are constructed of brickwork and covered with stucco. Their peculiar method of construction can be seen from the appended drawing (Pl. No. 2). Stone and laterite have also been used but this is very rare.

The outside is usually whitewashed, and in some cases richly gilt as well. They are slender conical piles, the chief peculiarity of which is the inward curvature of the contour on both sides. Shan pagodas are very much more slender in the spire than the Burmese ones. They retain the *hti* or umbrella which the Siamese pagodas discard. All the larger pagodas stand on a wide, open platform. On this, surrounding the main shrine, are a number of smaller pagodas, shrines or *tazaung-pyathats.*

The Burmese divide important pagodas into twelve parts :—

1. The base with the surrounding pagodas, or shoe.
2. The three terraces, called *pichaya.*
3. The bell.
4. The inverted *thabeik* or alms bowl.
5. The twisted turban or *baung-yit*
6. The lotus flower or *kyalan.*
7. The plaintain bud.
8. The brass plate for the *hti.*
9. The *hti.*
10. The artificial flowers or *seinbwin.*
11. The vane.
12. The bud of diamonds or *seinbu.*

A less elaborate division is into four parts :—

1. The square masonry or brick work terrace.
2. A high plinth of a boldly moulded stepped contour, generally of elaborate polygonal form in plan.
3. The bell-shaped body of the pagoda, divided into two portions by an ornamental band.
4. The spire, consisting of a number of rings; a lotus leaf band, with a bead moulding in the centre and leaves above and below, pointing in opposite directions; a terminal carrot-shaped cone, surmounted by the gilt metal-work crown, or *hti.* This is generally made of pierced iron-work, and consists of several rings rising in diminishing stages, and finished off with a long iron rod. When not completely broken down the pagodas were often smashed off at the top or middle of the bell-shaped body.

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TYPICAL SHAN PAGODAS.

Photographs by J. Coggin Brown. *G. S. I. Calcutta.*

VILLAGE MONASTERY OR "PONGYI KYAUNG" OF THE NORTHERN SHAN STATES.

Showing how the framework is supported on wooden piles.

G. S. I. Calcutta.

METHOD OF PAGODA CONSTRUCTION.

To illustrate the instability of such structures during Earthquakes.

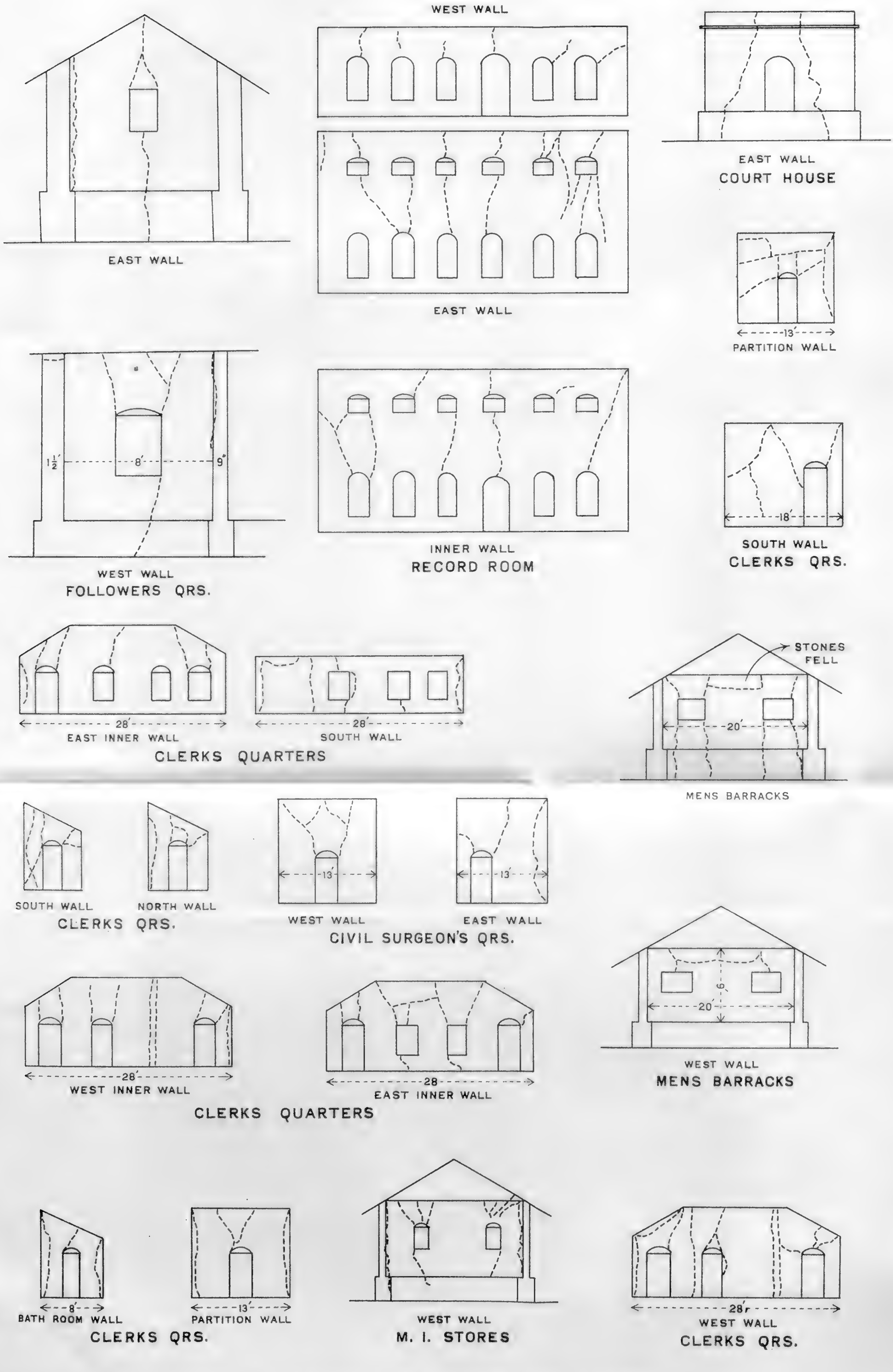
Memoirs. Vol. XLII. Pl. 3.

G. S. I. Calcutta.

SECTION OF TYPICAL BUNGALOW.

G. S. I. Calcutta

ELEVATION OF TYPICAL BUNGALOW.



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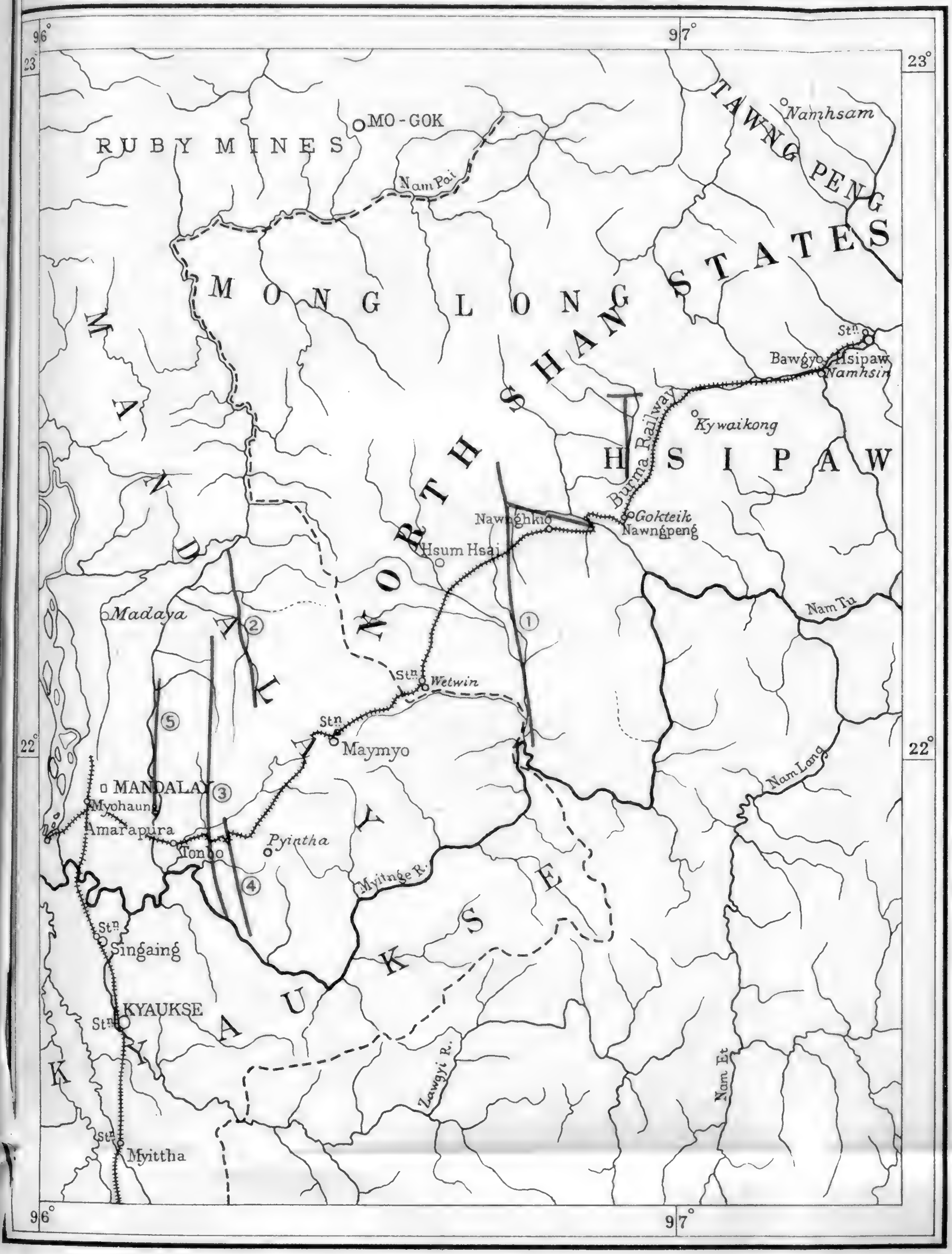
SKETCHES SHOWING DAMAGE TO VARIOUS BUILDINGS IN TAUNGGYI.

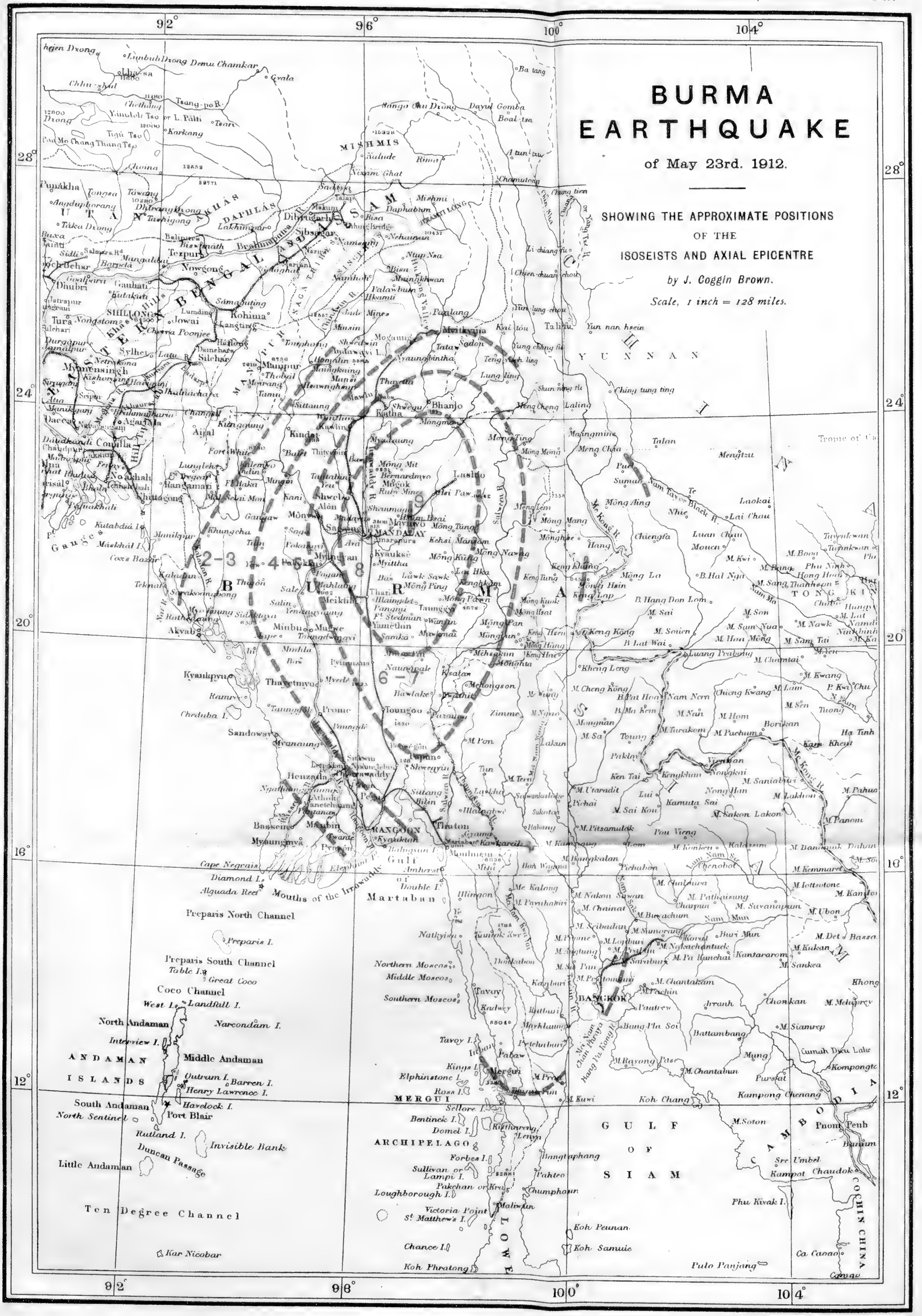


FAULTS OF THE NORTHERN SHAN STATES.

(after T. H. D. La Touche.)

Scale, 1 inch = 16 miles.

① *Kyaukkyan fault*
② *Chaung Magyi fault*
③ *Sedaw fault*
④ *Zebingyi fault*
⑤ *Tonbo fault*


BURMA
EARTHQUAKE
of May 23rd. 1912.
SHOWING THE APPROXIMATE POSITIONS
OF THE
ISOSEISTS AND AXIAL EPICENTRE
by J. Coggin Brown.
Scale, 1 inch = 128 miles.
92°
96°
100°
104°
28°
24°
20°
16°
12°
2-3
4-5
6-7
8
9
YUNNAN
GULF OF SIAM
MANDALAY
RANGOON
BANGKOK
Gulf of Martaban
ANDAMAN ISLANDS
MERGUI ARCHIPELAGO
CAMBODIA
COCHIN CHINA
Ten Degree Channel
Preparis North Channel
Preparis South Channel
Coco Channel
Mouths of the Irrawaddy

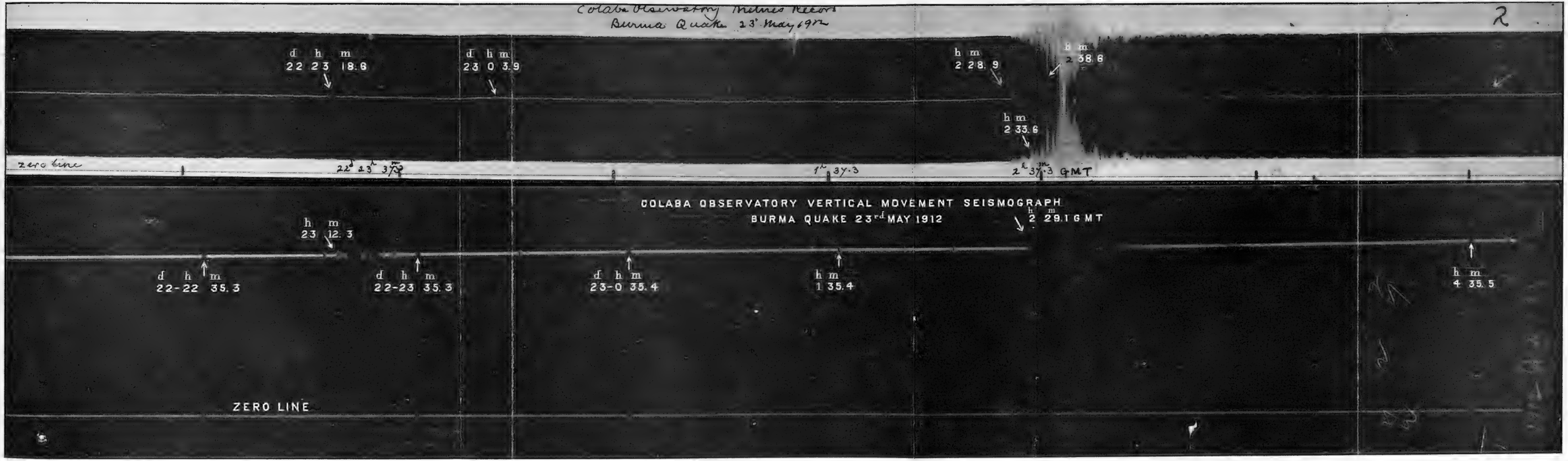
SIMLA OMORI SEISMOGRAPH

DIRECTION OF BOOM EAST AND WEST

SIMLA OMORI SEISMOGRAPH

DIRECTION OF BOOM NORTH AND SOUTH

BURMA EARTHQUAKE MAY 23rd. 1912.



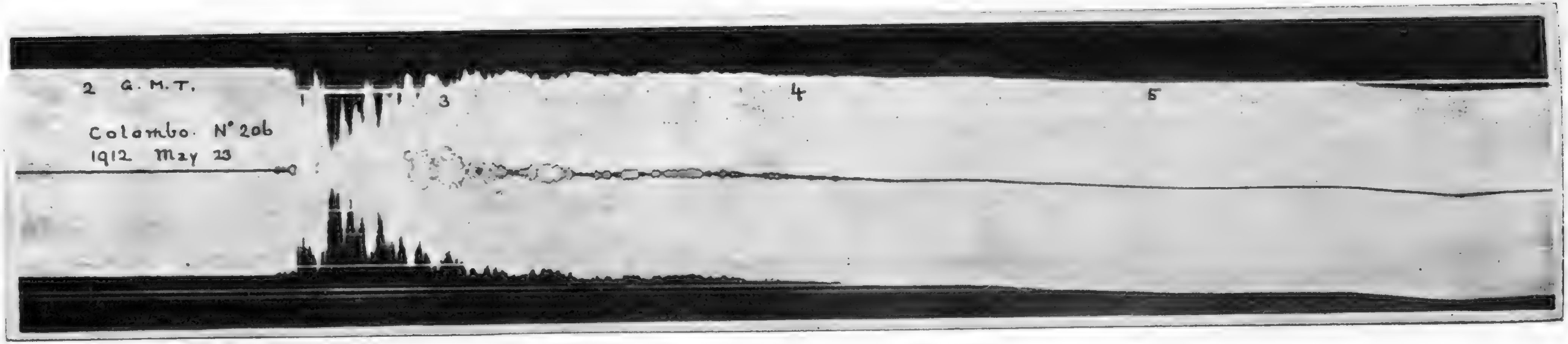
MILNE AND VERTICAL MOVEMENT SEISMOGRAPH.

Photo-Engraved & printed at the Offices of the Survey of India, Calcutta, [illegible]

BURMA EARTHQUAKE, MAY 23rd, 1912.

COLABA OBSERVATORY.

Memoirs, Vol. XLII, Pl. 10.



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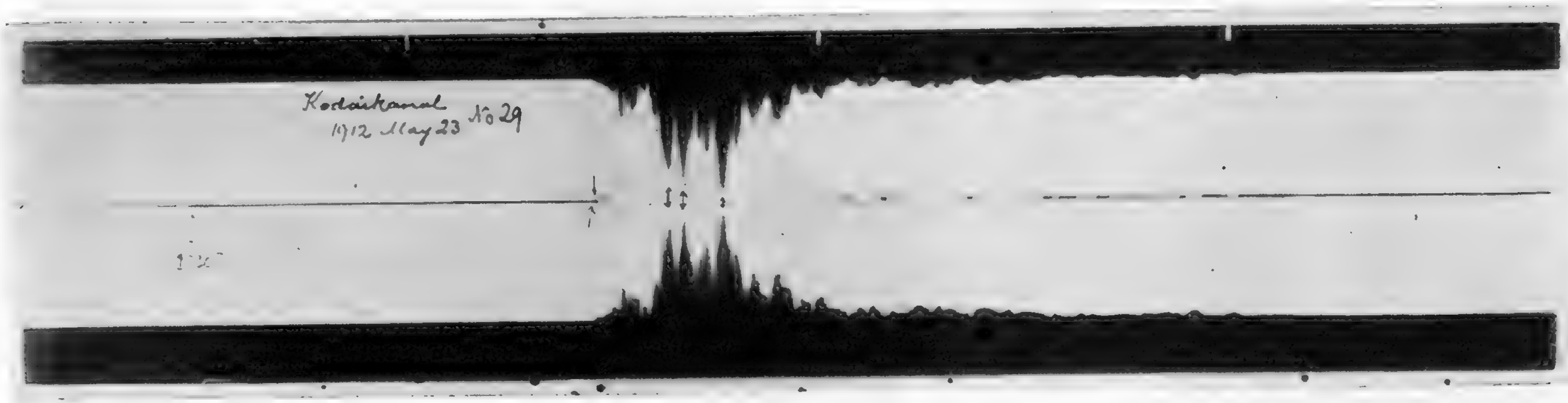

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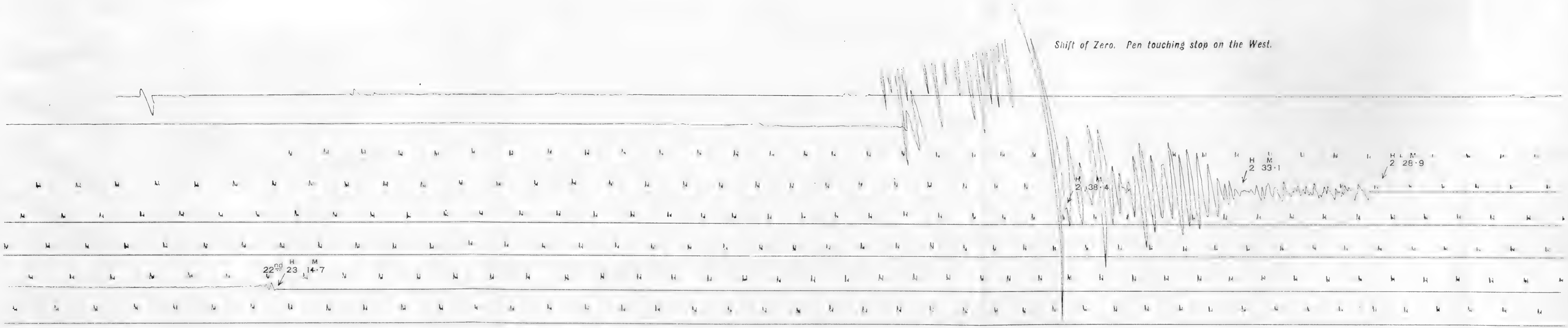
BURMA EARTHQUAKE MAY 23rd. 1912.



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THE GEOLOGICAL SURVEY OF INDIA

VOLUME XLII, PART 2.

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CHAPTER I.

INTRODUCTORY.

The annual reports of the Great Trigonometrical Survey have contained occasional reference to certain peculiarities exhibited by geodetic observation near the outer edge of the Himalayas, and to a belt of lesser density as a reasonable explanation of them. These references had attracted little attention on the geological side, for those geologists who could understand them, and were also acquainted with the results of geological examination, knew that just such a belt of rock, of less than average density, did run along the foot of the hills, and though the form of the trough, in which it lies, differs from that suggested as an explanation of the geodetic peculiarities, it was clear that the effect of the known geological structure would be similar in kind to that revealed by geodetic observation, and there was no reason to suppose that it might not also be sufficient in amount.

Matters might have remained in this state but for the publication, in 1912, of a brief paper, by Sir S. G. Burrard, on the Origin of the Himalaya Mountains.[1] The explanation offered would probably have attracted little attention, and in due course have gone to join a respectable company in the limbo of forgotten theories,

[1] *Survey of India.* Professional Paper No. 12. Calcutta, 1912.

had the paper not seemed to imply that the geodetic evidence necessitated the existence of a deep and comparatively narrow rift along the edge of the hills, filled with rock of lesser density than that on either side—with some suggestion of actual cavity—and at one place the figure of 20 miles was given for the depth of this rift.[1] Such at least was the interpretation which the paper seemed to bear, and the figure, mentioned for the depth, implied a diaclasm so far transcending in magnitude anything which has been established from observation, in the Himalayas or elsewhere, that its acceptance would have necessitated the revision of what had been regarded as well founded deductions from geological evidence. Diaclasms of three miles in depth are well established, and even five miles is not impossible, and these are the figures which had been regarded as the probable, and the extreme possible, limit of the faults along the southern boundary of the Himalayas. The assertion that the geodetic evidence pointed to, if it did not necessitate, the existence of a diaclasm of four times the extreme magnitude of which we had any indication in geological observation, naturally attracted attention, led to an examination of the grounds on which the assertion was based, and gave rise to a somewhat extensive literature, which, being mainly controversial, was mostly unprofitable.

I have no intention or desire to add to this literature; his main rift has been placed further south, and the figure of 20 miles has been explained away,[2] thereby removing the contradiction which appeared to exist between the geodetic and geological observation, yet the original statement cannot be regretted for it has drawn attention to the geodetic work of the Trigonometrical Survey and led to an examination of the light thrown by it on some interesting and doubtful points of geological structure, which it had not been possible to elucidate by geological observations alone. In the course of this examination I shall have occasion to refer to theories which have been offered in explanation of the origin of the Himalayas, but only so far as to indicate the influence which they might have on geodetic observations, and so afford a guide to the directions in which these should be examined; for the object of this investigation is not advocacy, or attack, of any

[1] *Loc. cit* p. 11. "A rift in the sub-crust south of Mussooree and 20 miles deep would explain the large deflections in the interior of the Himalayas."
[2] *Proc. Roy. Soc.*, Series A. XCI, 1915, p. 229.

particular theory, but an attempt to add to the stock of fundamental facts, on which alone a successful theory can be built.

In the sequel it will be seen that, so far as the origin of the Himalayas is concerned, the observations help us but little on the way, though they do to some extent diminish our ignorance of the processes which have been at work, but in other directions they have very considerably added to our knowledge of the underground structure of the northern part of India, by converting what were merely conjectural possibilities into well founded probabilities. The investigation has been limited to the region of the Himalayas and the alluvial plain to the south of them, though this does not cover the whole ground of possible cooperation between geodetic and geological observation. The curious band of excess of attraction which crosses the northern part of the peninsula, for instance, may be found to assist in the interpretation of the geology of the country, but the data at present available do not admit of any definite conclusion being drawn, and its discussion has, consequently, been omitted, though it is not impossible that, when observations are more numerous and complete, it may be found to help in the elucidation of the origin of the Himalayas.

The completion of this work has been retarded by the call of other claims on my time, but the delay has enabled the attainment of more complete results. I have to acknowledge with gratitude the receipt of much assistance, in the communication of material, from Sir S. G. Burrard, Surveyor-General, and Dr. H. H. Hayden, Director of the Geological Survey, also to Mr. D. B. Mair, for assistance in the mathematical part of the investigation. The actual calculations were done on a machine, in all but the simplest cases, and are sufficiently accurate for the purposes of this investigation, though they do not pretend to the refinement required in geodetic work.

The first step to be taken in this investigation is a statement of the issues which are or may be affected by the new evidence, and from these all questions of stratigraphy or correlation must be excluded, as well as all those questions of structure which do not involve the distribution of large masses of rock of materially different densities. With this necessary restriction the following seem to be the conclusions which are well enough established to necessitate their acceptance in any discussion of the observations.

(1) Firstly, there is the indubitable fact that the elevation of the Himalayas has been accompanied by the compression of the rocks of which it is composed. It is not meant that the whole of the disturbance of the Himalayan rocks has been the consequence, or the cause, of the elevation of the Himalayas; the contrary is indeed almost certain,[1] but the general distribution of the rocks, in the larger anticlines and synclines, along the general course of the range, and the fact that the prevailing strike is in the same direction, point to a connexion between the disturbance of the rocks and the elevation of the range. In the Siwalik region of the foot-hills the connexion is incontestable, for here we find that the rocks, which must have been deposited in practically horizontal beds at a time when the elevation of the Himalayas was already in progress, are now folded, disturbed, and compressed in a direction transverse to the general course of the range.

(2) There is, along the outer edge of the Himalayas, a great fault, known as the main boundary fault, which separates the northern area of the rocks of the Himalayas from the southern area occupied by the Upper Tertiary Siwalik rocks of the Sub-Himalayas. This fault, as was originally shown by Mr. Medlicott, marks very closely the original limit of formation of the Siwaliks, and the boundary separating an area of elevation and denudation, to the north, from an area of subsidence and deposition, to the south. He also showed that the Siwaliks were formed under the same conditions as the marginal deposits of the Gangetic alluvium, that the material of which they were composed was derived from the Himalayan area,—in other words, that the Himalayan range had already been marked out as an area of special uplift in early pliocene times. Along the greater part of the length of the Himalayas this fault brings the indurated older rocks of the Himalayas into direct contact with the soft sandstones and shales of the Upper Tertiary series, and throughout this region we have two groups of rocks of very markedly different densities separated by a nearly vertical plane of separation. A condition like this cannot but have a marked influence on the direction and amount of the force of gravity and, as will be seen in the sequel, a study of this effect enables us to form an approximate estimate of the vertical depth to which the contrast extends. Between the Jumna and the

[1] See *Manual of the Geology of India*, 2nd ed., p. 483; also *Records, Geol. Surv., India* XLIII, p. 140.

Sutlej rivers, older Tertiaries appear on the northern side of the main boundary fault and, beyond the Sutlej, the whole of the Tertiary system becomes involved in the mountain-forming disturbances. In this region the main boundary fault is no longer recognisable, having merged into one of a series of more or less parallel faults, of similar character, which traverse the area of Tertiary rocks in the outer Himalaya.

(3) Mr. Medlicott also showed that the main boundary fault was not the only feature of its kind, for a series of similar faults is found within the Siwalik area, which were regarded as marking successive limits between an area of uplift and erosion to the north, and of deposition to the south of the fault line. This conclusion was more fully worked out by Mr. C. S. Middlemiss [1] in the Sub-Himalayas of Kumaon and Garhwal, where he showed that not only was there a succession of faults within the Siwalik area, each of later date than the next one to the north and each in succession marking the limit of the region of Himalayan uplift, but that there was also a series of similar faults to the northwards, each in succession earlier than the one to the south and, presumably, marking the successive limits of the Himalayan area; and a similar conclusion is suggested by the geological structure of the Sikkim district.[2] From this it follows that, at any rate during the latter part of the period of elevation of the Himalayas, there has always been an abrupt limit of the region of compression and elevation, and that this boundary has progressively shifted southwards,[3] encroaching on an area of deposition and involving deposits of later date in the mountain-forming processes.

(4) The clearly defined character of the southern margin of the hills towards the plains, running with a regular sweep along the foot of the hills, and the absence of detached outliers rising out of the alluvium, irresistibly suggests that the boundary is determined by a structural feature similar to the main boundary and the faults in the Siwalik area, and though no direct measurement of the depth of the undisturbed alluvium is possible, the fact that it is identical with, and a continuation of, the Siwalik deposits

[1] *Memoirs*, Vol. XXIV, pt. 2.
[2] *Memoirs*, Vol. XI, pt. 1.
[3] This statement necessarily refers only to the position of the successive boundaries, relative to each other. There is no means of deciding whether there has, or has not, been any general movement of the Himalayas northwards or southwards, whether in latitude or as regards distance from the rocks of the peninsular area.

affords a tolerably secure indication. The total thickness of the Siwaliks, in the Kumaon and Garhwal districts, was estimated by Mr. Middlemiss at an average of about 16,500 feet [1]; Mr. Medlicott estimated the thickness of the Siwaliks north of Hardwar at 15,000 feet,[2] and the whole thickness is not exposed on this section. We may therefore take it that the depth of alluvial deposits, being the continuation of these Siwaliks, is not likely to be materially less than 15,000 to 16,000 feet at the northern limit of the plains, and we may safely say that the alluvium at the northern edge of the plains is very improbably much greater or less than about three miles in depth.

(5) At the southern edge of the alluvial plain the thickness is small, the boundary is irregular, following the contour of the much denuded surface of the older rocks of the Peninsular area, which crop out, near the boundary, in numerous isolated patches and hills, rising from the surrounding spread of alluvium. All the features, in fact, suggest a gradual encroachment of the alluvium on an old land surface of rock, and a gradual southward growth of the depression in which the Gangetic Alluvium has been deposited.

Besides these well established conclusions, there are certain others of a more conjectural character, which need confirmation, or greater amplification, than the present state of geological knowledge—or in some cases any conceivable advance in it—can afford. Of these the following seem capable of elucidation by the data to be dealt with: namely—

(1) The question of whether the elevation of the Himalayan range was caused, or merely accompanied, by its compression. The natural conclusion would be that they were related to each other as cause and effect, but in which direction cannot be regarded as proved. Were the elevation due to a simple process of tumefaction, or swelling up, of the material underlying the range, this would set up internal strains in the elevated mass and a tendency to spread, which might result in compression and folding. This hypothesis has in fact been proposed and experimentally illustrated on the small scale,[3] but it has never been tested by actual

[1] *Memoirs,* XXIV, p. 87.
[2] *Memoirs,* III, pt. 2, p. 118.
[3] E. Rayer, *Nature* XLVI, p. 224 (1892).

calculation of the relative magnitude of the stresses which would be set up, and of the resistance by which they would be opposed, nor does it seem that any such test could be satisfactorily applied, in view of the many unknown factors which would be involved. It will, however, be shown that the hypotheses, of elevation being due to compression or compression the result of elevation, each carry with them certain consequences in the underground distribution of matter, which would, in the case of the Himalayas, lead to results of recognisable magnitude.

(2) No direct measurement of the throw of the main boundary fault can be made, and of the similar faults within the Siwalik area measurement has only been effected in one case. Mr. Middlemiss was able to show that one of the faults, in the Ramganga Valley, must have a vertical throw of 6,380 feet, or 11,880 feet measured along the hade of the fault,[1] and as this is by no means the greatest of the faults we may take it that the throw at the main boundary must be at least as great, but beyond the fact that the throw of this fault must amount to several thousands of feet no more exact estimate is possible.

(3) Closely bound up with the last, is the depth of the pre-Tertiary floor of the Siwalik deposits within the Siwalik region. It has been generally accepted that the level is higher than in the alluvial area to the south, and that the elevation of the Siwalik hills has carried with it an elevation of the floor on which they rest. This conclusion is illustrated in some of the sections drawn by Mr. Middlemiss and in the generalised and diagrammatic section given in the "Manual"[2]; it is supported by the mode of occurrence of the inliers of older rock met with in the Tertiary area beyond the Sutlej, but it is by no means an inevitable conclusion in the region east of the Sutlej, where the main boundary becomes so well-marked a feature. If we consider the cross sections of the Siwalik area, those, for instance, which were reproduced in the "Manual," we find a compression of from 30 to 100 per cent., on comparing the original with the present horizontal extent of the beds. Now a series of deposits 15,000 feet in vertical thickness, if compressed to one-third less than their original extent would be thickened by no less than 7,500 feet. Actually the mean elevation of the Siwalik area over the plains to the south is not over

[1] *Memoirs*, XXIV, p. 87.
[2] *Manual of the Geology of India*, 2nd edition, p. 473.

a couple of thousand feet, and on most sections even less, so that, even allowing for the extensive removal of material, and lowering of the hills, by denudation, there is a possibility that the floor of the Siwaliks is not materially higher, and may even be lower, than that of the alluvial deposits immediately beyond them.

(4) As has been stated, we have very good reason for supposing that the thickness of the alluvial deposits, along the southern edge of the hills, is not less than some 15,000 feet; we also know that the thickness near the southern edge is very small, but we have no direct knowledge of what takes place between these limits, whether the depth of alluvium is at its maximum near the northern edge and gradually diminishes to the southwards, or whether it increases to a maximum and then diminishes, or whether it continues with a considerable depth to near the southern edge and then thins out rapidly. In other words, we are unable to draw a cross section of the Gangetic trough [1] with any degree of certainty.

(5) Though the alluvial areas of the Gangetic and Indus drainage areas are continuous with each other, and the whole area is coloured uniformly on the geological map, it has been recognised that there is a considerable difference in the surface contour, in the arrangement of the river courses, and in the character of the deposits which form the surface of the two regions. From the Jumna eastwards to the junction with the Brahmaputra Valley is the great tract of the typical Gangetic alluvium, which bears all the characters of a plain of deposit and across which the rivers flow in courses determined by their own action and interaction. In the plains of the Punjab these features are largely absent, and the surface features suggest a much smaller thickness of alluvial deposit, a suggestion which is strengthened by the occurrence of inliers of older rocks, rising as hills in the centre of the alluvial plain.

[1] The title of a paper by Sir S. G. Burrard, published in *Proc. Roy. Soc.*, Series A, XCI, p. 221, 'On the origin of the Indo-Gangetic Trough, commonly called the Himalayan Foredeep,' is liable to convey a wrong impression. The basin filled by the Indo-Gangetic alluvium is certainly not commonly called the Himalayan Foredeep, and the use of the terms as synonymous is improper. The word "foredeep" occurs in Prof. Sollas' translation of *Das Antlitz der Erde* as the English equivalent of the word *Vortiefe*, coined by Prof. Suess with the intention of conveying not only a description, but also a definite theory of origin. The word may be used without accepting this theory, but a term, which was invented to connote a definite theory of origin, cannot be used with propriety unless that theory is intended to be implied. I shall confine myself to the use of the word trough, which is purely descriptive and implies no theory of origin, and in using it shall refer only to the deep depression in the rock surface under the alluvial plain, not to the whole of the area which is mapped as alluvium.

(6) At the other extremity of the Gangetic plain we find the alluvium extending southwards, across the gap between the Peninsula proper and the plateau of the Assam range. The rocks of these two areas are similar in character and the Assam range must be regarded as, stratigraphically, part of the same geological area as the Peninsula. There is some geological suggestion that the stretch of alluvium, through which the Ganges and Brahmaputra reach the Bay of Bengal, forms no part of the depression, or trough, of the Gangetic plain of Upper India, and that the alluvium is a comparatively shallow covering over a rock barrier connecting the Rajmahal and Garo Hills.[1]

These are the geological problems in which elucidation may be helped by geodetic observations, they do not comprise the whole of those in which assistance from this line of research may be looked for, but the necessary observations are wanting for dealing with the others, and especially with the very important one of what has taken place in the regions at either end of the Himalayan ranges, where they pass into the mountain systems of Indo-China on the one hand and of Afghan Turkestan on the other.

[1] *Manual*, 2nd ed., p. 443.

CHAPTER II.

THE NATURE AND INTERPRETATION OF THE GEODETIC EVIDENCE.

Before dealing with the observations it will be well to devote some space to a consideration of the nature of the evidence and the bearing of the observations, when converted from their original object, of measuring the dimensions and form of the earth, to that of elucidating the structure of the outer portion which is called, for convenience and brevity, its crust. Though the treatment may be regarded as elementary by a portion of those who will read these pages, it is none the less necessary for two reasons, firstly because many may be unfamiliar with the nature and the meaning of the observations, and secondly because, for those who may be familiar with this aspect of the geodetic results, it is important to have a clear understanding of the possibility, and more especially of the limitations, of their application to the completion or checking of the results of geological observation, and it is this aspect of them which will alone be dealt with.

The geodetic observations which have to be considered may be described as measures of the direction and intensity of the force of gravity, and are of two classes. One deals with the deflection of the plumb-line from the direction which it would have on the surface of an ideal earth of perfectly regular form and uniform distribution of density, the other measures the variations in the attraction of gravity. Of these the first gives the horizontal and the latter the vertical component of the resultant of all the forces which produce a departure from the attraction which would be exerted by the ideal average globe.

The position of two places on the surface of the earth, with regard to each other, may be expressed in two ways, either by a difference in longitude and latitude, or by the length and direction of the shortest line connecting them. The determination of the first of these belongs to the methods of astronomy, the latter to those of trigonometrical survey, and the one could be converted into the other with equal accuracy if we knew with absolute accuracy the dimensions of the earth; but the principal problem of geodesy is the determination of these dimensions, on which depend the calculations by which the observations with the theodolite are converted into measures of distance and direction, and into differences of latitude and longitude.

Were the earth a perfectly regular spheroid, and of uniform constitution throughout, the problem would be a simple one, and a few comparisons, of measured distances with observed differences of latitude, would suffice to determine the form and size of the spheroid. But these conditions are far from being met with in practice. The difference in the astronomical position of two stations is determined by observations of the sun and stars, and a measurement of their angular distance from the vertical, as shown by the plumb-line, or from the horizontal, as shown by a fluid surface; the latter is that actually used, but the two are identical in result for the apparent horizontal plane and the apparent vertical line are always, and necessarily, at right angles to each other. Now the exact direction of the plumb-line, at any point, is determined not only by the attraction of the earth as a whole but by the attraction of local masses, and may be affected either by variations in the density of the rocks at, or below, the surface, or by irregularities in the form of the surface near the station. A mountain range, or a mass of rock of greater than average density, to the northwards of a station would attract the plumb-bob and cause the liquid surface to be tilted in such a manner that the latitude, as determined by astronomical observation, would appear to be less than the true latitude of a station situated in the northern hemisphere, and a similar excess of attraction to the south would make the apparent latitude greater than the true. Differences in the density of unseen portions of the earth can, obviously, not be allowed for; they must be searched for and detected by the discrepancies between astronomical and geodetic measurements; but it might be thought easy to calculate, and allow for, the effect of the visible masses of mountain ranges and the visible hollows of the ocean basins, and so it would be were mountains mere excrescences formed of material added on to the surface of the spheroid, or the oceans merely hollows carved out of its surface. Such, it has been found, is not the case; mountain ranges do not attract the plummet to anything like the extent they should do, nor do ocean basins cause it to be attracted away from them, and the explanation of this phenomenon has introduced two allied, though distinct, concepts of compensation and isostasy.

The word compensation we owe to Archdeacon J. H. Pratt,[1] but the notion, though not the word, was suggested at an earlier date, by Sir G. B. Airy.[2] Though the hypotheses regarding the constitution of the earth, used by these two investigators, differed radically from each other, the essence of the explanation was the same, that under every great protuberance of the earth's surface, such as a mountain range, there was a mass of density less than the average at that depth, and that the plumb-line was not merely affected by the attraction of the visible mass of the mountain range, but also by the defect in mass in the underlying portion of the earth, which would cause an apparent repulsion of the plummet and so neutralise, or compensate, in part or in whole, the direct attraction of the mountain range.

The most complete investigation of the effect of compensation, which has been published, is that carried out by Mr. J. F. Hayford, of the United States Coast and Geodetic Survey, in 1909.[3] Mr. Hayford adopted an hypothesis similar to that of Archdeacon Pratt, and assumed that compensation took the form of a defect of density, equal in amount to the excess of mass in the range and distributed uniformly through some definite depth which would be everywhere the same. The deflections which should be expected from the relief of the country surrounding each station, up to a distance of 2,564 miles, were calculated, and compared with the observed deflections, the difference being regarded as an unexplained "residual," and it was found by a series of trials, that these residuals were lowest if the depth of the layer, through which the defect of mass was supposed to be uniformly distributed, or "depth of compensation," was 113·7 km.; with a greater or less depth the "residuals" were larger, and from this it was concluded that the depth of compensation in the United States was somewhere close to 113·7 km., or 70·67 miles.

[1] J. H. Pratt, On the Deflection of the Plumb-line in India, caused by the Attraction of the Himalaya Mountains and of the elevated regions beyond; and its modification by the Compensating effect of a Deficiency of Matter below the Mountain Mass. *Phil. Trans.*, CXLIX, 745-778 (1859).

[2] G. B. Airy, On the computation of the Effect of the Attraction of Mountain Masses as disturbing the Apparent Astronomical Latitude of Stations in Geodetic Surveys. *Phil. Trans.*, CXLV, 101-104 (1855).

[3] The Figure of the Earth and Isostasy, from measurements in the United States, Washington, 1909.

This, which he called the solution *G*, was afterwards modified [1] on the inclusion of additional observations, and the depth of compensation increased to 122 km., but as the difference is trivial, and the earlier value has been used in the investigations published by the Great Trigonometrical Survey of India, and was used by Mr. Hayford himself in his investigation of the effect of compensation on the vertical force of gravity, it may be accepted as a close approximation to average conditions. The results of calculations based on it are so little different from those which would have been obtained from a slightly different depth of uniform compensation, that no useful purpose would be served by a revision of the calculations.[2]

It must not, however, be supposed that these depths of 113·7 or 122 km. have any real meaning; all that the calculations imply is that the effect of such compensation as actually exists is not materially different from that which would have resulted from a defect of mass equal to that of the material above sea level, if this were produced by a defect of density extending uniformly through a depth of 113·7 km. and everywhere proportionate to the excess of mass represented by the surface elevation above sea level. Any other form of distribution of density which would bring about the same result would be equally in accord with observation, and this conclusion is borne out by certain calculations made by Mr. Hayford. In addition to the hypothesis of uniform compensation he considered four others, namely—

(1) A compensation uniformly distributed between the depths of 25 and 35 miles.

[1] Supplementary Investigation in 1909 of the Figure of the Earth and Isostasy. Washington, 1910.

[2] In Mr. Hayford's calculation, as in other treatments, it is assumed that compensation should be applied directly to the elevations above, or depressions below, sea level. The sea level is, however, an artificial datum for these purposes and the differences of level should, strictly, be measured from a datum representing the mean level of the solid earth, or the mean level as it would be if the oceans were supposed to be solidified and condensed to the mean density of the rock forming their floor. This datum would lie at about 3,000 ft. below sea level and its introduction would require an extensive re-calculation of tables, which ought properly to be undertaken in a discussion of the effect of compensation, which included observations at stations near the sea coast. Where, as is the case in this investigation, the distances from the shore line are measured in hundreds of miles, and where, as will appear further on, the modification introduced by considering the effect of topography beyond a distance of one hundred miles is trivial, as compared with the differences indicated by observation, we may confine attention to the difference of effect due to difference of elevation above an arbitrarily assumed datum, such as the mean sea level, the effect of the mass of the crust below this level, but above the mean level of the solid spheroid, and of its compensation, being the same in amount at all stations.

(2) A compensation similarly distributed between the depths of 27 and 37 miles.

(3) A compensation produced by a defect of density decreasing uniformly from double the average value to zero; for this the depth which gave the best results was found to be 175·4 km.

(4) A compensation such as that suggested by Prof. Chambarlin, at first increasing and then decreasing at a variable rate; for this the depth which gave the best result was found to be 287·4 km.

Taking ten stations as typical of the different regions of the United States, and comparing the residuals with those resulting from the solution G, the mean differences were found to be ·25, ·22, ·19, ·09 seconds of arc, for the four hypotheses respectively, and the maximum differences were 1·13, 1·04, ·80, ·38 respectively. As the mean of the residuals resulting from the solution G was 3·04″ and the maximum 12·35″, it is evident that there are five different hypotheses of compensation, which vary widely in the assumed distribution of the compensation, but agree in giving it a mean depth of from 30 to 35 miles, and in giving almost identical results. This shows that the supposed depth, to which compensation extends, has no real meaning, and that, although the effect of compensation, as it actually exists in the United States, is on the average very much the same as would result from a uniform defect of density extending to 113·7 or 122 km, according to whether the earlier or later solution of the problem is accepted, any other distribution of density might be equally in accord with observations provided that the position of the centre of effect was not materially different. In this way we are introduced to the concept of the *locus of the centre of compensation.*

In any given mass, forming part of a visible protuberance on the earth's surface, or of the underlying portion through which the compensation is distributed, there will be a point, so situated that, if the whole of the mass were concentrated at that point, the effect at the station of observation would be the same as that actually produced by the sum of the effects of all the separate particles of which the mass is composed. This point may be called the *centre of effect*, and in the case of the defect of density by which compensation is brought about the expression *centre of compensa-*

tion is a convenient one. This centre of compensation must be clearly understood as something entirely different from the centre of gravity of the defect of mass by which compensation is produced, the two are not coincident in position, and the divergence, which will not be great in the case of distant topography, may or may not become important in the vicinity of the station, according as the distribution of the defect of density is concentrated in a layer of small, or distributed through one of great, thickness.

The calculation of the depth of the centre of compensation does not, therefore, give any direct information regarding the nature of the compensation, but an investigation of the effect of varying the assumed depth of the centre of compensation affords a ready means of seeing in what direction we may best look for an explanation of the departure of the observed from the calculated deflection of the plumb-line.

The general principle of this investigation can easily be determined. In Fig. 1 let A represent the centre of attraction of an ele-

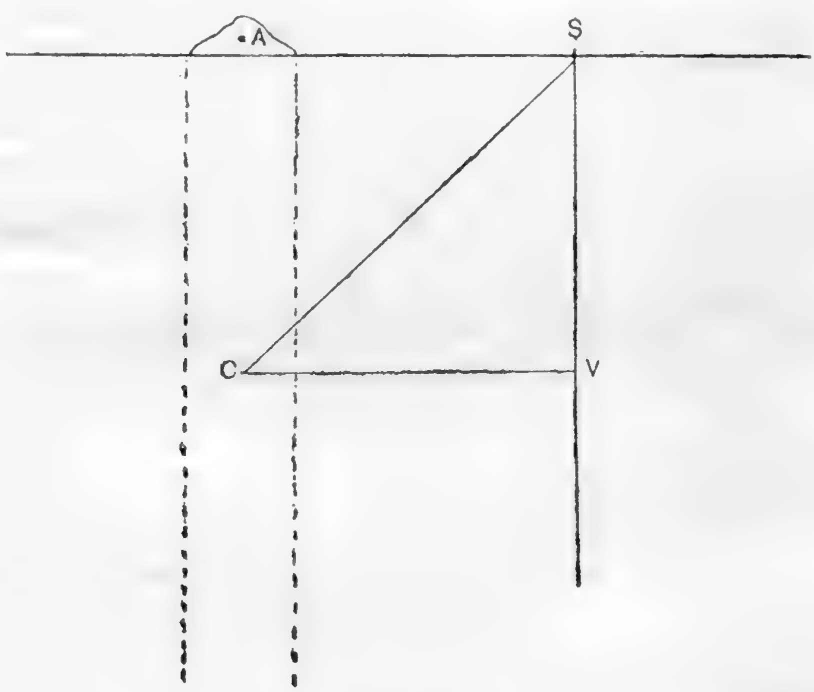

FIG. 1.

vated mass, whose compensation is distributed in an unknown manner, so that the centre of compensation lies at the point C, then, if the divergence of the line A C from the vertical is neglected, the effect of the compensation, at the station S, is represented by the formula

$$D' = \frac{m}{h^2} \sin^2 a \cos a$$

where D′ represents the deflection produced at S,

m, the mass whose effect is supposed to be concentrated at C,
h, the depth of C below the level of S, and
a, the angle of depression of C at A.

This expression has a limiting value of zero when a is 0° or 90° and attains a maximum when it has a value of about 50° 45′, or when the depth h is about 1·4 times the distance r. If this maximum effect, and the distance at which it is produced, are both expressed as 1·0, the proportion of this maximum effect which will be observed at other proportionate distances is given in Table 1.[1]

TABLE 1.—*Relation between distance and effect of the attraction of an under-ground mass.*

Distance.	Depression.	Deflection.
·1	86° 4′	·15
·2	83° 22′	·30
·3	80° 2′	·44
·4	76° 39′	·57
·5	73° 14′	·69
·6	69° 44′	·79
·7	66° 10′	·88
·8	62° 30′	·95
·9	58° 42′	·98
1·0	54° 45′	1·00
1·1	50° 35′	·98
1·2	46° 10′	·94
1·3	41° 23′	·85
1·4	35° 7′	·70
1·5	28° 52′	·53
1·6	21° 1′	·31
1·7	7° 38′	·04

[1] This table has a further utility in that it may be applied to the effect of any defect or excess of mass at any depth below the level of the station, where the distances involved do not introduce the necessity of considering the curvature of the earth's surface, and where the dimensions of the mass are such that it may be regarded as centrobaric at all the distances involved. In the case of more extended masses the effect is the sum of the effects of all the separate small masses of which it is composed, and this effect would usually diminish the ratio between the distance of maximum effect and the mean depth of the mass, but not reduce this below equality. It is unnecessary for the present purpose to treat this matter in further detail; it is sufficient that the mean depth of the centre of such a mass will lie somewhere between 1·0 and 1·4 of the distances between the positions of maximum and zero effect.

While the effect of the compensation varies as indicated in Table 1, the effect of the attraction of the visible topography varies inversely with the square of the distance, and, for any particular distance from the station of observation, there is a definite ratio between the effect of the direct attraction of the visible topography and of its compensation, and this ratio is easy to determine. Referring again to Fig. 1, the effect of the attraction of the elevated mass, if the divergence of A S from the horizontal is neglected, as it usually may be, is represented by the formula—

$$D = \frac{m}{r^2}$$

where D represents the deflection produced at S—

m, the mass of the elevated tract,

r, the distance A S.

Similarly the effect of compensation, expressed in terms of *r*, instead of *h* as in the formula on p. 16 will be—

$$D' = \frac{m}{r^2 \sec^2 a} \cos a = \frac{m}{r^2} \cos^3 a$$

The ratio of the effect of attraction to that of compensation is, therefore, $1 : \cos^3 a$ and the ratio to the net effect of attraction, and compensation, is, $1 : 1 - \cos^3 a$, which represents the compensation factor of Mr. Hayford, or the factor by which the calculated attraction must be multiplied to obtain the net effect, after allowing for compensation. This factor depends only on the angle *a* or, in other words, on the ratio between the distance from the station of observation and the depth of the centre of compensation, so long as the former of these is not large enough to necessitate the consideration of the effect of the curvature of the earth's surface.

As has already been pointed out, the centres of attraction and compensation, as the terms are here used, differ from the centres of gravity of the masses to which they refer; where the distance from the station is considerable, the two may be so nearly coincident as to become practically identical, but at lesser distances they may be largely divergent. To take the assumption, used by Archdeacon Pratt and Mr. Hayford, of a uniform defect of density, extending through a definite depth, then the centre of compensation would lie not far from one-half of that depth so long as the horizontal distance was such that the direct distance of the bottom of the column of rock from the station did not exceed that of the top by more than a small fraction of the whole. At lesser distances the effect of the portions near the top outweighs those near the bottom, because not only are they much nearer, but also their effect is more nearly in the horizontal plane, and, consequently, the centre of compensation comes nearer and nearer to the surface till, at the limit when the distance becomes zero, the depth of the centre of compensation also becomes zero.

It is obvious that if the compensation factor can be determined when the depth of the centre of compensation is known, the process can equally be reversed, and the corresponding depth of centre of compensation can be deduced from the factors. Taking the case of uniform compensation to a depth of 113·7 km., or 70·7 miles, we find that the depth of the centre of compensation at a distance of—

1·2	miles,	is	4·5	miles.
2·4	,,	,,	7·0	,,
4·9	,,	,,	10·9	,,
10·0	,,	,,	16·5	,,
20·4	,,	,,	23·5	,,
41·5	,,	,,	31·0	,,
84·4	,,	,,	35·5	,,

allowing for the effect of the curvature of the earth in the last two cases.[1] The value obtained for the depth of the centre of compensation at 84·4 miles is just over half the total depth through which compensation is supposed to extend; at greater distances the depth is more or less than 35 miles, but in all these cases the three figures, to which the compensation factor was calculated, are insufficient to give more than approximate results.

[1] It would seem that there is some small inaccuracy in the factors calculated by Mr. Hayford, so far as the neighbourhood of the station is concerned. This is shown by the fact that the factors, given on page 150 of his memoir, for a compensation confined to a layer between 25 and 35 miles from the surface, which are derived from those for uniform compensation from the surface to a depth of 113·7 km., give depths of less than 25 miles for distances of less than about 7 miles from the station; at greater distances the depth rapidly sinks to between 29 and 30 miles. As the depth of the centre of compensation could not, in any case, be less than 25 miles, there is evidently some mistake here, which may have partly arisen from working with too few decimals, but is more probably attributable to the fact that the supposed exact formula, from which the factors are derived, is itself merely an approximation, which fails when the depth of the column of rock is more than about three times the horizontal distance. The discrepancy may be left out of account, as it is confined to near-by distances, where the effect of compensation is in any case trivial.

These figures apply equally to any depth of compensation, so long as the proportion between that depth and the distance is preserved, and for distances equal to or greater than the assumed depth of uniform compensation the centre of compensation lies very close to the centre of gravity of the column of rock, but at lesser distances approaches nearer the surface. Here, then, we have a useful guide to the investigation of observations; instead of dealing with hypotheses of compensation, and the cumbrous calculations which their investigation involves, we may first of all see what position of the centre of compensation accords best with observation, and then consider the hypotheses which are in accordance with this.

In carrying out this comparison it will be convenient to retain Mr. Hayford's system, and dimensions, of compartments, with the modification that the horizontal distance, with which we are now concerned, will not be the outer, but the mean effective, radius of the compartment, which lies at ·455 of the distance between the inner and outer boundaries, this being the distance from the station to the centre of effect of a difference of density distributed uniformly over the area of a compartment. If we assume a depth of the centre of effect equal to the radius of any zone then the ratio of depth to distance will be the same for each successive zone within or without that from which a start is made, and the angle of depression and compensation factor will be as given in Table 2, from which it may be seen that, for any given distance from the

TABLE 2.—*Compensation factors for various ratios of distance from station* (r) *to depth of centre of compensation* (h).

Ratio $\frac{r}{h}$	Angle a.	cos ^3a.	Factor.
·2419	76° 24·1′	·013	·987
·3449	70° 58·2′	·035	·965
·4918	63° 48·7′	·086	·914
·7013	54° 57·5′	·190	·810
1·000	45° 0·0′	·353	·647
1·426	35° 2·4′	·549	·451
2·033	26° 11·5′	·723	·277
2·899	19° 1·9′	·845	·155
4·134	13° 35·9′	·918	·082
5·895	9° 37·7′	·958	·042
8·406	6° 47·0′	·979	·021
11·99	4° 46·0′	·990	·010

station, an increase in the depth of compensation is accompanied by a decrease in its effect, or in other words an increase in the net effect of the attraction of the visible mass and of its compensation.

From the general considerations which have been set forth we may conclude that the existence of a residual, or a divergence between a computed and an observed deflection of the plumb-line at any station may be explained in one or other of three different ways, or by a combination of more than one of them. It may indicate

(1) that the compensation of the visible topography is not exact, but either in excess or defect;
(2) that the compensation is exact, but lies at a greater or less depth than that assumed in the calculation;
(3) that there is an excess of density, either in the surface rock or at some depth from the surface, which has not been allowed for in the calculation.

One or other of these conclusions is indicated, and it is only by the comparison of a number of separate observations in the same region that a decision can be reached as to which is the most probable explanation of the observed deflections.

Before leaving this subject it will be necessary to devote a few words to the nature of the evidence available. In practice the deflection of the plumb-line from the vertical can only be determined in the two directions of the meridian and the prime vertical; the latter is more difficult than the former and more liable to small errors, the observations moreover are too few in number, in the region under consideration, to be made use of, but this is a matter of small importance, seeing that the general trend of the Himalayas, and of the Gangetic trough, approaches more nearly to an east and west, than to a north and south, direction; consequently, the effect on the plumb-line is much greater in a north and south than in an east and west direction. Only incidental reference will, therefore, be made to the few available determinations of the deflections in the prime vertical, and attention concentrated on the more numerous and important determinations of the deflection in the meridian; and in getting at the meaning of them it is important to remember that the published figures represent differences, not actual deflections. There is no known method of determining the departure of the plumb-line from the vertical at any one station, all that can be measured is the difference of the deflections at one station as compared with another. A station is therefore selected as the station of origin, in India it is Kalianpur, and the figures published represent the difference in deflection between the direction of the plumb-line at that station and the other station of observation. Further it must be noted that the calculation of the deflections necessitates the use of certain assumed figures as representing the mean dimensions of the earth, dimensions which are known with approximate, but not absolute, accuracy. In the publications of the Great Trigonometrical Survey the published deflections of the plumb-line are based on an assumed zero deflection of the plumb-line at Kalianpur, and the dimensions of the Everest spheroid, which has an equatorial diameter of 20,922,932 ft. and a flattening of 1/300·8. It seems certain that this is not the closest approximation possible to the true dimensions of the earth, and in the more recent publications of the Survey of India the Bessel-Clarke spheroid [1] has been adopted, which has an equatorial diameter 3,270 ft. greater than the Everest and a polar flattening of 1/299·15; but the deflections are still calculated and published in terms of the Everest spheroid, and will be used without any attempt to adjust them to more modern dimensions of the earth. Any such adjustment would only give an illusory appearance of accuracy, for the difference in the absolute deflection at Lambatach, the station most distant from the reference station of Kalianpur, does not amount to more than 3″ of arc, and the differences, with which we are concerned, would not be altered by more than a single second in any of the groups of stations considered, an amount which is trivial in comparison with the differences actually observed.

A more important correction, which will be applied, depends on the probable existence of a southerly deflection at the reference station of Kalianpur, where no deflection is assumed in the published figures. Of the reality of this southerly deflection there seems no possibility of doubt, but the amount is open to uncertainty. In 1905 Sir S. G. Burrard adopted a value of +6″, in 1912 a value of +4″ is used in Major Crosthwait's investigation and, being the latest authoritative estimate, it has been used and a correction of +4″ has been applied to the published figures. It

[1] See *Phil. Trans.*, Series A, CCV, 1905, p. 298

is obvious that this constant correction does not affect the differences between the deflections, but it is convenient as bringing the deflections into closer approximation to their true values.

We may now pass on to the consideration of the variations in the attraction in a vertical direction. These are measured by comparing the period of a free-swinging pendulum at different stations; in practice many precautions have to be taken and corrections applied for temperature, pressure of the atmosphere, flexure of the support, etc., with which we are not here concerned, and in the result it is now possible to determine the vertical force of gravity at any particular station with a very high degree of accuracy. This result has been expressed in several different forms; at one time it was commonly expressed by the number of swings in twenty-four hours of a pendulum which would beat exact seconds at sea level on the equator, or it might be expressed by the acceleration which would be produced in a free falling body; more recently, however, it has become customary to express it in dynes per gramme of mass, the dyne being the unit of force which, acting on a mass of one gramme for one second, would produce a velocity of one centimetre per second. Numerically, the value in dynes is identical with the acceleration, expressed in centimetres and seconds, but it is sometimes more convenient to express the result as a force than as an acceleration.

Having obtained a local measure of the force of gravity, it is compared with the theoretical value of gravity at the station, and the difference expressed as an "anomaly" which is positive if the former is in excess, and negative if it is in defect, of the theoretical value; but before this can be done it is necessary to reduce the observed value to what it should be at sea level immediately under the station, and to reduce the accepted equatorial value of gravitation to the latitude of the station.

To take the latter question first, the mean value of the force of gravitation at the equator is not far from 978·03 dynes with an error of not more than ·01; the formula for the reduction from this to the latitude of the station depends on the form of the earth, which is not yet known with exactitude, but any error introduced by this cause would not vary largely within the limits of the groups of observations to be considered. The position is very similar to that of the deflections of the plumb-line, in neither case can the absolute values be determined with certainty, but the differences, between the observed values in the stations taken into consideration, may be depended on, and in both cases we have departures from the values reckoned, without consideration for the disturbances produced by local departures from a condition of uniformity, which are far in excess of any possible error in the factors used in the calculations.

The reduction of the observed value of the force of gravity to sea level is a matter introducing much larger possibilities of variation than the determination of the theoretical value at sea level. The corrections to be applied are as follows:—

(1) for the height of the station above sea level;

(2) for the attraction of the masses above sea level, but below the level of the station;

(3) for the attraction of masses which rise above the level of the station;

(4) for the effect of compensation of the elevated masses.

The first of these depends on the fact that the force of gravity decreases as the surface of the earth is left below. This correction can be applied with great exactitude and there is no doubt of the reality of its effect; it is sometimes referred to as the "free air" correction, as, in applying it, the whole of the underlying ground is supposed to be removed and the station left standing free in the air. Here it will be referred to as the correction for height.

The second correction is sometimes also called the Bouguer correction, a term which refers to the particular method of calculation adopted, by which the station is supposed to be situated on the surface of a level plateau. The combined effect of this and the correction for the actual irregularity of the surface, often referred to as the orographical correction, will here be referred to as the correction for visible mass, that is for the attraction of all the mass which lies above sea level at and around the station.

The fourth correction is a modern development, first applied by Messrs. Hayford and Bowie,[1] and a consideration of its effect is necessary for the understanding of the interpretation of the anomalies discussed further on.

[1] The Effect of Topography and Isostatic Compensation upon the Intensity of Gravity, by J. F. Hayford & W. Bowie. Washington, 1912.

Referring back to Fig. 1 the attraction of a mass, centred at C, is exerted at the station S in the direction C S. We have already considered the variation in the horizontal component, and in Table I the proportionate variation in this, with a varying distance of the station, is given; it is obvious that these same factors apply equally to the vertical component of the force, if the angle is measured from the vertical, instead of the horizontal, plane. The effect of any small mass, situated on the vertical drawn through C, will reach a maximum value when the angle joining it to the station S makes an angle of about 54° 45′ with the vertical, and at any greater or less depth the effect will diminish in the proportions given in Table 1.

So far we have only considered the case of a single small mass represented by C, but it is obvious that every other similar mass situated at the same depth and distance from S will have the same effect; and if, instead of the line C S, we consider, as is shown in fig. 2, the space included between the surfaces of two cones and

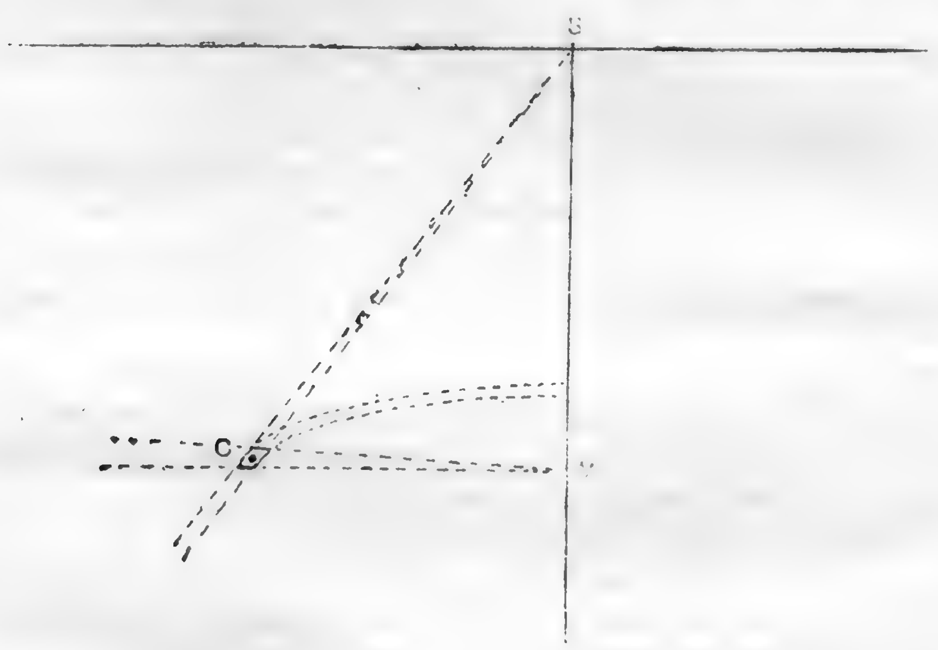

Fig. 2

two vertical radial plane surfaces, both diverging from each other at a very small angle, and instead of the horizontal line C V we take a very thin layer included between two horizontal planes represented by C V, we get a small volume, which may be treated as an ultimate particle, and of which the mass is directly proportional to the square of distance S C or S V. The effect at S being inversely proportionate to the square of the same distance, it results that the effect of the small portion of the thin horizontal slab is the same, whatever the depth of C may be below the level of the station S and, as the same is true of every portion of the circles included between the lines C S and S V at any depth, we reach the conclusion that the attraction, of any layer of rock included between two horizontal planes and a conical surface whose apex is at the station, will be proportionate to the thickness of the layer and the density of the rock, and independent of the depth of the layer below the station.

The formula by which this principle is translated into numerical calculation is

$$A = kd\,2\pi\,\delta\,(1 - \cos\alpha)$$

where

A is the attraction, expressed in dynes per gramme, at S,
k, the gravitation constant,
d, the thickness of the layer, measured in centimetres,
δ, the density of the rock,
α, the angle from the vertical of the outer surface of the cone;

and from this formula we may calculate, taking the value of k as about 6673×10^{-11}, that the pull exerted by 100 feet thickness of average rock, included in a cone whose outer surface makes an angle with the vertical of about

84°	is	·003 dyne,
66°	is	·002 ,, ,
45°	is	·001 ,, .

It may be pointed out that the volume or mass of these three cones is in the proportion of 1 : 5 : 90, while their effect is only in the proportion 1 : 2 : 3, and if the angle of the cone is taken at 90, that is, if the layer of rock is of infinite extent, and so of infinite mass, the effect is only increased to ·0033 dyne, so small is the influence of the more distant masses as compared with those nearly underneath the station.[1] Moreover these figures are not

[1] It must again be noted that these statements and figures would only be true of a plane earth of infinite extent, and require modification when applied to a spherical or spheroidal earth, but within the distances and depths with which this investigation is concerned the effect of the curvature of the earth's surface is inappreciable.

only true of a simple layer of rock 100 feet in thickness, but are equally true of a proportionate excess or defect of density, distributed through a greater thickness in such a manner that the mass of any vertical column of rock, which wholly includes the cone, is in excess or defect by the equivalent of 100 feet of rock of average density.

This formula, and the figures derived from it, will be useful in comparing the effect which should be expected on different hypotheses of the nature and distribution of compensation. The way in which these differences arise will be most readily explained by a reference to fig. 3, which represents the case of a station S on the surface of an elevated plateau; it will be affected by the

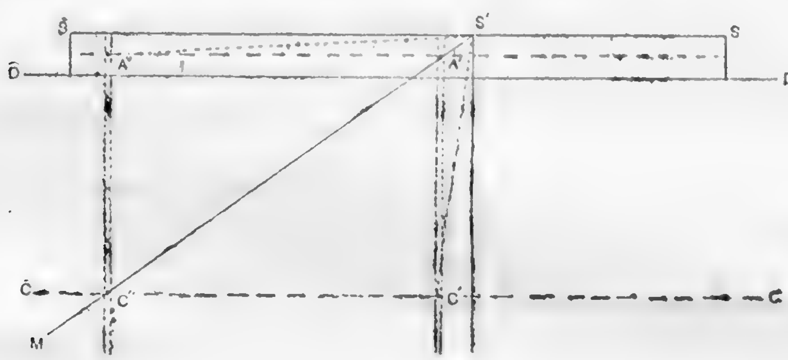

Fig. 3.

downward pull of the mass of rock lying between the level of S and sea level, represented by D D, it will also be affected by a defect of downward pull, due to the diminution of density by which the weight of the plateau above D D is compensated. To simplify the consideration of the relative effects of these two forces we will suppose that the variations of density are so distributed that the centre of effect of any column of small area lies at the depth A A in the case of the plateau, and of C C in the case of the compensation; and that the line S M represents that along which any given mass will produce a greater effect at S than if it were situated at a greater or less depth on the same vertical line.

Now take the case of a small column so situated that the centre of attraction of the plateau at A′ is on the line S M, and the centre of compensation vertically below it at C′; here the effect of the attraction of the plateau is obviously larger in amount than that of the compensation, and the net effect will be a downward pull at S, which will increase the amount of the local measure of gravitation at that station. Conversely in the small column of rock situated so that the centre of compensation lies at C″, on the line S M, and of the attraction of the plateau at A″, the effect of the compensation is obviously in excess of the attraction of the mass above sea level, and the net effect at S will be a diminution of the local measure of gravity. Somewhere between these two points must come a limiting distance, where the effect of the attraction of the mass above sea level is exactly balanced by that of the compensation and the net effect at S reduced to zero; at lesser distances the effect of the elevated mass will exceed that of the compensation, and the net effect will be an increase in the local measure of gravity, but to a less extent than if there were no compensation, and at greater distances the effect will be reversed, and the net effect be a diminution of the force of gravity at S.

The distance from the station at which this reversal takes place depends in part on the height of the station and the surrounding topography above sea level, and partly on the depth and nature of the compensation. For the particular hypothesis of compensation used by Messrs. Hayford and Bowie the distance is about five or six miles ordinarily, but in the case of stations of great altitude may reach nearly twelve miles. An idea of the nature and amount of the effect of the direct attraction of an elevated mass and its compensation may be got from Table 3 (on next page), which shows the effect of the attraction of a circular plateau, of varying heights and dimensions, at a point in the centre of its upper surface, the values being expressed in dynes and calculated from the Hayford and Bowie tables.

Here we see that the effect of the mass of a circular plateau of 1,000 feet in height, contained within a radius of 1·4 miles, amounts to ·031 dynes, and that no appreciable increase results from an enlargement of the plateau to a radius of 100 miles, the more distant masses being so nearly on a level with the station that the vertical component of their attraction is negligible. If, however, we take the effect of compensation into consideration a reduction in the net effect becomes apparent beyond five miles from the station. For greater heights there is a continuous increase in the effect of the visible mass up to the limits considered in the table, but beyond a distance of 40 to 50 miles the further increase is very small, and may be ignored. The effect of the compensation on the other hand increases and the net effect, after reaching a maximum, goes on diminishing with an increase in the dimensions of the plateau.

TABLE 3.—*Attraction of a circular plateau, of varying radius and elevation, at a point centrally situated on its upper surface, due to the visible topography, and to the same, compensated in accordance with the Hayford and Bowie tables. All values positive and expressed in dynes.*

Radius in miles.	1,000 ft.		5,000 ft.		10,000 ft.		15,000 ft.	
	top.	comp.	top.	comp.	top.	comp.	top.	comp.
1·4	·031	*·031*	·118	·114	·172	·164	·196	·185
2·2	·031	*·031*	·135	·129	·215	·203	·260	·244
3·2	·031	*·031*	·146	·137	·250	·234	·321	·297
5·2	·031	*·031*	·154	*·141*	·282	·258	·383	·345
7·5	·031	·030	·159	*·141*	·301	*·266*	·422	·367
11·7	·031	·028	·163	·137	·315	·264	·452	*·373*
17·9	·031	·025	·165	·127	·325	·249	·473	·359
36·5	·031	·020	·168	·101	·335	·202	·494	·295
61·4	·031	·015	·170	·075	·338	·155	·502	·226
103·3	·031	·009	·170	·050	·341	·108	·508	·159

From the figures in Table 3, it will be seen that in the case of a plateau extending for distances measured by hundreds of miles, it may well be that the effect of compensation will completely neutralise that of the attraction of the visible mass, and the resulting attraction of gravity be the same as if the whole of the elevated mass were non-existent. We may also find in these figures an explanation of the fact that the anomalies of gravitation above sea level tend to be positive if the effect of the visible topography is ignored, and negative if it is considered, for in the first case no regard is paid to the increase in the local attraction due to the mass above sea level, and in the second a greater effect is attributed to it than it actually exerts. Further, it is obvious, from a consideration of fig. 3, that an increase in the depth of compensation would enlarge the limits within which the effect of the visible mass predominates over that of its compensation, and so increase the force of gravity at the station, while a lesser depth of compensation would have the reverse effect.

Taking all the considerations into account we may conclude that if, after allowing for the effect of the surrounding topography and its compensation, there is left a positive, or a negative, anomaly at any station, it may be due to one of three causes, and may indicate

(1) that the compensation of the elevated masses is incomplete, or in excess;

(2) that the real compensation is such that its centre of effect lies at a greater, or a lesser, depth than that of the compensation assumed in the calculation; or

(3) that there is a local excess, or defect, of density in the matter lying below the level of the stations, independent of the effect of the elevated masses and their compensation.

The form in which the gravity observations of the Survey of India have been published has undergone greater changes than in the case of the deflection of the plumb-line. The older calculations are based on Prof. Helmert's 1884 formula for the theoretical variation of gravity with latitude, and on values of 5·6 and 2·8 for the mean densities of the earth, as a whole, and of surface rock, respectively. All the published anomalies, making allowance for the effect of height alone or of height and visible masses, were calculated on this basis, but, with the introduction of the consideration of the effect of compensation, different values for the density of the earth and of surface rock were adopted, namely 5·576 and 2·67 respectively, and Helmert's 1901 formula replaced the earlier one of 1884. The result is that the anomalies allowing for compensation are not directly comparable with those in which it is not considered. The difference in the densities used has but a small effect, except in the case of the Himalayan stations, but the 1901 formula gives a larger value for the theoretical value of gravity and, consequently, a negative change in the value of the anomaly which amounts, in the stations dealt with, to from —·022 to —·027 dyne.

There are, fortunately, a sufficient number of stations for which the Hayford anomalies have been calculated to serve most of the objects of this investigation, and these will be made use of, so far as possible, as they not only give a closer approximation to the absolute values of the anomalies but also to the differences between them. The other values of the anomaly of gravity, which are available for all stations, are comparable with each other, though not directly comparable with the Hayford anomaly, and afford an indication of the nature, and approximately of the amount, of the difference in the anomaly at any two stations and in this way will be utilised, as far as seems practicable.

So far, attention has been confined to the fact of compensation and the effect of variation in the depth at which it takes place; it will now be necessary to devote some space to a consideration of the manner in which compensation may be brought about, and to the cognate concept of isostasy.

The word isostasy was introduced by Major C. E. Dutton,[1] and by etymology implies merely the statical condition that the mass —or, more correctly, weight— of matter under every considerable portion of the earth's surface of equal area is the same, irrespective of the elevation of that area above or below sea level. The statement is not intended to apply to every small protuberance or depression in the surface of the land or bed of the sea, but to the general level, and involves, of necessity, a lesser density of the matter under an elevated region, such as a great mountain range, than under the plains at its foot, and a greater density under the depressed floor of the ocean. This leads to the same result as the concept of compensation, but the two are not synonymous; for the elevated regions of the dry land are continually suffering a loss of weight by denudation, while the material removed is deposited on the lowlands, and especially on the bed of the sea; in this way the load on one area is diminished, that on the other is increased and isostasy is destroyed, till the strain set up by this shift of load causes an underground flow of matter from the overburdened to the lightened area and so isostasy is re-established. From this it will be seen that the two principles of isostasy and compensation are related to each other in as much as the former necessitates the latter, and further that, whereas compensation merely expresses a static fact, isostasy, in spite of its name, implies

[1] *Bull. Phil. Soc. Washington*, XI, p. 53 (1889).

a dynamic process,[1] which could only take place in a medium possessing a considerable degree of plasticity under the stresses to which it is exposed.

The various hypotheses which have been proposed, to account for the elevation of mountain ranges, excluding those which do not provide for compensation, may be divided into two categories, those which regard the elevations of the earth's surface as being supported by some form of tumefaction, and those which regard them as supported by some form of flotation. The earliest suggestion, that of Sir G. B. Airy,[2] was of the latter class; adopting the notion, still prevalent when he wrote, that the earth consisted of a comparatively thin solid crust floating on a fluid core, he showed that the crust would not be able to support the stresses set up by the weight of a great mountain range, which would break through the crust, and sink into the denser magma, till the buoyancy of this depressed portion was sufficient to support the weight of the range, and the difference in weight, between the depressed portion of the crust and the denser magma displaced by it, while supporting the range, would also produce that compensation which the observations indicated.

This hypothesis was afterwards adopted and developed by Rev. O. Fisher[3] who, taking the elevation of mountain ranges as due to compression, and consequent thickening, of the earth's crust, recognised that the additional weight thereby imposed on the mountain region would cause a depression of the crust into the underlying denser magma and give rise to a protuberance on the underside of the crust corresponding to the mountains on the upper.

Though both of these investigators based their explanation on the notion of a comparatively thin crust, floating on a fluid earth of greater density, it must be remarked that the latter condition is by no means essential, for the whole of the processes concerned would take place within the outermost 60 miles from the surface of the earth, leaving the odd 3,900 miles of the radius unaffected, so that, provided there was a fluid or even plastic layer, of greater density than the overlying crust, in that region which lies above a depth of 60 miles from the surface, all the requirements of the hypothesis would be fulfilled, and the constitution of the more

[1] Major Dutton recognised that the term was inappropriate, but the word which would have expressed his intention was preoccupied in a different sense.

[2] *Phil. Trans.*, CXLV, 101-104 (1855).

[3] *Physics of the Earth's Crust*; 1st ed. 1881; 2nd ed. 1889.

deeply seated portions would not enter into consideration. It must also be remarked that any hypothesis which regards the elevation of mountain ranges as a result of compression, seems necessarily to involve some form of isostasy by flotation, in order to account for compensation, for if the whole of the thickening took place in an upward direction the mountains would be an uncompensated excrescence of additional matter, but if the thickening took place both upwards and downwards, and the outer crust consisted of less dense matter than that underlying it, there would be a defect of attraction which, at a sufficient distance, would neutralise the attraction of the mountain mass to a greater or less degree, according to the ratio of the excess and defect of matter. For complete compensation the two would have to be equal in mass, a condition which would imply complete isostasy and a support of the mountains by flotation.

Much the same effect, and the same considerations will apply to any form of hypothesis which attributes the elevation of the surface to an intrusion of fluid matter below it. Here again, if the whole effect was the raising of the crust between the upper surface and the intrusive mass, the range would be a mere excrescence of the surface and its attraction would be unmodified by compensation, unless we could assume that the intrusion was devoid of density, which is inconceivable, or that the displacement of the upper surface was accompanied by a downward displacement of the lower surface, leading to the replacement, under the upraised tract, of denser material by lighter. Any hypothesis of this kind, therefore, falls into the same great category as the supposition that the elevation of the range is due to a thickening of the crust by compression, in that it would imply an actual transfer of matter from a region outside, resulting in an increase of the mass of the outer crust underneath the upraised tract; and on any hypothesis involving this, it seems impossible to account for the accepted fact of compensation, without admitting that the upward protuberance of the upper surface is accompanied by a downward protuberance of the under surface of the crust, the "root" of Mr. Fisher's investigation, with the consequences of a displacement of the denser material under the crust by the lighter material of the crust itself, and an isostasy and support by flotation.

An hypothesis of this kind opens up a further possibility of a considerable departure from locally complete isostasy and a distribution of the load of the range, or of the flotation power of its root, over a considerable portion of the crust on either side of the range. This effect may work in one of two ways; if the growth of the upward protuberance exceeded that of the root there would be a local defect of support, which would be taken up by a depression of the crust on either side till the requisite support was attained. In this case the compensation of the range would be in defect, or in other words the mass of the range would be in excess of the defect of mass below it, while the tract on either side would be over compensated, so that the deep-seated defect of mass would exceed that of the visible elevation. This is a variation from a condition of the compensation of the range being complete, in the portion of the crust underlying it, which was actually investigated by Mr. Fisher; but it is also conceivable that the reverse might take place, and the development of the root be in excess of that of the range. In this case the surplus buoyancy would be taken up by a raising of the crust not only under the range but on either side of it, and the range would be over compensated while the tract on either side would show an excess of load over compensation.

This modification of the hypothesis of support by flotation has not, so far as I know, been investigated as yet, but its possibility cannot be excluded, and, if supported by the geodetic observations, is in some ways an attractive one. It would give a ready explanation of some of the features in the geological history of the Himalayas, such as the simple upward lift, of which there is evidence in the Deosai, north of Kashmir, in the plains of Hundes and elsewhere; the peculiarities and origin of the great boundary fault would find an easy explanation, as also the tilting of the surface of the gravel slope along the foot of the Hills, which is noticeable in many parts, and the fact that the range seems still to be rising.

An alternative group of hypotheses involves no addition to the material under the elevated tract, but regards the elevations of the visible surface as due to an actual swelling up of the matter under them, or, what comes to the same, a greater condensation under the more low-lying tracts of the surface. An hypothesis of this sort may be described as attributing the differences in level of different tracts of the earth's surface to some form of tumefaction, and the effect has usually been attributed to differences of temperature. This explanation has the defect of being apparently insufficient, quantitatively, to account for the facts, and even if it might suffice for the original formation of an elevated tract, with the accompaniments of compensation and a condition of isostasy, it would not provide for the maintenance, or re-establishment of the latter after disturbance by the removal of material by denudation from the higher and its deposition on the lower levels. Recently an hypothesis of tumefaction has been proposed by Dr. L. L. Fermor,[1] which appears to be more competent to account for the facts met with in nature; starting with the fact that igneous rocks of the same chemical composition may present themselves in different forms of mineral constitution, and that these forms vary in specific gravity, he concludes that this variation is the result of the conditions of temperature and pressure under which the different forms of rock consolidated, and distinguishes between the plutonic and the infra-plutonic forms of rock, which may originate from the same magma according to the pressure under which it cooled down to crystallisation. From this concept the consequence follows that in appropriate conditions of temperature and pressure, there might be a passage from one mode of mineral aggregate to another, of different density, accompanied by a corresponding change in volume. As the difference in density of the extreme forms of mineral aggregate may amount to as much as 20 per cent., it seems that we might find in an action of this nature a sufficient explanation for the elevation of even so lofty a range as the Himalayas and, in the opposite direction, for even the greatest depths of the sea, without having to invoke either too great a difference in density, or too large a bulk of material, to fall within limits which are justified by other observations. Dr. Fermor's hypothesis would also account for the maintenance of a mountain tract against the action of denudation, for the change in the deeper layers of the crust might easily be a progressive one, and to some extent dependent on the decrease in load.

We are not, however, here concerned with a discussion of hypotheses of mountain formation, but with the effect which an hypothesis of origin by tumefaction would have on the question of compensation. This, it will easily be seen, is provided for by the hypothesis, for the protuberance of the surface is the manifestation of a corresponding decrease in density below, and in this way compensation is provided for. It is also obvious that the denudation of the upraised tract and the deposition of the material removed

[1] *Geol. Mag.* Decade VI, Vol. I, pp. 65-67 (1914); *cf.* also *Rec. Geol. Surv. Ind.*, Vol. XLIII, pp. 41-47 (1913) and XLII, pp. 133-207 (1912).

by denudation, on lower lying tracts may lead to departures from a condition of complete isostasy, but these will necessarily be in the direction of an excess of compensation in the hills and a defect in the plains; it is not conceivable that any hypothesis belonging to this class can account for the hills being under compensated or in other words showing an excess of load. In this way, then, we have a test which will distinguish between the two groups of hypotheses; so long as the geodetic observations indicate that the compensation of the hills is complete, or that the compensation is in excess of the visible mass of the range, we are free to choose between the hypotheses, but if they indicate an unmistakeable excess of mass in the hills, or a defect under the plains, after allowance has been made for compensation, the whole of one group is excluded. We are then restricted to the other, and can only choose between those hypotheses which involve an addition to the mass of the crust underlying the hills, whether this is brought about by the compression of the crust or by an underground migration of material from outside the limits of the range.

CHAPTER III.

THE IMAGINARY RANGE AND TROUGH.

In applying the general principles, outlined in the preceding chapter, and endeavouring to find the real meaning of the irregularities noticed in the geodetic data, two courses are open. The first is to take the whole of the stations, or a selected series of them, and calculate what the deflections should be at each, according to different forms of compensation, and then see which assumption gives the smallest average departure from observed results, or, more accurately, the least value for the sum of the squares of the differences between the observed and the calculated deflections. This is the method of geodesy, and is the only one admissible where minute numerical accuracy is essential, but it has the drawbacks of being extremely laborious, and of liability to degenerating into mere juggling with figures, unless great care is taken to keep in mind the exact significance of the calculations being gone through. Moreover, it is a method more suited to the final calculations of an investigation than to the preliminary stages, which may show that the more refined method would be no more than a vain attempt at a greater degree of precision than the nature of the data permits.

For these reasons it is necessary to discover simpler means of dealing with the problem, and this is to be found in ignoring the complicated contour of the actual Himalayas, and substituting for them an *Imaginary Range* which shall not differ too largely from the actual range, while simplifying the calculations necessary for estimating the consequences of various hypotheses. It will then be an easy matter to compare these results with those of observation, and so determine which of the hypotheses must be rejected, and which, if any, can be profitably pursued in greater detail.

It is not difficult to devise such an Imaginary Range as will render calculation easy, and at the same time be in agreement with the actual average contour of the Himalayas, that is with their average or generalised form, apart from the irregularities due to the erosion of the river valleys. Broadly speaking, the Himalayas proper, excluding for the present the foot-hills of the Siwalik area, rise abruptly on their southern margin to a height of about 5,000 to 6,000 feet above the level of the sea; in the interior of the range is the great plateau of Tibet, which, presenting very considerable irregularities of contour, may, in view of the distance separating it from the stations of observation with which we will be concerned, be regarded as a plain of about 15,000 feet of elevation above the sea level.[1] Along the southern edge of this plateau runs the great snowy range, including the highest peaks, and south of the snowy range comes the region of the lower Himalayas, where the summits do not rise to more than ten or twelve thousand feet above sea level. Though the distinction between these two regions, of the snowy range and the Lower Himalayas, is fairly well defined and somewhat abrupt, the average level of the ground shows a less abrupt change and in the Lower Himalayas themselves there is a gradual decrease in general altitude to about 5,000 feet at the southern margin of the hills, where the ground drops abruptly to the foot-hills, or Sub-Himalayas, of the Siwalik region. These may conveniently be represented in that portion of the range which will come into consideration, by a plateau of twenty miles in width, and fifteen hundred feet in elevation above the plains to the south. The generalised cross-section of the elevated mass of the Himalayas may therefore be represented as a plateau of 15,000 feet in elevation, bordered by an inclined plane of 100 miles in width, sloping from 15,000 to 5,000 feet of elevation, and a plateau of 1,500 feet in height by 20 miles in width. For purposes of calculation, it will be simpler to substitute for this inclined plane a series of steps each ten miles broad and 1,000 feet lower than the next step to the north. The Imaginary Range would then have a cross-section like that shown in fig. 4 (page 38), where two actual cross-sections of the Himalayan Range are also given, for comparison.

In the calculations regarding this Imaginary Range, it will be assumed to have an east to west direction, with the elevated plateau on the north and the plains on the south. This is not only in general agreement with the Himalayas, but will allow of deflections towards the range being expressed as northerly deflections, in accordance with the usual convention, by the minus sign, and

[1] I have followed previous writers in accepting 15,000 ft. as the mean height of the central plateau; actually the mean height would be more correctly 16,000 ft. or a little more. As the elevation of the land south of the Himalayas is ignored in the calculations, and only the height of the hills above the sea considered, the difference is partly eliminated, and in any case would have but a very small effect at the stations at which observations have been made.

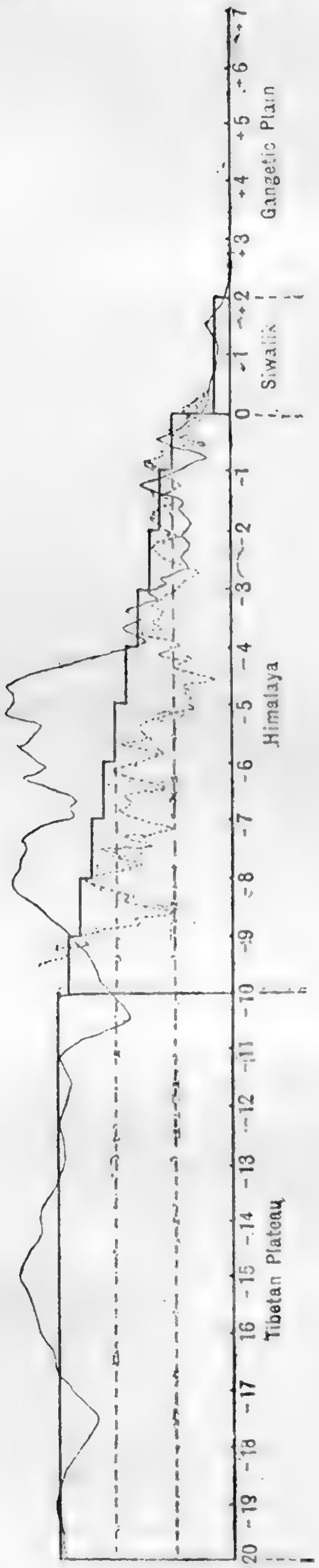

FIG. 4.—Cross section of the Imaginary Range; two actual cross sections of the Himalayas are represented, on the same scale, for comparison. Below is indicated the numbering of the stations, as used in the tabular statements.

deflections away from the range as southerly, by the plus sign. A series of supposed stations, at intervals of ten miles apart, can conveniently be distinguished in the same manner, the station at the edge of the hills, which is here regarded as coincident with the main boundary fault, being 0, those to the north being successively −1, −2, and so on, and to the south, in a similar manner as +1, +2, &c. The geodetic effect which should be looked for having been calculated for each of these stations, the results were plotted on squared paper and a curve drawn through the points, which will not be very widely different from the smoothed curve calculated for a set of stations similarly situated on the actual Himalayas.

Having decided on the cross-section of the Imaginary Range, it is necessary to decide on how much of it is to be considered in each calculation. The smaller the distance from the station which enters into the calculation, the simpler this will be, and there are three considerations which put a limit to the distance which can profitably be considered. The first of these is the fact that the attraction of any given mass of rock decreases with the square of the distance, so that its effect becomes negligible after a certain distance is exceeded. The second is the fact that the methods of geodetic observation can only give a differential, not an absolute, result. In practice some one station is taken as a station of reference, and the observations at other stations are expressed as differences from that station. Now the nearer two stations are to each other, the smaller will be the proportionate difference in distance of any point remote from both, and, consequently, the smaller the difference in the effect of the attraction at each of the two stations; and so, for any pair of stations there is a certain distance beyond which all masses affect each in so nearly equal degree that their effect may be neglected, so far as the consideration of the difference in deflection at the two stations is concerned. For a distance of 10 miles between the stations this limit would be about 50 miles, for a distance of 25 miles between the stations the limit would be about 100 miles, and for a distance of 100 miles the differential effect of topography more than 400 miles away would be trifling, even if the effect of compensation is ignored. The third consideration, limiting the distance from the station which need enter into calculation, is the fact that when the effect of compensation is considered, the effect of distant topography is almost or completely neutralised by its compensation.

In my earlier investigation of the effect of the Gangetic Alluvium on the Plumb-line,[1] only those masses lying within 50 miles of each station were considered, but in this more extended investigation the limit has had to be enlarged and in each case a strip running transverse to the range and extending 100 miles on either side of the station, and so much of this strip as lies within 100 miles of it, has been taken into consideration. In other words each station successively has been conceived as lying in the centre of a 200-mile square, and everything outside this limit has been put out of consideration. It will be shown, further on, that the effect of this limitation, of the area considered, is so small, in proportion to the effect produced by the area actually considered, that it may be left out of consideration for the purpose of this investigation.

We are now ready to take up the effect of different hypotheses of compensation as applied to the Imaginary Range and, as a starting point, the tabular statement No. 4 (page 41) gives the deflections which would be produced by the Range proper, excluding the effect of the Siwalik Hills, at a series of stations 10 miles apart, the masses within a square of 200 miles a side being alone considered, and as they would result (1) from the uncompensated effect of the visible mass and (2) allowing for the effect of compensation according to Mr. Hayford's factors for uniform compensation to 113·7 km.

Before proceeding further it will be useful to consider what modification in these figures would result from including a larger area in the calculations and, as an extreme case far exceeding anything to be met with in nature, I have supposed the stations to be situated in the centre of a square of 2,400 miles on the side, and the plateau, slope, and plain of the Imaginary Range, to be extended over the whole of the area thus taken into consideration. In these circumstances the uncompensated deflection at the station 0, on the edge of the hills, would be increased by 78″; at station 10, or at a distance of 100 miles from the edge of the hills, in either direction, the deflection would be increased by 69″; the difference would, therefore, be increased by 9″. If, however, the effect of the Hayford compensation be taken into account, the increased deflections would be reduced to just under 3″ at the edge of the hills and just over 2″ at 100 miles away, and the difference would be but

[1] *Proc. Roy. Soc.*, Series A, XC, pp. 32-41 (1914).

TABLE 4.—*Deflections produced by the Imaginary Range due to the attraction of the visible masses; (I) uncompensated and (II) compensated by Hayford factors for depth 113·7 km.*

STATION No.	I Uncompensated.	II Compensated.
— 20	0	0
— 19	0	0
— 18	1	0
— 17	1	0
— 16	2	0
— 15	3	1
— 14	5	1
— 13	7	2
— 12	11	3
— 11	15	6
— 10	23	11
— 9	28	13
— 8	32	15
— 7	35	16
— 6	38	17
— 5	40	18
— 4	42	19
— 3	43	20
— 2	45	21
— 1	48	24
0	76	53
+ 1	34	15
+ 2	23	9
+ 3	17	5
+ 4	12	3
+ 5	9	2
+ 6	6	1
+ 7	4	0
+ 8	2	0
+ 9	1	0
+ 10	0	0

0·7″. It may be said that no reasonably admissible hypothesis of compensation could increase this difference by more than about 1″, and so the limitation of area, adopted for the purpose of simplifying calculation, is justified, for the effect of increasing the area would be much less in nature than in the artificial circumstances assumed for this calculation.

The same conclusion is reached by a comparison of the deflections, calculated as due to the Imaginary Range, with those of the actual topography of the Himalayas, and this can readily be done, since the necessary calculations have been made, for certain stations, and published by Major H. L. Crosthwait.[1] In Table No. 5 a list of these stations is given, together with their distances from the main boundary fault, and the deflections which were calculated for the actual station, as well as those at stations similarly situated on the Imaginary Range, allowance being made for the departure of the actual range from a due east and west direction. In each case the values are given (I) for the supposition that the visible masses are uncompensated and (II) for the supposition that the compensation is in accordance with Mr. Hayford's tables for uniform compensation to a depth of 113·7 km. Finally there is given the difference between the value for the Imaginary Range, and for the actual topography on each supposition, or the amount of deflection, northerly or southerly, which the latter gives as compared with the former.

TABLE 5.—*Comparison of deflections due to the actual topography, with those due to the Imaginary Range, at stations similarly situated, allowing (I) for the effect of the visible masses and (II) for the same as modified by the effect of Hayford compensation.*

STATION.	Distance from main boundary in miles.	Deflections due to the Imaginary Range, in the meridian.		Deflections calculated by Major Crosthwait.		Difference between the effect of actual and imaginary topography.	
		I	II	I	II	I	II
Lambatach	44 N.	— 33	— 14	— 71	— 9	— 38	+ 5
Kurseong	3 ,,	— 54	— 29	— 103	— 23	— 49	+ 6
Mussooree	3 ,,	— 40	— 19	— 86	— 17	— 46	+ 2
Birond	2 ,,	— 51	— 20	— 74	— 14	— 23	+ 6
Dehra Dun	6 S.	— 34	— 17	— 86	— 18	— 52	+ 1
Siliguri	12 ,,	— 30	— 13	— 84	— 11	— 54	+ 2
Jalpaiguri	33 ,,	— 14	— 5	— 77	— 8	— 63	+ 3
Kaliana	41 ,,	— 6	— 2	— 58	— 3	— 52	+ 1

It will be seen that the uncompensated deflections derived from Major Crosthwait's calculations show a large northerly deflection, in

[1] Investigation of the Theory of Isostasy in India: *Survey of India, Professional Paper* No. 13, Dehra Dun, 1912. In addition to the results published in this paper, I am indebted to the courtesy of Sir S. G. Burrard, Surveyor-General, for the details of the calculations from which they were obtained.

excess of those due to the Imaginary Range, but this is due to the fact that Major Crosthwait's calculations include all topography within 2,564 miles of the station, and therefore the whole of the highlands of Central Asia, whereas those for the Imaginary Range only include topography within 100 miles distance. If we turn to the compensated deflections this great difference disappears and we find that Major Crosthwait's calculations give rather smaller values for the northerly deflections. At the stations north of the boundary fault, that is to say within the Himalayan region proper, the difference varies from 6″ to 2″, an irregularity which finds a natural explanation in the irregularity of the contour of the actual Himalayas and in the deep cut valleys which penetrate it. At stations outside the Himalayas, where these irregularities have less effect, a greater uniformity is observable and a closer agreement; the greater difference at Jalpaiguri is doubtless due to the inclusion in Major Crosthwait's calculation of the southerly pull of the highlands of the Assam Range and the Peninsula.

From this comparison two conclusions may be drawn. Firstly that the limitation, of the extent of topography considered, to that lying within 100 miles of the station is justified by the smallness of the effect of more distant topography, when the opposite effect of its compensation is taken into consideration; in none of the stations does the effect of the topography beyond 100 miles, and up to 2,564 miles, differ materially from about a couple of seconds of arc, and in every one of them it is in the same, northerly direction, so that no change is introduced in the difference between the calculated deflection for any pair of stations. Secondly it appears that the Imaginary Range will serve the purpose for which it was intended; that the deflections calculated from it are, on the average of the same order of magnitude as those which would be deduced from the actual topography; and that the departures from the deflections calculated from Mr. Hayford's tables which would result from a variation in the hypothesis of compensation will agree in character and order of magnitude with those which would result from the application of a similar hypothesis to the more complicated topography of a station, similarly situated, in the Himalayas.

No more than this is, at present, required, so far as the range representing the Himalayas proper is concerned; but for the greater part of its length the main range is bordered by a tract of lower hills, which have to be included in making a comparison between the effect of actual and imaginary topography. These are absent in the Sikkim area; elsewhere they lie south of the main boundary, and belong properly to the region of the Gangetic trough, but must be considered as part of the topography so far as they affect the deflection of the plumb-line. They will be simplified into a plateau of 20 miles in width and 1,500 feet in height above the plains, dimensions which conveniently, and approximately, represent the actual topography; and, as the mean density of the Siwalik rocks is about 2·2, and of the rocks of the main range about 2·7, the deflections will be estimated at eight-tenths of those which would result from Mr. Hayford's figures. In table No. 6 the deflections so obtained are given on the assumptions respectively, of no compensation, and compensation according to Mr. Hayford's tables; the difference does not in any case exceed one second of arc, and though there seems some reason, in this area, for not using the hypothesis of compensation, it will be safer to use the figures in the second column, which must be added to those obtained from other tables, when it is necessary to consider the attraction of the hills of the Sub-Himalayan region.

TABLE 6.—*Deflections due to an Imaginary plateau, representing the Sub-Himalaya or Siwalik Hills, assumed 20 miles broad by 1,500 feet in height and of density ·8 of average rock.*

STATION.	Uncompensated.	Compensated.
—5	+1	0
—4	+1	0
—3	+1	+1
—2	+2	+1
—1	+3	+2
0	+14	+13
+1	0	0
+2	—14	—13
+3	—3	—2
+4	—2	—1
+5	—1	—1
+6	—1	0
+7	—1	0
+8	0	0

Having formed an estimate of what the effect of compensation would be, if it is given the average value determined by observations in the United States of America, which may be accepted as not widely different from the average effect elsewhere, the next stage in the investigation is to calculate the result of supposing a departure from these average conditions in one direction or another. The first of these, to be considered, is a variation of the depth of compensation, still supposed to be uniform throughout the depth to which it extends, and the depths taken for calculation will be those for which Mr. Hayford has given tables, namely 162·3 km. or about 100 miles and 79·8 km. or about 50 miles.

In table No. 7, the result of calculation for these two depths is given, to the nearest whole second of arc, as well as the deflections resulting from Mr. Hayford's factors for uniform compensation to a depth of 113·7 km., or about 71 miles, and the differences between these values. The meaning of these differences being that, if the calculation had been made according to the Hayford

TABLE 7.—*Deflections which would be produced by the Imaginary Range on the supposition of uniform compensation to various depths.*

Station.	Assumed Depth of Compensation.				
	162·3 km.	Diff.	113·7 km.	Diff.	79·8 km.
— 10	— 13	— 2	— 11	+ 3	— 8
— 9	— 16	— 3	— 13	+ 3	— 10
— 8	— 18	— 3	— 15	+ 3	— 12
— 7	— 20	— 4	— 16	+ 4	— 12
— 6	— 21	— 4	— 17	+ 4	— 13
— 5	— 22	— 4	— 18	+ 4	— 14
— 4	— 23	— 4	— 19	+ 4	— 15
— 3	— 25	— 5	— 20	+ 4	— 15
— 2	— 26	— 5	— 21	+ 4	— 17
— 1	— 29	— 5	— 24	+ 4	— 20
0	— 58	— 5	— 53	+ 5	— 48
+ 1	— 19	— 4	— 15	+ 3	— 12
+ 2	— 11	— 2	— 9	+ 3	— 6
+ 3	— 7	— 2	— 5	+ 2	— 3
+ 4	— 5	— 2	— 3	+ 1	— 2
+ 5	— 3	— 1	— 2	+ 1	— 1
+ 6	— 2	— 1	— 1	0	— 1
+ 7	— 1	— 1	0	0	0
+ 8	— 1	— 1	0	0	0
+ 9	0	0	0	0	0
+ 10	0	0	0	0	0

factors for a depth of 113·7 km., observation at a station 50 miles north of the edge of the hills would show a northerly deflection of 4″ in excess of that due to calculation, or, in other words, a "residual" of — 4″ if the depth of compensation were 100 miles and a defect, or "residual," of + 4″ if the depth were only 50 miles. From this it appears that a variation in the depth to which compensation extends, assuming it to remain similar in character to Mr. Hayford's assumption, would introduce residuals which would be northerly for a greater depth of compensation and southerly for a lesser one. These residuals would not, however, amount to more than three or four seconds of arc, unless a much greater depth of compensation is assumed than there is any reasonable justification for adopting, and further, the residuals would have their maximum value at the edge of the hills, decreasing in both directions but more slowly towards the interior of the range than beyond its limits.

TABLE 8.—*Comparison of deflections produced by the Imaginary Range for Uniform Compensation to depth 113·7 km., with those produced by various depths of Centre of Compensation.*

Station.	Compensation Uniform.	Depth of centre of Compensation.					
	To depth 113·7 km.	45 miles Defl.	45 miles Diff.	35 miles Defl.	35 miles Diff.	25 miles Defl.	25 miles Diff.
— 10	— 11	— 14	— 3	— 12	— 1	— 9	+ 2
— 9	— 13	— 17	— 4	— 14	— 1	— 11	+ 2
— 8	— 15	— 19	— 4	— 16	— 1	— 13	+ 2
— 7	— 16	— 21	— 5	— 18	— 2	— 14	+ 2
— 6	— 17	— 22	— 5	— 19	— 2	— 15	+ 2
— 5	— 18	— 23	— 5	— 20	— 2	— 15	+ 3
— 4	— 19	— 24	— 5	— 21	— 2	— 16	+ 3
— 3	— 20	— 26	— 6	— 22	— 2	— 17	+ 3
— 2	— 21	— 27	— 6	— 23	— 2	— 18	+ 3
— 1	— 24	— 31	— 7	— 27	— 3	— 22	+ 2
0	— 53	— 61	— 8	— 57	— 4	— 52	+ 1
+ 1	— 15	— 20	— 5	— 17	— 2	— 13	+ 2
+ 2	— 9	— 12	— 3	— 9	0	— 7	+ 2
+ 3	— 5	— 7	— 2	— 5	0	— 3	+ 2
+ 4	— 3	— 4	— 1	— 3	0	— 2	+ 1
+ 5	— 2	— 3	— 1	— 2	0	— 1	+ 1
+ 6	— 1	— 2	— 1	— 1	0	— 1	0
+ 7	0	— 1	— 1	0	0	0	0
+ 8	0	— 1	0	0	0	0	0
+ 9	0	0	0	0	0	0	0
+ 10	0	[0	0	0	0	0	0

The Hayford values for the effect of compensation depend, as has been pointed out, on a wholly empirical distribution of the variations in density, a distribution which would not accord with those theories of mountain formation, which, so far as they admit of compensation at all, demand a limitation of the effect to a certain layer, or, at least, a concentration of the greatest effect within these limits. A calculation was, therefore, made of the effect of an assumption of a uniform depth of the centre of compensation at 25, 35, and 45 miles below sea level; the result is given in the table No. 8 (page 46), in which the result of the Hayford compensation is also included, for comparison. Here, again, we see that a greater depth of compensation results in an increased northerly deflection; we also see that if the depth of the centre of compensation is as much as, or over, 35 miles the maximum difference is at the outer edge of the hills and decreases at stations further in, while a shallower depth gives an apparent southerly deflection, when compared with the result of the Hayford compensation.

So far the compensation has been supposed to be uniform in character and depth; we must now consider the effect of a variable compensation, such as would be introduced by an hypothesis involving the support of the range by flotation, and a thickening of the crust downwards into the denser matter below, as well as upwards into the air. The most complete investigation of such an hypothesis, is that of Mr. O. Fisher, and it will be convenient to adopt his constants, and then investigate the effect of a variation in them. According to these, the mean thickness of the undisturbed crust is 25 miles, and the difference in density between it and the subjacent magma is such that the general elevation above mean sea level would require a downward protuberance of 9·6 times as much to compensate, by its buoyancy, for the weight of the upward protuberance.

On this supposition the bottom of the crust would lie at a depth of 25 miles under the plain, and under the first step of the Imaginary Range it would lie at 34·1 miles, under the second step at 35·9 miles and so on, and the whole of the compensation would be concentrated in that part of the crust lying below 25 miles.

The result of calculation from this supposition is given in table No. 9 (page 48), which shows that, as compared with the Hayford compensation, it not only gives rise to considerable northerly differences or "residuals" at stations within the hills, a result which

TABLE 9.—*Comparison of the Deflections produced by the Imaginary Range for uniform compensation to depth 113·7 km., with those which would be produced on the hypothesis of support by simple flotation, using Fisher's constants.*

Station.	Uniform compensation to 113·7 km.	Simple flotation.	
	Deflection.	Deflection.	Difference.
— 10	— 11	— 14	— 3
— 9	— 13	— 17	— 4
— 8	— 15	— 19	— 4
— 7	— 16	— 20	— 4
— 6	— 17	— 21	— 4
— 5	— 18	— 22	— 4
— 4	— 19	— 22	— 3
— 3	— 20	— 23	— 3
— 2	— 21	— 24	— 3
— 1	— 24	— 27	— 2
0	— 53	— 56	— 3
+ 1	— 15	— 16	— 1
+ 2	— 8	— 8	0
+ 3	— 5	— 5	0
+ 4	— 3	— 3	0
+ 5	— 2	— 2	0
+ 6	— 1	— 1	0
+ 7	— 1	— 1	0
+ 8	0	0	0
+ 9	0	0	0
+ 10	0	0	0

is the consequence of the greater average depth of the centre of compensation, but these differences are greater within the range than at its southern edge, and show a maximum at about 50 miles in. Moreover, the differences must be regarded as minimum values, since Mr. Fisher's constants, though arrived at by him on grounds independent of the particular hypothesis of mountain formation and support, represent a minimum value for the thickness of the crust and a maximum value for the difference in density between the crust and the underlying magma. If instead of 25 miles for the former a thickness of 30 miles is assumed, and instead of a difference of density such that for each 1,000 ft. of elevation representing 1·8 miles it be taken to represent 3 miles of "root," values which are not beyond reasonable limits, then the "residuals" become —7″ at the station 0, —8″ at station —5, and —6″ at station —10.

Actually, on any reasonable hypothesis of support by flotation the differences would probably lie somewhere between these two extremes, but nearer the lower than the higher value.

It has been pointed out that an hypothesis of support by flotation not only allows, but has a necessary consequence, of the likelihood that compensation would not be complete within the limits of the range, but might be partly distributed over the crust on either side. This want of balance may take place in two ways, and the one which will be considered first is a superelevation of a part of the range, accompanied by a bending down of the crust on either side. In table No. 10 the result of such a departure from complete local support by flotation is given on two separate suppositions, namely (1) that a tract 100 miles in width is superelevated by 1,500 ft. and that the defect in support is taken up by a depression of the crust on either side, gradually diminishing to nothing in 100 miles; and (2) that the same tract is superelevated by 3,000 ft.

TABLE 10.—*Corrections to the deflections due to the hypothesis of support by simple flotation, on two separate suppositions of partial support, corrected by depression of the adjoining tracts, supposed to be confined (A) to the topography and (B) to the compensation.*

Distance from southern edge of superelevated tract (in miles).	DEFLECTIONS RESULTING FROM HYPOTHESIS			
	No. I.		No. II.	
	(A)	(B)	(A)	(B)
50 N.	0	0	0	0
40	— 2	— 1	— 4	— 1
30	— 4	— 2	— 7	— 3
20	— 7	— 3	— 12	— 5
10	— 12	— 4	— 20	— 7
0	— 27	— 5	— 44	— 8
10	— 11	— 4	— 19	— 8
20	— 5	— 3	— 12	— 7
30	— 2	— 2	— 8	— 6
40	0	— 1	— 5	— 4
50	+ 1	0	— 3	— 3
60	+ 2	0	— 1	— 2
70	+ 3	+ 1	0	— 1
80	+ 4	+ 1	+ 1	0
90	+ 4	+ 1	+ 2	+ 1
100 S.	+ 4	+ 2	+ 3	+ 1

and the defect in support taken up by a depression of the crust on either side by the equivalent of 1,500 ft. gradually diminishing to nothing in 200 miles. In each case the figures given in table No. 10 must be added, algebraically, to those given in table No. 9 for the hypothesis of support by simple flotation, and so will increase or diminish the differences from the deflections due to the Hayford compensation, as the case may be.

The effect of the opposite supposition, that the buoyancy of the downward protuberance is in excess, and the surplus power of flotation absorbed by an upward bending of the crust on either side, would be practically the same in amount, but with the opposite sign, as that shown in the table No. 10, the surplus buoyancy being supposed to be of equal amount and extent as the surplus load considered in that table.

In considering the gravity observations a somewhat different course to that adopted in the case of the deflection of the plumb-line will be more convenient. The effect of the direct attraction of the visible masses is always determinable from the published observations, and different formulæ of calculation make very small differences in the amount to be allowed for this effect; the anomalies, or more properly the difference of anomaly between two stations in the same region, may therefore be looked upon as representing local differences in the density of the matter under the station, of which the most important is that due to the effect of compensation. It is, consequently, convenient to consider the effect of the compensation only, and the differences which would be introduced by varying the hypothesis.

The first of these comparisons to be made is that of the Hayford compensation with an hypothesis of support by flotation. This is given in table No. 11 (page 51), and a few words of explanation will show the use of this and the other tables; taking station 0, at the edge of the hills, and calculating the gravity which should be found at it according to the Hayford factors, we would have to allow for the effect of the visible masses and a further correction of — ·075 dyne for the effect of their compensation; but if the support had in reality been, as considered in the second column, one of simple flotation its effect would have amounted to — ·085 dyne, and the observed force of gravity would show a defect, or anomaly, of — ·010 dyne. At stations more than 50 miles into the hills this would be reversed, and a calculation based on the Hayford tables would show a

TABLE 11.—*Gravitation effect of the compensation only of the Imaginary Range (I) according to the Hayford tables and (II) on the hypothesis of support by flotation, using Fisher's constants. All quantities negative and expressed in dynes.*

STATION.	Hayford Compensation.	Fisher Constants.
— 20	·350	·310
— 10	·305	·280
— 5	·200	205
— 4	·180	·185
— 3	·155	·165
— 2	·130	·140
— 1	·105	·115
0	·075	·085
+ 1	·045	·060
+ 2	·130	·040
+ 3	·020	·025
+ 4	·015	·015
+ 5	·010	·010

positive anomaly, increasing at stations further into the hills till, on the plateau, it rises to as much as + ·040 dyne.

In the table No. 12 are given the gravitation effects of a compensation supposed to have a uniform depth of the centre of compensation of 25, 35, and 45 miles respectively, which shows the

TABLE 12.—*Gravitation effect of the compensation only of the Imaginary Range supposed to be centred at various depths. All quantities negative and expressed in dynes.*

STATION.	DEPTH OF CENTRE OF COMPENSATION.		
	25 miles.	35 miles.	45 miles.
— 20	·380	·330	·300
— 10	·345	·295	·265
— 5	·235	·200	·180
— 4	·210	·180	·160
— 3	·180	·155	·140
— 2	·150	·130	·115
— 1	·120	·105	·095
0	·085	·080	·075
+ 1	·060	·055	·055
+ 2	·040	·040	·040
+ 3	·025	·025	·030
+ 4	·015	·015	·020
+ 5	·010	·010	·015

extent to which the attraction of the visible masses is neutralised by a compensation whose centre of effect lies at these depths. And finally in table No. 13 are given the effect of the two modifica-

TABLE 13.—*Gravitation effect of two suppositions of departure from a condition of support by simple flotation.*

Distance from southern edge of superelevated tract.	GRAVITATION EFFECT OF SUPPOSITION. I	II
50	+ ·035	+ ·080
40	+ ·035	+ ·075
30	+ ·030	+ ·070
20	+ ·025	+ ·060
10	+ ·015	+ ·045
0	+ ·005	+ ·025
10	— ·005	+ ·010
20	— ·010	— ·005
30	— ·015	— ·015
40	— ·020	— ·020
50	— ·020	— ·025
60	— ·020	— ·025
70	— ·015	— ·025
80	— ·015	— ·025
90	— ·010	— ·020
100	— ·010	— ·015

tions to the hypothesis of simple support by flotation which were dealt with in table No. 10. Here again a reversal of the suppositions and an assumption of over-compensation of the range, or part of it, balanced by a corresponding under-compensation elsewhere, would hardly affect the numerical value of the correction but would reverse its sign. In either case the values given in table No. 13 must be added, algebraically, to those given in table No. 11 for the hypothesis of simple flotation.

The Gangetic trough will be treated in a manner similar to that adopted in the case of the range, and the effect calculated of an Imaginary Trough, or rather series of troughs of different forms and dimensions; but before this can be done it is necessary to determine what value will be adopted as representing the mean density of the material with which they are filled, and this can be determined within narrow limits. The mean density of the superficial deposits of the Gangetic plain is about 1·8, but the deeper layers have certainly a greater density than this; at the same time they can hardly attain a greater density than that of the Siwaliks, which are composed of the same materials and have been subjected to the pressure of superincumbent deposits, as well as to the induration due to age and the compression to which they have been subjected in the course of the upheaval of the Sub-Himalayas. This fixes the upper limit of density at 2·2 and the probable mean density must lie somewhere between the two, though nearer the higher than the lower limit. In my earlier investigations a density of 2·1 was accepted, or a deficiency of two-ninths of the mean density of the rock forming the floor and sides of the trough; later a slightly higher density was adopted, for convenience of calculation, and the deficiency put at two-tenths of the mean density of the rocky floor of the trough, representing a density of 2·16.

Doubts have been expressed [1] as to the reality of so great a difference in density between the material forming the Himalayas and that which fills the Gangetic trough, and especially it has been urged that the material in the lower layers of the trough would be compacted, by the pressure of the superincumbent material and the percolation of water holding carbonate of lime in solution, till the difference in density between it and ordinary rock would be negligible. These objections might be valid where depths of many miles are postulated, but, as will be seen further on, there is no need to suppose that the Gangetic trough is anywhere more than 20,000 ft. in depth, and as the Siwalik rocks, which have been subjected to the pressure of superincumbent deposits of about the same thickness, have an average density of only 2·2 or not much greater than the mean density assumed for the whole of the deposits in the Gangetic trough, of which the Siwalik rocks are the most dense, it is evident that the deficiency of two-tenths, corresponding to a mean density of 2·16, does not err on the side of being too high.

At first sight it might seem strange that there should be so great a difference between the density of the rocks forming the Himalayas and the material filling the Gangetic trough, seeing that the latter is the debris of the former, but all the denser minerals of the former have been decomposed, oxydised and hydrated, and the hard quartzites of the Himalayas broken up, to form the soft sandstones

[1] S. G. Burrard, *Prof. Paper, Surv. Ind.*, No. 12, p. 4 and T. H. Holland, *B.A., Report* 1914, p. 355.

and loose sands, silts and clays of the Siwaliks and Gangetic trough. Now the softer sandstones, such as the New Red, used for building purposes, have a density of 2·1 to 2·2, and river sand or clay both about 1·9, and as these types of rock represent the material of which the contents of the Gangetic trough is composed, the difference between its density and that of the Himalayas is about what would be expected from the difference in composition and state of aggregation.

The effect of such a mass of lighter material, at stations outside the trough, is that the attraction towards one side is not counterbalanced by that towards the other, and the material filling the Gangetic trough would exercise an apparent repulsion, causing a northerly deflection at stations to the north, and a southerly at stations to the south, of it. Within the limits of the trough the effect would depend on the position of the station and on whether, and to what extent, the effect of that portion lying on one side of the station exceeded that of the portion lying on the other.

TABLE 14.—*Deflections due to troughs, 50 miles broad, of various sections; density ·8 of average rock.*

Station.	Depth uniform.		Depth varying from		
	10,000 feet.	15,000 feet.	15,000 to 10,000 feet.	0 to 10,000 feet.	0 to 15,000 feet.
— 10	0	0	0	0	0
— 9	0	0	— 1	0	0
— 8	— 1	— 1	— 1	— 1	— 1
— 7	— 1	— 2	— 2	— 1	— 1
— 6	— 2	— 3	— 2	— 1	— 2
— 5	— 3	— 4	— 3	— 2	— 3
— 4	— 3	— 5	— 4	— 2	— 3
— 3	— 4	— 6	— 5	— 3	— 4
— 2	— 5	— 8	— 7	— 3	— 5
— 1	— 8	— 11	— 10	— 6	— 8
0	— 19	— 27	— 24	— 16	— 21
+ 1	— 6	— 9	— 6	— 1	— 2
+ 2	— 2	— 3	0	+ 2	+ 4
+ 3	+ 2	+ 3	+ 5	+ 6	+ 8
+ 4	+ 6	+ 9	+ 9	+ 8	+ 10
+ 5	+ 19	+ 27	+ 21	+ 8	+ 11
+ 6	+ 8	+ 11	+ 9	+ 3	+ 5
+ 7	+ 5	+ 8	+ 6	+ 3	+ 4
+ 8	+ 4	+ 6	+ 5	+ 2	+ 3
+ 9	+ 3	+ 5	+ 4	+ 2	+ 2
+ 10	+ 3	+ 4	+ 3	+ 1	+ 2

The underground form of the trough cannot be determined by surface observation of a geological character, and the readiest means of applying the geodetic results to the solution of this problem appeared to be the calculation of the effect of a series of troughs of various forms and dimensions, by the combination of which a series of cross sections could be built up and the calculated compared with the observed results. This has been done in tables 14 to 16; in table No. 14 (page 54) a width of 50 miles is assumed and we have the deflections which would be produced if it had a uniform depth with vertical sides, if it had vertical sides and a floor sloping upwards from a depth of 15,000 ft. on the north side to 10,000 ft. at the south, and if it had a vertical side on the north and a floor sloping gradually upwards to the surface at the southern edge. Table No. 15 gives the deflections which would be produced by a

TABLE 15.—*Deflections due to a trough 100 miles broad of various sections; density ·8 of average rock.*

Station.	Uniform depth.		Depth varying from 0 to	
	10,000 feet.	15,000 feet.	10,000 feet.	15,000 feet.
— 10	0	0	0	0
— 9	0	— 1	0	— 1
— 8	— 1	— 1	— 1	— 1
— 7	— 1	— 2	— 1	— 2
— 6	— 2	— 3	— 2	— 2
— 5	— 3	— 4	— 2	— 3
— 4	— 3	— 5	— 3	— 4
— 3	— 4	— 7	— 4	— 5
— 2	— 6	— 10	— 5	— 7
— 1	— 9	— 14	— 7	— 11
0	— 21	— 29	— 18	— 25
+ 1	— 9	— 13	— 5	— 7
+ 2	— 6	— 8	— 1	— 1
+ 3	— 3	— 5	+ 2	+ 2
+ 4	— 2	— 2	+ 3	+ 5
+ 5	0	0	+ 4	+ 6
+ 6	+ 2	+ 2	+ 5	+ 8
+ 7	+ 3	+ 5	+ 6	+ 8
+ 8	+ 6	+ 8	+ 6	+ 9
+ 9	+ 9	+ 13	+ 6	+ 9
+ 10	+ 21	+ 29	+ 6	+ 9

trough 100 miles in width, of uniform depth, or with a vertical side on the north and a floor sloping gradually upwards to the south. Table No. 16 gives the deflections due to a trough 200 miles in width,

TABLE 16.—*Deflections due to a trough 200 miles broad, 20,000 ft. deep diminishing to nothing; density ·8 of average rock.*

STATION.	DEFLECTION.	STATION.	DEFLECTION.
0	— 40	15	+ 8
1	— 14	16	+ 7
2	— 7	17	+ 7
3	— 3	18	+ 7
4	0	19	+ 7
5	+ 2	20	+ 6
6	+ 4	21	+ 3
7	+ 6	22	+ 2
8	+ 7	23	+ 1
9	+ 8	24	+ 1
10	+ 8	25	+ 1
11	+ 8	26	0
12	+ 8	27	0
13	+ 8	28	0
14	+ 8	29	0

with a vertical northern side 20,000 ft. in depth and the floor sloping gradually upwards to the surface; in this case the calculation is extended to a distance of 100 miles beyond the limit of the trough to indicate the rate at which the effect of such a trough would die out as the southern limit of the Gangetic alluvium is left. In every case the trough is supposed to run east and west, and the northern limit is assumed to coincide with the southern boundary of the range, or with station 0; this enables the effect to be conveniently stated in the tables, and by combination, with reversal where necessary, of two or more of the cross sections given in the table, an approximation to any cross section which need be considered can readily be built up. Further, although the deflections have only been calculated for certain depths of trough, they may be determined for other depths by interpolation or extrapolation, which will not introduce any material error, at any rate between the limits of 5,000 and 30,000 feet of maximum depth.

In these tables two features are noteworthy; one, that in every case we have a high northerly deflection at the foot of the hills, which decreases rapidly both northwards and southwards, but more rapidly in the latter direction, especially in the case of a floor sloping upwards to the south; the other that, at a distance from the edge of the hills which varies with the form of the floor, the northerly gives way to a southerly deflection which, in the case of a uniformly sloping floor, soon settles down to a value approximately proportionate to the amount of the slope, and nearly constant in amount right up to the southern limit, after which it rapidly diminishes and becomes negligible at stations more than 30 miles beyond the boundary.

The figures given in the tables are all based on the assumption that the defect in density of the material filling the trough is not compensated. It is by no means certain that a structural feature like this would have a separate compensation of its own, apart from the general compensation of the surface-relief, but it is not unreasonable to suppose that a defect of density, and consequently of weight, which may amount to the equivalent of 3,000 ft., or more, of average rock and having a horizontal extent of many hundreds of miles, would be compensated in the same way as a corresponding irregularity in the surface of a region composed of average rock.

The amount of the correction which would be introduced in this way has not been calculated in every case, but in the case of a trough 100 miles in width and 15,000 ft. in depth at the northern edge, diminishing to nothing at the southern, the deflections, supposed to be compensated according to the Hayford tables, would be as shown in table No. 17 (page 58) where the values, if compensation is not considered, are repeated from table No. 15, for comparison. It will be seen from this that the character of the curve of variation in deflection is not materially altered, but the reduction of effect beyond the limits of the trough is more rapid than when compensation is not considered; the deflections within the limits of the trough are reduced by about one-fifth at the deep northern edge, and by nearly one half in the southern portion of the trough, while they are practically unaffected in that part where the effects in opposite directions nearly balance each other. The general effect of introducing the consideration of compensation would be to increase the estimate of the maximum depth by about one quarter at the northern edge, and of the slope of the floor of the trough, near the southern, by about four-fifths; consequently, deflections which would give a maximum depth of 15,000 ft. and a uniform slope of the floor, if regarded as due to the effect of the trough without compensation, would give a maximum depth of about 18,000 ft. at the north and a slope of about 270 ft. to the mile in the

TABLE 17.—*Deflections due to a trough 100 miles broad, 15,000 ft. deep at the northern, diminishing to nothing at the southern, edge, supposed to be (I) uncompensated (II) compensated according to the Hayford tables for uniform compensation to depth 113·7 km.*

STATION.	DEFLECTIONS.	
No.	Uncompensated.	Compensated.
— 5	— 3	— 1
— 4	— 4	— 1
— 3	— 5	— 2
— 2	— 7	— 3
— 1	— 11	— 6
0	— 25	— 20
+ 1	— 7	— 4
+ 2	— 1	0
+ 3	+ 2	+ 2
+ 4	+ 5	+ 3
+ 5	+ 6	+ 4
+ 6	+ 8	+ 4
+ 7	+ 8	+ 5
+ 8	+ 9	+ 5
+ 9	+ 9	+ 5
+ 10	+ 9	+ 5
+ 11	+ 5	+ 2
+ 12	+ 3	+ 1
+ 13	+ 2	+ 1
+ 14	+ 1	0
+ 15	+ 1	0

southern part of the trough, and, therefore, would necessitate a cross-section whose floor did not have a uniform slope, but would

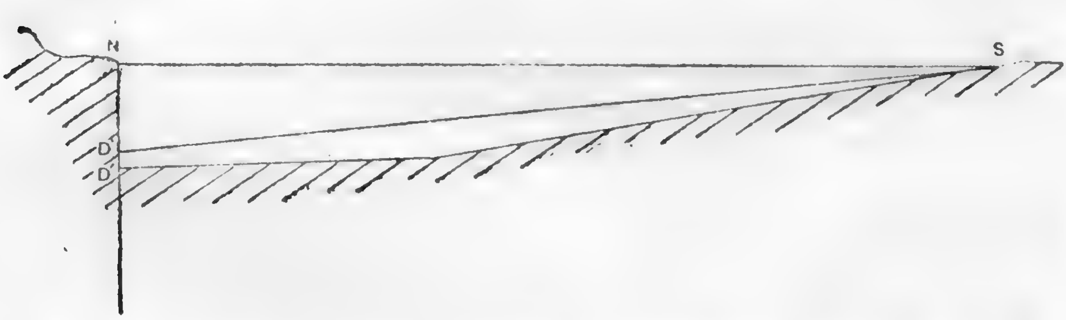

FIG. 5.—Showing the effect of separate compensation of the trough on the interpretation of the deflections. If NDS represents the cross section which would be indicated if there were no separate compensation, then ND'S represents the interpretation if compensation is considered.

need to carry the depth at the northern limit outwards at a lesser, and then upwards at a steeper slope to the southern margin as is shown in fig. 5 (page 58). From this it will be seen that the effect of introducing the concept of compensation would not materially alter the conclusions drawn from the observations if it is not considered; the exclusion of compensation would merely reduce the depth by about one quarter in the deeper and by nearly one half in the shallower southern part of the trough, and slightly modify the general form of the cross section.

The gravitational effect of the alluvium is easily dealt with; the anomaly having been calculated on the assumption that the whole of the alluvium consisted of average rock, there would be, apart from other causes, an apparent defect of gravity, due to the diminished attraction of the alluvium, whose density is only about four-fifths of the rock by which it was assumed to be replaced. As a layer of average rock of indefinite extent exerts an attractive force equivalent to ·0033 dyne for each one hundred feet of thickness, it follows that the gravitation effect of a depth of 15,000 ft. of alluvium, of sufficient extent, would exert an effect of — ·100 dyne. If the boundary of this trough were vertical the effect at the boundary would be exactly half this value, and at intermediate distances the effect would be as shown in table No. 18.

TABLE 18.—*Gravitational effect of the defect in density of a vertical-sided trough of alluvium, 15,000 ft. in depth, and density ·8 of average rock. All values negative and expressed in dynes.*

STATION.	DEFECT OF GRAVITY.
— 5	·000
— 4	·001
— 3	·002
— 2	·003
— 1	·005
— ·5	·011
0	·050
+ ·5	·089
+ 1	·095
+ 2	·097
+ 3	·099
+ 4	·100
+ 5	·100

An examination of this table shows that the effect of the limitation of the trough is barely noticeable at distances of over ten miles from the edge, and even at a distance of only five miles it has still nearly nine-tenths of the value which it would have at an infinite distance. Put differently, we may conclude that eighty per cent. of the total effect of a great expanse of alluvium, having a depth of 15,000 feet, is exerted by that portion which lies under a circle of five miles radius from the station, and ninety per cent. by that which lies within a distance of ten miles. As the limitation is even closer with a lesser depth, it follows that we may leave the effect of more distant alluvium out of consideration and, except close to the main boundary, regard the effect of the alluvium as directly proportionate to its depth under the station and as amounting to about ·006 dyne for each 1,000 feet of depth.

As in the case of the deflections, the effect of the trough may be subject to modification, if the invisible defect of density is compensated in the same way as a corresponding irregularity of the surface. The effect of this modification would be to diminish the negative attraction of the trough, and a calculation for the case of a trough 100 miles in width with a maximum depth of 15,000 feet at the northern limit, diminishing regularly to nothing at the southern, showed that the effect, using Mr. Hayford's tables, would be—

at the northern edge	+ ·013 dyne
at 35 miles from the northern edge	+ ·037 ,,
,, ,, ,, southern ,, ...	+ ·024 ,,
at the southern edge	+ ·014 ,,

and for comparison with these figures the uncompensated effect of the same trough may be given; it would be

at the northern edge	— ·100 dyne
at 35 miles from the northern edge	— ·067 ,,
,, ,, ,, ,, southern ,, ...	— ·033 ,,
at the southern edge	·000 ,,

The effect of the compensation, it will be seen, is not proportional to the depth of the trough under the station of observation on account of the depth of the centre of compensation, which makes the effect felt to a greater distance than that of the trough itself. The modification in the conclusions drawn, if compensation is not considered, would be least at the northern edge of the trough, and would lead to the depth being under-estimated; this modification would increase in amount in a southerly direction and at about 20 miles from the southern edge, the negative effect of the trough would be neutralised; still further south the effect of the compensation would outweigh that of the trough and produce a small positive effect on the force of gravity.

Calculations were not made for other sections and dimensions of the trough, as an estimate, sufficiently accurate for the purpose of this investigation, may be made for any section of trough which will have to be considered, and, besides, there is the uncertainty of whether the trough should be considered as having a separate compensation of its own.

One more condition must be considered; besides the possibility of the separate compensation of the trough there is the possibility that its origin is due to a depression of the crust into, or a subsidence of the crust due to a removal of, the denser material below. In either case there would be a replacement of denser by less dense material of the same shape and form as the trough itself, but situated at some depth below it, as is illustrated in fig. 6.

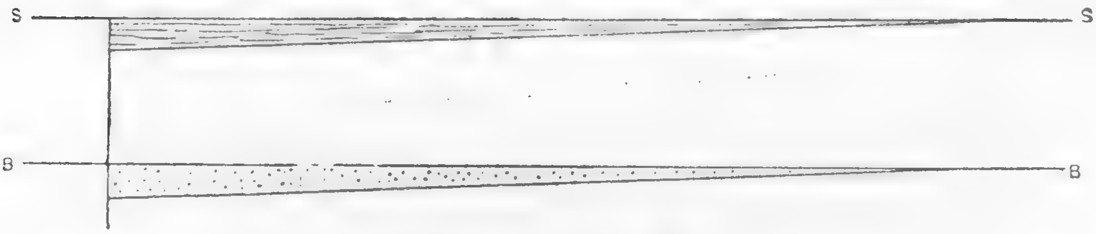

Fig. 6.

An hypothesis of this form has actually been investigated by Mr. O. Fisher, [1] who supposed the depression of the Gangetic trough to be due to a bending down of the earth's crust in partial support of the weight of the mountain range, but the same result might be brought about in other ways. On any form of hypothesis, which involves an isostasy and support of the range by flotation, it is conceivable that the support might not be completed under the range itself, but partly transferred to the crust on either side, with the consequence of an equal displacement of the denser material under the crust by the lighter material of the crust itself. The bearing

[1] *Phil. Mag.*, Jan. 1904, pp. 14-25.

of this hypothesis on the support of the Himalayas will be dealt with further on; here its effect on the observations in the region of the alluvial plain will alone be considered.

To begin with, it is evident that no question of separate compensation of the trough need be introduced, as it would be merged in the general compensation of the range and trough combined, and we need only take into consideration the effect of the deficient density of the alluvium filling the superficial depression, and of the buoyancy of the corresponding depression of the lower surface of the crust. For the purpose of calculation the two will be assumed to be of equal dimensions, with a depth of 20,000 feet at the edge of the hills and a width of 200 miles; corresponding approximately to the dimensions of the Gangetic trough in the region of its greatest development. The thickness of the crust will be taken as 25 miles, and the difference in density between it and the underlying material as one-tenth of the density of the crust, so that each 10 feet of depression has a buoyancy to support the weight of a thickness of 1 foot of rock.[1]

Taking these constants, and considering the deflection of the plumb-line first, the effect of the depression of the under side of the crust, expressed to the nearest whole second of arc, would be

at the northern edge	— 4″
,, middle	+ 2″
,, southern edge	+ 1″

The effect of the corresponding depression on the upper side of the trough, supposed to be filled with alluvium, would be

at the northern edge	— 40″
,, middle	+ 8″
,, southern edge	+ 6″

The general character of the deflections is, therefore, similar in both cases, but whereas the change from northerly to southerly deflection takes place at about forty miles from the northern edge, in the alluvial trough, the northerly deflections produced by the depressed under-surface of the crust would extend for fully fifty miles, before the southerly deflections set in. At the extreme

[1] This difference is slightly less than that adopted by Mr. Fisher (*Physics of the Earth's Crust*, 2nd ed., p. 168), which gives a ratio of 1 : 9·57. The difference is trivial and as that adopted by Mr. Fisher is, if anything, a little too great, the simpler ratio has been adopted to ease calculation.

northern edge it will be seen that the depressed tract gives a deflection which is only one-tenth of that due to the alluvial trough, but the latter drops in value much more rapidly in amount than the former, and in the central and southern portions of the trough, where all but a very few of the stations are situated, the effect of the depressed lower surface of the crust ranges from one quarter to one-sixth of the effect of the alluvial trough on the upper surface, if the two are supposed to be of equal dimensions.

In one respect this is not likely to be the case, for the boundary of the alluvium does not mark the limit of the depression. To the south of the alluvial boundary the general level of the country continues to rise for some distance and, if the origin of the trough is that assumed by the hypothesis just considered, the width of the depressed lower portion of the crust must be taken at 250 to 300 miles. In this case the effect near the centre of the alluvial area would be reduced by from one-quarter to one-third, and the effect at the southern limit of the alluvium increased in about the same proportion; the effect, therefore, of the depressed lower portion of the crust may be taken as round about one-fifth of the effect of the alluvial trough over the greater part of the plain. Only in the northern part of the alluvium, for a distance of at most 60 miles from the northern edge, would the ratio of the two separate effects differ materially from this proportion, and it is just in this region that the deflections give the least satisfactory and certain indications of the form of the floor of the trough.

The effect of the depressed lower portion of the crust on the force of gravity at the surface may be simply and easily expressed, with sufficient accuracy for present purposes. The defect in mass of the depressed lower portion of the crust is ·1 of the whole, that of the alluvial trough is ·2, the defect in attractive power is therefore one half as great in the one case as in the other; but besides this we have to take into consideration the effect of the greater distance from the surface in the former case, which will have the effect of diminishing the apical angle of the cone covering two circles of the same radius. Taking this radius at 100 miles, and it is needless to take a larger radius seeing that the trough is only 200 miles broad, we find that a disc of the lower surface of the crust would produce an effect of ·76 of the amount which a disc of the same total mass would produce at the surface; and as the mass is taken at one-half, the ratio of the effect of the alluvial trough to that of the depressed lower portion of the crust is as 1·0 to 0·4, except near the northern margin where, in the last thirty miles or so, it falls to about ·3 of the effect produced by the trough.

The figures which have been calculated for the particular dimensions of trough considered, apply with proportionate variation to any other dimensions of a trough of similar form, and the ratio, between the effect of the superficial trough and of the depressed lower surface of the crust, would not be materially altered. We may, therefore, apply the results obtained to the conclusions, drawn from observation, and find that the depth of the trough, deduced from the deflections on the assumption that the whole effect is due to it alone, would have to be reduced by about 14 to 20 per cent., if the total effect is resolved into its two components, and that the reduction would have to be about 28 per cent. in the case of the gravity observations; but apart from this there would be no material alteration in the general form of the trough. Consequently the adoption of this hypothesis of origin of the trough would not lead to any modification in the conclusions drawn as to the general form of the trough, though it would lead to a reduction in the estimated depth of the alluvium by somewhere about one quarter, at most, of the estimate which would be formed if the whole effect was attributed to the trough alone.

CHAPTER IV.

THE UNDERGROUND FORM OF THE FLOOR OF THE GANGETIC TROUGH.

The latitude stations on the Gangetic alluvium are ranged across the plain in four series running north and south, and a more scattered group in the Punjab. Of these five series, only two are complete, in the sense that they are continued across the northern boundary of the alluvium into the region of the Himalayas, but it will be more convenient to begin with another series, which forms a remarkably complete series, extending from the northern boundary of the alluvium across the plain, and into the Peninsular rock area to the south, in the neighbourhood of the 81° meridian of east longitude.

TABLE 19.—*Latitude Stations near 81° Longitude.*

Station.	Distance from N. and S. boundaries of the alluvium.	Calculated Deflections.		Observed Deflections.
		I	II	
Manichauk	14 — 176	— 13	— 13	— 15
Pathardi	14 — 168	— 13	— 13	— 15
Ghaus	16 — 156	— 12	— 12	— 13
Basadela	20 — 156	— 10	— 9	— 9
Dadawra	16 — 180	— 12	— 12	— 11
Ramuapur	24 — 200	— 7	— 6	— 7
Masi	32 — 164	— 2	— 3	— 6
Jarura	48 — 160	+ 2	+ 2	— 2
Imlia	60 — 160	+ 6	+ 7	+ 3
Nimkar	80 — 130	+ 8	+ 9	+ 4
Utiaman	80 — 140	+ 8	+ 9	+ 9
Etora	96 — 114	+ 9	+ 10	+ 9
Parewa	96 — 114	+ 9	+ 10	+ 11
Sora	110 — 96	+ 10	+ 10	+ 12
Pariaon	140 — 48	+ 10	+ 10	+ 10
Dewarsan	144 — 80	+ 10	+ 9	+ 9
Kanakhera	164 — 40	+ 10	+ 9	+ 9
Pavia	180 — 16	+ 9	+ 9	+ 8
Potenda	40 S.	+ 1	+ 1	+ 6
Karara	76 ,,	0	0	+ 4
Amua	88 ,,	0	0	+ 5

A list of these stations is given in table No. 19 (page 65) with the addition of four stations, ranged along the northern fringe of the alluvium to the eastwards of the meridional series. It is in no case possible to measure the exact distance of any of these stations from the main boundary, as this runs through Nepal territory to the north of this section, but the distance from the outer edge of the hills can be determined with sufficient accuracy, and a comparison of the section at the western end of Nepal with that along the road to Khatmandu, shows that the width of the Siwalik tract is probably about 20 miles, so that the main boundary may be taken as lying at that distance from the outer edge of the hills and, where it needs to be taken into consideration, this must be added to the distance of each station from the outer edge of the hills as given in the table No. 19. In this table are also given the distances from the southern boundary of the alluvium, the figures in each case being approximate and measured to the boundaries of the alluvium as drawn on the general geological map of India on the scale of 32 miles to the inch.

The deflection, actually observed at each station, is given, to the nearest whole second, in the last column of the table, and the first thing to be noticed is the presence of a considerable southerly deflection at the stations beyond the alluvium to the south. The distances of these stations from the boundary are too great for the deflections to be attributable to the effect of the alluvial trough, and we may look for their cause in the "hidden range" or belt of underground excess of density which has been found to exist in the northern part of the Peninsula.

Turning to the stations on the alluvium, and comparing the observed values with the calculated deflections given in tables 14 to 16, we see that, so far as the southern half of the section is concerned, they indicate a trough deepening steadily from south to north at about 130 ft. to the mile, and that this slope is continuous for over 100 miles from the southern edge, so that in this way we reach an estimated depth of over 13,000 and probably about 15,000 feet. The northern part of the section gave more trouble, for here the effect of the Himalayas, which is negligible at the southern stations, becomes considerable. As it was impossible to calculate the effect of the actual topography at each station it seemed best to assume that the effect would not be very different from that of the Imaginary Range, allowing for Hayford compensation, at a station situated at a corresponding distance, reckoned from the main boundary; at the stations nearest to the hills a small additional correction was included, for the effect of the attraction of the foot-hills of the Sub-Himalayan region. The figure allowed in this way, for the effect of the attraction of the Himalayas, is a little less than the reality, but the difference would not exceed one second of arc, or at most a couple, at any of the first six stations, included in the table No. 19, and is negligible at the rest.[1]

Allowing for this effect, a first attempt at calculation, on the supposition that the slope of the floor of the trough continued regularly up to the main boundary, showed that this would give too small northerly deflections at the northern stations, nor were matters much improved by supposing that the maximum depth was continued outwards from the main boundary for some considerable fraction of the width of the trough, before the upward slope commenced. It became evident, therefore, that the maximum depth of the trough could not be at the northern edge, but must be somewhere out towards the centre, though nearer to the northern than the southern edge; a supposition was accordingly adopted, that the trough had a depth of 15,000 feet at the main boundary, increasing to 20,000 feet at 50 miles away and then decreasing to nothing in 150 miles. The result of this calculation is given in the column headed I, but at a later period, when the study of other sections had revealed a possibility that the trough attains its greatest depth close to the outer edge of the visible hills, another assumption was made, that the maximum depth was 25,000 feet at the outer edge of the hills, that the floor sloped regularly upwards from this to the southern edge of the plain, and on the north rose abruptly upwards to a depth of 20,000 feet diminishing to 15,000 feet at the main boundary. The result of this supposition is given in the column headed II.

[1] We have a check on the correctness of method of arriving at the allowance to be made for the effect of the trough, and any other invisible influence, in Major Crosthwait's calculation of the residuals at Pathardi and Nimkar. On the same basis of reference as is here used in the text, the residuals, after allowing for the effect of visible topography and its compensation, are —12″ and +5″ respectively, the values derived by using the Imaginary Range were —9″ and +4″. The use of the Bessel-Clarke spheroid would introduce a change of 1″ in the values of the residuals. Evidently the Imaginary Range gives a larger deflection than the actual topography of this part of the actual range, but it must be remembered that the Himalayas in Nepal territory are quite unsurveyed.

Comparing the calculated with the observed deflections, it will be noticed that either supposition gives results which are in very fair agreement with reality; only in the stations from Masi to Nimkar is there any considerable irregularity, but these stations are situated in the tract where northerly are passing into southerly deflections, and where a small variation in the assumed form of the trough would lead to considerable changes in the calculated deflections. Apart from this, the general course of the variation, as well as the actual values, of the calculated and the observed deflections are in very good agreement; at the northern stations the calculated deflections are in slight defect, and the same is true of the stations in the southern half of the section, but the former of these is easily accounted for by the probable excess of the northerly attraction of the Himalayas over that allowed for in the calculations, or both the deficiencies could be eliminated by assuming a rather greater depth of the trough, but no real benefit would accrue from any attempt at obtaining a closer agreement between calculation and observation.

This study of one of the groups of latitude stations serves to illustrate at once the method which will be followed, and the limitations of any attempt to derive geological information from geodetic observations. The method, though differing in form, is essentially the same as that adopted in geodetic work; a certain assumption is made, calculation is made on that basis and the results of calculation and observation compared, another assumption is then made and fresh calculations made until the average difference between the calculated and observed values of the deflection is reduced to the smallest amount. In geodetic work proper the closeness of agreement is tested by comparing the sum of the squares of the individual differences, and adopting the supposition which gives the smallest value to this sum, as the one which most closely approaches the average conditions. This method is the only oneadmissible where a large number of observations, extending over a large area, have to be dealt with; it is not only unnecessary, but would give a wholly illusory appearance of precision, if applied to a limited number of observations, and to the extraction of the information for which we are in quest.

Here we must start with those conditions which represent a near approach to the average, and apply to them a correction for local departure from the average, in this case represented by the defect of density in the Gangetic trough, and it will be seen that either of the suppositions considered in table No. 19, if combined with the average conditions assumed in calculating the observed deflections, would largely reduce the differences between the calculated and observed values. They may therefore be regarded as approximations to the actual form of the trough, but it is not possible to obtain a closer approximation, with any degree of certainty, owing to the uncertainty in which we are as to the density of the alluvium in the lower layers of the deposit, as to the nature and extent of the separate compensation of the trough, and as to the presence and character of any independent cause which would affect the direction of the plumb-line. The effect of the last two elements of uncertainty has been dealt with in the last chapter, and need not be enlarged on here. With regard to the possible increase in density of the lower layers of the alluvium, the depth, indicated by the observations, of 20,000 to 25,000 feet, even if allowance is made for the possible increase due to a separate compensation, is not so great as to necessitate or suggest a condensation of the sands and clays of which the alluvium is composed to a much greater density than the 2·16 which was assumed as the mean density of the deposit, and against this must be placed the fact that the upper layers have certainly a considerably lower density than that assumed as the mean of the whole deposit.

Allowing for all these possible modifications of the conclusions come to if the whole of the deflections, so far as they are not accounted for by the visible topography, are due to the alluvial trough, the fact remains, that the published deflections agree so well with those which should result from a cross section and dimensions of the trough which are in accord with those suggested by a wholly independent line of research, as to render it probable that this is the preponderating, if not the sole, influence at work; and we reach the conclusion that the maximum depth of the trough lies at, or a little south of, the edge of the hills and need not exceed about 25,000 feet; it can hardly be less than 20,000 and is not likely to exceed 30,000 feet, so far as the indications of this group of latitude stations are concerned.

The northern part of the section, which was not represented in the group just considered, is covered, further west, by a very complete group of stations in and around the Dehra Dun; it will, however, be best to defer the consideration of these observations and confine attention to the southerly continuation of the series, across the alluvial plain. This series forms a double line of stations stretching across the alluvium and ranged on either side of the 78° meridian, which will be most conveniently treated as two separate series and are given in the table No. 20 in two columns,

TABLE 20.—*Latitude Stations near 78° Longitude.*

STATION.	Distance from Main Boundary.	Observed Deflections.		Deflections due to the Range.
Sarkara	32		— 8	— 6
Nojli	38	— 10		— 5
Sirsa	56		— 5	— 2
Kaliana	58	— 3		— 2
Bansgopal	76		— 1	— 1
Datairi	92	— 2		
Bostan	104	— 1		
Sankrao	108		+ 4	
Chandaos	124	+ 3		
Salimpur	124		+ 4	
Noh	144	+ 4		
Agra	168	— 1		
Usira	200	— 2		
Gurmi	200		+ 6	
Majhar			+ 7	
Kesri		+ 10		
Algi			+ 6	
Pahargarh		+ 4		

of which the left hand one includes the western, and the right hand one the eastern, stations; the actual deflections are given, and in the last column the amount of deflection attributed to the attraction of the Himalayas. For two of the stations in this series, Kaliana and Bansgopal, Major Crosthwait has calculated the effect of the visible topography, of which the Himalayas form all but a small proportion, and obtained a deflection of —3″ at Kaliana, as against —2″ in the table; at Bansgopal the agreement is complete.

The eastern stations are situated well out in the alluvial plain and exhibit much the same features as the series near the 81° meridian. The point of passage from the northerly to southerly deflections lies at about 70 miles from the main boundary, a somewhat greater distance out from the edge of the hills than in the series just dealt with. The southerly deflections at the stations further south are smaller in amount than further east, but it must be borne in mind that this series of stations lies not far from where the general course of the boundary of the alluvium runs about north-north-west ; the deflections due to the trough would, therefore, be more nearly east and west than north and south and the component in the meridian, which is that measured by latitude observations, is necessarily reduced in amount. Still further south larger deflections come in, but here the effect is partly, and probably mainly, due to the southerly deflections in this part of the peninsular area, with which we are not here concerned.

The western series exhibits some peculiarities which it is not easy to explain, though they are doubtless connected with the narrowing of the alluvial area on the continuation of the line of the Aravalli hills. The northerly deflection is maintained for a distance of a hundred miles from the main boundary, and only beyond this distance does a small southerly deflection come in at a couple of the stations in the alluvium. Then, we have the northerly deflections at Agra, and further south the southerly deflections of the northern peninsular area. It is evident that on this section there are other influences at work counteracting the effect of the trough ; or, in other words, that the trough is of smaller dimensions than further east, and no longer has that preponderating effect which was there met with, and it is noteworthy that the stations of Datairi and Bostan, where the northerly deflections show that there is no regular shallowing of the alluvium in a southerly direction, or that it is insignificant in amount, are situated on the direct continuation of the line of the main range of the Aravallis, which may reasonably be expected to continue under the alluvium with much the same surface contour as they show further south.

A third series of latitude stations is situated near the 85° meridian but does not extend across the alluvium, and in its southern portion is affected by some local cause leading to abnormal deflections. In spite of these drawbacks the series gives some information and needs notice. A list of the stations is given in table No. 21 ranged in order of distance from the outer edge of the

TABLE 21.—*Latitude Stations near 85° Longitude.*

STATION.	Distance from edge of Hills.	Observed Deflections.
Pahladpur	60	+ 10
Jalapur	72	+ 10
Dubauli	96	+ 11
Nuaon	110	+ 12
Mednipur	140	+ 12
Bihar		+ 17
Mahar		+ 14
Teona		+ 15
Hurilaong		+ 15
Chendwar		+ 7
Bulbul		+ 13
Mahwari		+ 8

Himalayas, so far as the stations within the alluvial plain are concerned, and in order of latitude in the case of those situated on rock to the south of the alluvial plain. The alluvium here is about 150 miles in width, and, on the road section to Khatmandu, the main boundary lies about 24 miles from the outer edge of the hills; the total width of the Gangetic trough is, therefore, about 170 miles. The southern boundary of the alluvium exhibits a peculiarity in this region which, as will be seen, may not be without influence on the deflections of the plumb-line at stations near its southern boundary; just at the 84° meridian the boundary turns nearly due southwards to the line of the Son River, and eastwards of this numerous outliers of rock rise through the alluvium between the main continuous rock area and a line running about E. N. E., on the continuation of the line of the Son Valley. Over this area the alluvium, between the hills rising from it, is probably nowhere of great depth, and the region as a whole should be included in the rock, rather than the alluvial, area. One station, Bihar, is situated on a small outlier, which is the last visible towards the continuous alluvial plain, another, Teona, is close to the line where it approaches the N-S stretch of the boundary, and a third, Mahar, is on a hill about 15 miles from the line bounding this archipelago of inliers.

Turning to the consideration of the deflections we find that the stations of the alluvial plain show southerly deflections of about 12″; the most northerly is about 60 miles from the outer edge of the hills and probably about 80 from the main boundary. This group of stations indicates an upward slope of the floor of the trough at about 200 feet per mile, or a little less, which would correspond to a maximum depth of about 20,000 feet, and so far the observations accord with what was found further west. The southern part of the section, however, shows some remarkably anomalous features; instead of a decrease of southerly deflections at, and beyond, the southern limit of the trough, we find the very high southerly deflection of 17″ at Bihar and at Teona of 15″. It might be possible to explain these deflections by the effect of the alluvium alone, if we assumed that the upward slope of the floor of the trough was not continuous to the southern margin, but ended in an abrupt rise of some 1,500 to 2,000 feet, an explanation which is not geologically impossible, for the boundary of the rock area, between Teona and Bihar, lies on the continuation of the Son Valley, the line of flexure marking the boundary between an area of elevation, to the south, and of depression, to the north. This structural feature is of great geological age, but it is not impossibly continued under the alluvium to beyond Bihar, and movement may have taken place along it during the formation of the Gangetic trough.

Though not impossible, this explanation is decidedly improbable, even if looked at from a geological point of view alone; regarded as an explanation of the high southerly deflections at Bihar and Teona it might be sufficient, it might even suffice for that found at Mahar, but it fails altogether when the southern stations are considered. Hurilaong, for instance, gives a deflection of 15″, but if the 17″ at Bihar were entirely due to the alluvium, the deflection at Hurilaong should not exceed 4″, at Bulbul 2″ and at Chendwar and Mahwari less than a second; even at Mahar it would take some forcing of the hypothesis to get a deflection of more than 10″. It is evident, therefore, that something besides the alluvium is at work, and that we are within the range of influence of an excess of density, in the rock area to the south of Bihar.

The high southerly deflection at Bihar is, therefore, made up of two parts, of which some 9″ or 10″ may be attributed to the effect of the trough and the remainder to some other cause, such as an underground excess of density to the south. At the stations north of Bihar the effect of this last-named cause must be small; it may be felt, to the extent of a couple of seconds or so, at Mednipur, Nuaon, and possibly Dubauli, but at the stations further north it can have no appreciable effect, and the observed deflections may be ascribed principally, if not wholly, to the effect of the Gangetic trough.

The easternmost group of latitude stations is ranged near 88° of longitude; in table No. 22 a list of those which lie in or near

TABLE 22.—*Latitude Stations near 88° Longitude.*

STATION.	Distance from Main Boundary (in miles).	Calculated Deflections.	Observed Deflections.
Kurseong . . .	4 N.	— 44	— 46
Siliguri	12 S.	— 19	— 18
Jalpaiguri . . .	30 ,,	— 2	— 2
Lohagara . . .	52 ,,	+ 5	+ 6
Chanduria . . .	76 ,,	+ 7	+ 8
Charaldanga . . .	120 ,,	+ 1	+ 5
Madhupur . . .			+ 8

the alluvial plain is given, ranged from north to south. In deciding on the assumption to be made in calculating the deflections which should be expected we encounter the difficulty that, owing to the absence of a belt of foot-hills corresponding to the Siwaliks, it is impossible to form any direct estimate of the depth of the trough next the hills. The gravity determinations, as will be seen, indicate that this is not materially different from the depth in the Dehra Dun region, and so we may take it at about 15,000 feet; the width is less easily determinable, as, though the alluvium extends continuously to the sea-face of the Gangetic delta, the real boundary of the trough probably lies on a line connecting the northern end of the Rajmahal Hills with the western end of the Garo Hills. Here, as has already been mentioned, there is some geological ground for supposing the existence of a ridge of rock, covered by a comparatively shallow layer of alluvium, the crest of which might lie about 20 miles north of Charaldanga, or about 100 miles south of the main boundary, but would probably be more nearly under that station. It will, consequently, be convenient to assume a width of 100 miles and a maximum depth of 15,000 feet for the trough in this region, and the deflections which should result from the effect of such a trough, combined with the effect of the Imaginary Range, are shown in the table.

So far as the stations from the north down to Chanduria are concerned the agreement is very close, and the correctness of the method of calculation is confirmed by Major Crosthwait's calculations which give residuals, after allowing for the effect of visible topography and its compensation, of — 7″ at Siliguri, + 6″ at Jalpaiguri, and + 10″ at Chanduria, as compared with deflections of — 5″ + 3″ and + 8″ allowed for the effect of the assumed trough in obtaining the figures of table 22. Southwards of Chanduria there is a considerable discrepancy at Charaldanga, but here it must be remembered that the width assumed for the trough was only 100 miles; if the width is taken at 120 miles, the southerly deflection at Charaldanga would be increased to about 5″, provided that the effect of the alluvium to the south was small, and this is not an improbable supposition.

The large southerly deflection at Madhupur, which is continued, though in lesser amount at Calcutta, may well be due to another cause than the effect of the alluvium. These stations lie in a region where the geological structure, confirmed, as will be seen further on, by the gravity observations, indicates that the depth of the alluvium is probably small, and that we are outside the limit of the Gangetic trough proper. At Calcutta a boring, which reached a depth of 481 feet, met with deposits indicating the proximity of a rock area, and it is probable that, over the tract separating the Peninsula from the Assam Hills, the depth of the alluvium is to be measured by hundreds, rather than thousands, of feet, so that it can have little effect, either on the deflection of the plumb-line or the force of gravity. We must, in fact, regard this area as belonging, so far as deep-seated structure is concerned, to the Peninsular area, and not to the Gangetic trough.

At the stations north of Charaldanga the deflections are sufficiently accounted for on the supposition of a trough shallowing from a depth of about 15,000 feet near the hills to a shallow depth of alluvium at about a hundred and twenty miles to the south of them, and the conclusion may be drawn that the southern boundary of the deep trough sweeps across, under the alluvium of the Ganges and Brahmaputra rivers, in an easterly or north-easterly direction from the point where its course ceases to be defined by the boundary between rock and alluvium. Whether the trough extends up the valley of the Brahmaputra cannot at present be decided; the geological evidence of the rocky hills in the alluvium, and the structural analogy which exists between the Assam Hills and the Salt Range, at opposite ends of the Himalayas, both suggest that the deep trough does not extend up the valley of the Brahmaputra, and this conclusion is to a certain extent borne out by the easterly deflection of the plumb-line at Jalpaiguri.

At this station Major Crosthwait's calculations show that the effect of the visible topography and its compensation should produce no deflection in either direction, yet observation shows that there is an easterly deflection amounting to 18″ or 13″, according to the Everest and the Bessel-Clarke spheroids, respectively. As this deflection is not due to visible topography we must look to some underground cause, of which a very probable one is to be found in the fact that the station lies near the eastern limit of the Gangetic trough, if this is presumed not to extend up the Brahmaputra Valley. In this case there would be the whole of the trough to the west of the station, unbalanced by any similar extension on the east, and so an easterly deflection would be produced. The magnitude of this deflection is greater than anything met with in the southern part of the trough, further west, and indicates an upward slope, of the bed of the trough, which may amount to as much as 300 to 400 feet per mile, or about 4° of arc, if the whole of the deflection is due to the effect of the trough.

The gravity observations in the alluvial plains have been dealt with by Dr. H. H. Hayden,[1] who showed that they indicated a gradual shallowing of the trough in a southward direction, but it will be well to review the more complete evidence, which is now available. In table No. 23 (page 77) a list of the gravity stations in the region of the Gangetic trough is given, arranged in three natural groups; the first a series ranged from north to south, along the 78° meridian; the second, a more extended group, covers the central portion of the trough, where it reaches its maximum development; and the third ranged along the 88° meridian. The

[1] *Rec., Geol. Surv. Ind.*, XLIII, 163-167 (1913).

TABLE 23.—*Gravity Stations in the Gangetic alluvium.*

Station.	Approximate distance from north and south boundary of alluvium.		Bouguer anomaly for height and mass.	Hayford compensation of the Imaginary Range.	Resulting thickness of the alluvium.	Thickness of the alluvium deduced from Hayford anomaly.
Roorkee	10 :		— ·107	— ·020	13,000	9,500
Nojli	30 :		— ·095	— ·014	12,000	..
Kaliana	40 :		— ·058	— ·008	7,500	4,000
Meerut	70 :	30	— ·027	..	4,000	2,500
Khurja	100 :	30	— ·042	..	6,500	5,500
Gesupur	100 :	10	— ·020	..	3,000	2,000
Aligarh	120 :	40	— ·026	..	4,000	4,000
Hathras	130 :	30	— ·006	..	1,000	1,500
Muttra	150 :	10	000	..	0	1,000
Agra	170 :	0	— ·004	..	500	500
Gorakhpur	50 :	120	— ·101	..	15,000	13,500
Majhauli Raj	60 :	100	— ·079	..	12,000	12,000
Muzaffarpur	60 :	70	— ·061	..	9,000	9,000
Sultanpur	100 :	70	— ·040	..	6,000	..
Arrah	100 :	50	— ·083	..	5,500	7,000
Buxar	110 :	40	— ·023	..	3,500	5,000
Moghalsarai	150 :	20	— ·013	..	2,000	2,500
Allahabad	160 :	20	+ ·002	..	0	..
Sasaram	150 :	0	— ·002	..	0	2,000
Siliguri	10 :		— ·137	— ·045	14,000	9,000
Jalpaiguri	30 :		— ·096	— ·020	11,500	6,000
Kesarbari	50 :		— ·043	— ·008	5,000	..
Ramchandpur	80 :		+ ·001	..	0	..

first column of the table gives the name of the station, the second the approximate distance from the northern and southern boundaries of that portion of the Gangetic trough which is covered by the Gangetic alluvium. These distances, consequently, differ from those used elsewhere, which are measured from the main boundary on the north, the difference being due to the fact that the position of the main boundary is uncertain for a large portion of its course, where it runs through the territory of Nepal, and partly to the fact, which will appear further on, that the northern boundary of the alluvium marks a distinct break in the floor of the trough, in that portion of the range where the Siwalik region, the foothills of the Sub-Himalaya, is distinctly developed. On the south the distances are measured from the boundary of the trough proper, so far as it can be inferred from surface observations, excluding the spreads of, presumably shallow, alluvium with inliers of rock rising from it, which belong more properly to the rock area of the Peninsula than to the Gangetic alluvium. The third column of the table gives the Bouguer anomaly, or the difference between the observed value of gravity at the station and the theoretical value, after allowing for the effect of latitude, altitude, and the attraction of the mass above sea level, reckoned as rock of average density.

This anomaly is negative at every station but two, where its positive value is so small as to be practically non-existent; in other words, there is everywhere an apparent defect of gravity. At the stations nearer to the Himalayas a part of this defect is due to the compensation of the range, and in the case of these stations the fourth column gives the amount which this compensation would be in the case of the Imaginary Range, a figure which is slightly, but not materially, less than the compensation of the actual range as calculated by Mr. Hayford's tables. After allowing for this there still remains a defect which may be due to various causes, of which one is the defect of density of the Gangetic alluvium as compared with an equal bulk of average rock, and in the fifth column is the depth of alluvium, to the nearest 500 feet, which would be equivalent to the anomaly of gravity at the station.

It must not be supposed that these figures necessarily represent the actual depth of the alluvium, for they might be modified in various ways; the adoption of the later formula for the variation of gravity with latitude would increase them by about 3,500 feet; the newer densities would introduce only a very slight change at any of the stations, but the effect of distant topography, beyond a radius of 100 miles, and its compensation, which is not taken into consideration, introduces a further correction to the depth of the alluvium. The amount of this last correction has been published in the case of only one of the stations, Arrah, where it is ·028 dyne, and at Dehra Dun, to the north of the group included in the table, it is ·057 dyne; as the effect is in both cases negative it would reduce the numerical value of the anomaly and consequently the apparent depth of the alluvium by from 4,000 to 8,000 feet. All these corrections would, however, affect the stations to much the same extent and, though they would alter the absolute value of the inferred depth of the alluvium, would have little effect on the differences, or at any rate the differences between any two adjacent stations.

Confining attention to these differences alone, it will be seen that in the first group there is a steady decrease in depth as the distance from the northern boundary increases and the southern boundary is neared; the second group repeats the same feature, as does the third, though here the position of the southern boundary can only be inferred from the geological structure of the rock area on either side of the alluvium which stretches southwards to the delta of the Ganges, and from the geodetic observations themselves.

The gravity observations, then, agree with the observations of the deflection of the plumb-line in bearing out the conclusions, which had been drawn from geological examination, as to the general upward slope of the floor of the Gangetic trough from north to south; and the fact that the gravity observations indicate a thickness of less than 500 feet at stations near the southern margin, where the thickness of the alluvium is either known, or may be presumed, to be small, suggests that the various corrections, which have been referred to above, neutralise each other, so that the figures given in the table may be regarded not merely as comparative, but as not far from the actual depth, or at least of about the same order of magnitude as it. There are, however, two considerations which may introduce a modification of this conclusion.

The first of these is the effect of distant topography and its compensation. As has been mentioned, this is greater by about ·030 dyne at Dehra Dun, just north of the stations included in the table, than at Arrah, and as the difference is probably very largely due to the greater proximity of Dehra Dun to the Himalayas, it is also probably greatest at the northern stations of each group, and decreases progressively in the southern. As the effect of this correction would be to decrease the apparent thickness of the alluvium, it is evident that the variation in its amount would decrease the difference between the apparent depths at the northern and the southern stations; and, as the thickness at the southern edge must necessarily be nothing, the result would be an apparent decrease in the depth at the northern stations of each group by some 3,000 to 4,000 feet.

Secondly, we have to consider the effect of a separate compensation of the trough. The amount of this effect is indicated by the figures given on page 62 which show that it would amount to about ·015 dyne at the southern margin, and to about ·040 at thirty or forty miles from the northern margin, or more where the trough has a greater width than 100 miles or a greater maximum depth than 15,000 feet. The former of these figures would neutralise the effect of about 2,000 feet of alluvium, the latter about 5,500 feet to perhaps 7,000 in the central portion of the trough; and so, the difference between the northern and the southern stations, or the apparent depth at the northern stations of each group, would be increased by about 3,000 to 5,000 feet.

From this it will be seen that the modifications introduced by these two considerations practically neutralise each other and the figures in the table remain as the closest approximation to the actual depth of the alluvium which can be attained by this method.

In the last column of the table No. 23, another series of figures is given, based on the Hayford anomalies, where these are available. The thickness given here is not directly deduced from the anomalies, because these are positive at several stations, indicating a negative thickness of the alluvium, which is impossible. The positive anomaly reaches its maximum at Agra, where it is equivalent to the effect of about 2,500 feet of alluvium, and if the thickness at Agra is made equal to 500 feet to bring it into accord with the depth of the alluvium, which is known to be 480 feet at that place, a correction of 3,000 feet must be made to the thickness deduced at the other stations, assuming that the difference in the anomaly is due to a difference in thickness of the alluvium.

In this way the figures in the last column were obtained, and it will be seen that they follow the same general course as those in the preceding column, but indicate a lesser depth at the northern stations. Here, however, it must be remembered that the Hayford anomaly includes the effect of distant topography and its compensation, and if allowance is made for this, the figures in the last two columns would come into very fair agreement with each other, as close, probably, as can be expected. In both columns there are some departures from a regular decrease in depth as the southern margin of the alluvium is approached, departures which may be due to local variations in the force of gravity, quite unconnected with the trough, and also to irregularities in the form of its floor, which may be considerable when expressed in feet, though subordinate to the general slope of the floor. The western group, in its southern half, runs close to the margin of the trough, which here has a course of about N.N.W.—S.S.E., and in its northern half suggests a depth of about 15,000 feet at the outer edge of the Siwalik hills—the northerly continuation of this section across the Dehra Dun being dealt with further on. The central group, situated where the trough attains its maximum breadth, indicates that the maximum depth may reach 20,000 feet or more. The eastern group indicates a depth of about 15,000 feet at the northern boundary, and also the existence of a rock barrier, covered by no great depth of alluvium, connecting the Peninsular area with the Assam Range. This last conclusion is in agreement with the deduction which has already been drawn from the deflection of the plumb-line, and is of interest as showing that the broad expanse of alluvium, which stretches southwards to the Gangetic delta, forms no part of the Gangetic trough.

A confirmation of this deduction is to be found in the gravity observations at the two stations of Kisnapur and Chatra. These are situated on the alluvium, but, in spite of this, both have positive anomalies, the Bouguer being + ·033 and + ·009 dyne, and the Hayford + ·039 and + ·005 dyne, respectively. The high positive anomaly at Kisnapur is evidently the result of a deep-seated excess of density in the rock underlying the alluvium, but its magnitude, and the smaller positive anomaly at Chatra, show that the alluvium cannot have any great thickness, comparable to that in the Gangetic trough, for if there were any great thickness of alluvium the negative effect of the defect in density would more largely neutralise the deep-seated excess of density in one case, and in the other would make the anomaly negative, instead of positive. We may, therefore, reasonably conclude that the alluvium, spread over the gap between the north-east corner of the Peninsular area and the hills of Assam, is of no great thickness, and forms no part of the Gangetic trough, in the sense in which these words are used here, although it has to be coloured the same as the plains of Upper India on a map showing the surface geology.

There remains one station in the alluvial plain which requires separate notice, as the results are somewhat anomalous. This is the station of Monghyr, near the southern margin of the alluvium, where the width of the plain has diminished to ninety miles. Though situated close to the southern edge of the alluvium it gives a Bouguer anomaly of — ·031, and a Hayford of — ·024 dyne, and, as it is difficult to believe that there can be a thickness of over 4,000 feet of alluvium under this station, we must fall back on the supposition that the anomaly is due to a more deep-seated deficiency of density. A similar, though smaller, defect of density at the station of Sasaram, included in table No. 23, suggests that in both cases the anomaly may be due to a deep-seated defect of density in the rocks below the alluvium.

However this may be, the solitary exception, if it be an exception, does not affect the general conclusions which have been drawn from the gravity and latitude observations, conclusions which are besides in agreement with the inferences from geological observations. It is, of course, possible that the results might be due to a defect of density in, or below, the rocky crust of the earth, of an amount and variation similar to that which has been attributed to variations in the depth of the alluvium, but this explanation is not probable, and is inapplicable in the case of the deflections at stations near the main boundary, for these could not be explained by any deep-seated cause, but require a defect in density immediately below the surface, such as would necessarily result from the known facts of geological structure. We may take it, therefore, that the results of geodetic observation at stations on the Gangetic alluvium indicate, firstly, that the southern margin of the Gangetic trough is very much as marked on the map, Pl. 12; secondly, that a large area of alluvium east of the Aravallis does not, properly speaking, belong to the trough, but is merely a thin covering of alluvium laid down upon, and obliterating the unevenness of, an irregular land surface; thirdly, that the alluvium east of the Rajmahal Hills, stretching southwards to the Gangetic Delta and eastwards into the valleys of the Brahmaputra and Barak, also lies outside the limits of the Gangetic trough, and is formed by a comparatively thin covering of alluvium, whose thickness may be measured by hundreds, instead of thousands of feet, and, fourthly, that the Gangetic trough proper, reaches a depth of 15,000 to 20,000 feet towards its northern edge, and that its floor has a fairly regular upward slope to the southern margin.

The geodetic stations in the Punjab plains are fewer in number and more scattered, than those on the Gangetic alluvium, yet, interpreted in the light of the latter, they give some interesting information. A list of the latitude stations, ranged in order of their distance from the main boundary, is given in table 24, from which it will be seen that there is first a northerly deflection, which

TABLE 24.—*Latitude Stations in the Punjab.*

Station.	Approximate distance from main boundary.	Observed deflection in the meridian.	Resulting deflection normal to range.	Deflection due to range.	Remainder.
Ranjitgarh	30	— 2	— 2	— 5	+ 3
Isanpur	50	0	0	— 2	+ 2
Shahpur	55	+ 5	+ 7	— 2	+ 9
Amritsar	85	+ 8	+ 12		+ 12
Sangatpur	90	+ 5	+ 7		+ 7
Rakhi	110	+ 3	+ 5		+ 5
Khimuana	120	+ 1	+ 1		+ 1
Sawaipur	140	+ 3			
Tasing	190	+ 4			
Ram Thal	200	+ 3			
Garinda	230	+ 3			

becomes southerly with increasing distance, increases in amount to a maximum at Amritsar, and then diminishes. This is exactly the character of the change in the deflections noticed in the Gangetic trough, though there spread over a greater distance, and the similarity is more striking if the stations of Sawaipur and the three others following it are left out of count; these, as will be seen by reference to the map, are detached from the rest, and it is doubtful whether the southerly deflections are due to the trough, or to some cause independent of it, such as has been met with south of the Gangetic trough, in the northern part of the Peninsular rock area. To some such cause must be attributed the southerly deflections at the last three stations in the list, which lie within the area mapped as alluvium, but in a region where geological observations show that there is probably no great depth of alluvial cover on the rock floor, and where it is difficult to believe that the southerly deflections can be due to the effect of an alluvial trough.

Omitting these, we have a fairly compact group of latitude and gravity stations which deserve more detailed study, but before this can be done it is necessary to convert the recorded deflections, which were measured in the meridian, into the corresponding deflections normal to the general course of the range, here somewhat north of north-west; it is then necessary to allow for the attraction of the range, the figure used being the deflection calculated for the Imaginary Range at a similarly situated station, and by deducting this from the observed deflection we obtain a remainder, given in the last column of the table, which may be treated as the effect of the trough. Here we see that at the first two stations there is a small deflection away from the range, indicating that they lie a little beyond the point at which the effect of the trough changes from a northerly to a southerly deflection, but these two stations are situated at opposite extremes of the group; at the more centrally situated station of Shahpur, at about the same distance from the main boundary, we have a deflection of 9″ which increases to 12″ at Amritsar, representing a slope of about 250 feet per mile of the bottom of the trough; at the more distant station of Sangatpur this has dropped to 7″ and at Khimuana to 1″ from which we may conclude that both these stations lie outside the limits of the trough, and, consequently, that the alluvium forms a comparatively thin covering over the rocky floor.

Turning to the gravity observations, a list of which is given in table No. 25, we find a high negative anomaly at Pathankot, a lesser one at Ludhiana, and small positive anomalies at the other

TABLE 25.—*Gravity Stations in the Punjab.*

STATION.	Distance from outer edge of hills.	Bouguer anomaly.	Equivalent thickness of alluvium.
Pathankot	1	— ·179	23,000
Ludhiana	30	— ·048	8,500
Mian Mir	90	+ ·004	500
Ferozepore	90	+ ·006	0
Montgomery	180	+ ·003	500

three. Taking the highest of these positive anomalies as the zero and interpreting the difference of the others as due to the lesser density of the alluvium, we obtain the thickness given in the last column, where allowance has been made, in the case of Pathankot, for the effect of the compensation of the range. Here again we find that the stations of Mian Mir and Ferozepore, at about the same distance from the main boundary as Khimuana, seem to lie on a comparatively thin covering of alluvium, which is 8,500 feet thick at Ludhiana and 23,000 feet at Pathankot. From these figures we may conclude that the trough is, on this section, less than 100 miles broad, but has a depth which is comparable with, and possibly quite as great as, that of the much broader trough in the Gangetic region; further, if we take the stations of Mian Mir and Pathankot, the gravity observations give a mean slope of the floor of the trough of about 250 feet per mile, or just about the same as is indicated by the deflection at Amritsar, a station which lies between the other two, and close to where the southern edge of the depression seems to lie.

The conclusions drawn from the Bouguer anomalies require some modification when the Hayford anomalies are used. At Mian Mir and Pathankot these are + ·040 and — ·077, respectively, giving a difference of ·117 dyne, equivalent to the effect of about 17,500 feet of alluvium. The large positive anomaly at Mian Mir precludes this interpretation and the actual anomaly at Pathankot represents a depth of only 11,500 feet, if the anomaly is solely due to this cause. The positive anomaly at Mian Mir shows that the alluvium cannot have any great thickness here, but the anomaly itself must be due to an excess of density in the rocks below the alluvium, and may be deep-seated enough to account for part of the high southerly deflection at Amritsar; some such cause is necessary if the depth of alluvium at Pathankot, deduced from the Hayford anomaly is approximately correct, for this would give a mean slope of only about 120 feet per mile to the floor of the trough, and produce a deflection of not more than 6″ to 7″ away from the range.[1]

The geodetic observations in the Punjab, like those further east, give different numerical results according to the way they are dealt with, but, in spite of this difference in the dimensions of the trough, they agree as to its general form and show that the depression, now filled with alluvium, which has been traced along the southern edge of the Himalayas from near the 89° meridian, continues westwards at least as far as 74°; and that it there maintains the same general character of deepening regularly from the

[1] At this station the adoption of the Bessel-Clarke spheroid would increase the southerly deflection by about 3″ (S. G. Burrard, *Phil. Trans.*, Series A, CCV, pp. 301 and 308).

outer edge towards the hills. The section is not complete but it is probable that the maximum depth is not at the northern boundary of the trough though nearer to it than to the southern, and probably close to the outer edge of the hills, as is found to be the case on the section through the Dehra Dun. The westerly extension of this trough cannot be traced for want of observation, but it is natural to expect that it dies out as the point is reached where the Salt Range impinges on the Himalayas, just as it seems to die out in the east where the Assam range, in a similar manner, bridges the angle between the Himalayas and the ranges separating India from Burma.

The geodetic observations also show, in confirmation of the deduction which was drawn from geological evidence, that the great spread of alluvium in the Punjab differs from that of the Gangetic plains, in that it is formed by a comparatively thin covering over the rocky floor, and only when the hills of the western frontier are approached do we find indications of a trough comparable with that which borders the Himalayas; but this is a matter which cannot be dealt with here.

The observations, dealt with so far, are confined to that portion of the Gangetic trough which lies south of the limit of the hills, and only incidental reference could be made to the form of that portion of the trough which lies within the Siwalik area, between the outer edge of the hills and the main boundary. There are only two series of geodetic observations which cross this boundary, one near the 88° of longitude, where there is only a narrow fringe of hills between the main boundary and the edge of the plain, and the other near the 78° of longitude, where there is an exceptionally complete series of latitude and gravity observations in the Dehra Dun and in the Himalayas on the one hand, and the plains on the other.

Taking the latitude observations first, these are included in table No. 26 (page 87), to which the two northernmost stations of the series in table No. 20 are added, in order to bring the two series into relation with each other. In the table No. 26 the distance of each station from the main boundary, and from the southern edge of the Siwalik hills is given in the second column, these distances being in every case measured in a direct line, normal to the course of the boundaries, and expressed in the nearest whole mile. In the case of the first three stations two values are given for the

TABLE 26.—*Latitude Stations in and south of the Dehra Dun.*

Station.	Approximate distance from main boundary and outer edge of Siwaliks.		Deflections due to Imaginary Range, Siwaliks and Trough.		Observed deflections.
			I	II	
Rajpur	0 & 5 :	19	— 43	— 42	— 44
Dehra Dun, old	1 & 6 :	14	— 33	— 36	— 33
Dehra Dun, new	2 & 7 :	13	— 35	— 33	— 33
Dehra Dun, E. Base	10 :	9	— 25	— 26	— 26
Shorpur	12 :	5	— 23	— 27	— 25
Khajnaur	13 :	6	— 24	— 26	— 23
Lachkua	13 :	2	— 24	— 27	— 25
Bullawala	14 :	1	— 24	— 27	— 25
Amsot	15 :	5	— 24	— 25	— 25
Hatni	16 :	3	— 23	— 26	— 26
Sarkara	32 :	20	— 10	— 10	— 8
Nojli	38 :	22	— 8	— 7	— 10

distance from the main boundary, this being due to the fact that, immediately east of Rajpur, the general course of this boundary is interrupted and thrown southwards for a distance of about five miles, the exact distance being indeterminable as the boundary is covered over with recent or sub-recent gravels. As a consequence of this, a single value cannot be given for the distance from the main boundary of the stations close to this change in its course ; Rajpur, for instance, is a station on the main boundary, so far as the hills to the westwards are concerned, but lies about five miles north of the main boundary so far as it is affected by those to the eastwards.

In the last column of the table is given the observed deflection at each station, and in these it will be noticed that from the Dehra Dun E. Base to Hatni they give practically identical deflections, in spite of the increasing distance from the edge of the main range ; the only exception is the station of Khajnaur, at which the northerly deflection is in slight defect, as compared with the other stations, a defect doubtless due to the position of the station on the northern slope of the Siwalik Range, where it is subject to a purely local southerly attraction which would easily account for the small defect in the northerly deflection. Form this uniformity in the deflections over so broad a strip it is evident that there is some cause at work, counteracting the decrease in deflection which would otherwise take place with increasing distance from the main boundary, and the first supposition which was investigated was that this cause is the attraction of the mass of the Siwalik plateau, above the general level of the plain. The figures given in table No. 6 show that this would produce a southerly deflection of about 14″ at the northern boundary, decreasing to zero in the centre, about coincident with the position of the Dehra Dun E. Base station, and a northerly deflection in the southern half, increasing to about 14″ at the southern edge. This effect was added to that of the Imaginary Range and of a trough of uniform depth of 15,000 feet; and the sum, converted into the meridian, by allowing for the departure of the course of the range from due east to west in this region, is given in column I of the table.

It will be seen that the figures are in very fair accord with the result of observation, except in the case of the two stations at Dehra Dun, but here the uncertainty as to the precise course of the main boundary, under the surface gravels north-eastwards of the stations, introduces so great an uncertainty into the calculation of the deflections to be expected at them, that these two stations might well have been left out of account in this connexion. Apart from this, the hypothesis not only gives about the same difference between the deflections at Rajpur and at the Dehra Dun E. Base station, and the group beyond it in the Siwalik hills, but provides for the same uniformity of deflection, at all distances between 10 to 16 miles from the main boundary, which is exhibited by the actual deflections; and this uniformity would not be seriously disturbed by a difference of anything under 5,000 feet in the assumed depth of the trough, though the actual figures, and the difference between the calculated values at Rajpur and Hatni, would be somewhat increased or diminished as the case might be. An assumption that the depth of the trough decreased continuously with increased distance from the main boundary would seriously disturb this uniformity, for it would introduce a rate of decrease in the northerly deflections which would more than counterbalance the effect of the Siwalik plateau, and require a distinctly greater northerly deflection at the Dehra E. Base station than at those further removed from the main boundary. From this we might conclude that the depth of the trough at Rajpur is somewhere about 15,000 feet and that this depth is maintained in a southerly direction to a distance of 30 or 40 miles from the boundary, before the shallowing of the trough begins.

This, however, is not the only possible explanation, or the only supposition which will fit in with the facts. If we supposed the depth of the trough under the Siwaliks to be about 10,000 feet the effect of the defect of density through this depth would be approximately equal in amount to that of the Siwalik plateau, but opposite in sign. The two would, in these circumstances, neutralise each other, and if we then supposed the trough to be deepened outside the Siwaliks, or, in other words, the floor of the trough to form a step upwards under the outer edge of the Sub-Himalayan region, we would have much the same effect produced as in the supposition just examined. In reckoning the effect of such an hypothesis as has been outlined it will be necessary to make some modification in the distance from the outer edge of the hills, as given in table No. 26, for the two stations Lachkua and Bullawala. The distances given in the table are measured from the outer edge of the visible hills, as marked on the one 1-inch map, but it is not reasonable to suppose that a rise in the floor of the trough, if it exists, would follow all the sinuosities of the boundary between the hills and the gravel slope at their base, and these two stations are situated where the outer edge of the hills takes a distinct curve inwards from its general course. If we suppose that the rise in the floor of the trough spans this inward bend, these two stations would lie at some three or four miles from the course of the rise, or from the edge of the deeper trough. Making this allowance, and assuming a depth of 10,000 feet under the Siwalik plateau and of 15,000 feet outside it, we get the figures given in column II of the table, which will be seen to agree almost equally well with the results of observation as those in column I. A slightly closer agreement might be obtained by varying the assumed depth of the trough outside and within the Siwalik area, but no real advantage would be obtained by trying to attain a greater degree of precision than the method permits.

As has already been pointed out, the calculations, both of the observed deflections and of the deflections which are to be expected on any given hypothesis, involve the adoption of certain assumptions, which in no case exactly agree with what is found in nature, but are approximations to the conditions which are either known, or may be expected, to exist. A variation in these assumptions would produce a change in the absolute value of the deflections given in the table, but any such variation, if applied to every station, would produce a similar change in all, and the differences would be little affected, or in many cases not affected at all. Consequently we may take it that the form of the underground floor of the Gangetic trough is similar in kind to one or other of the two assumptions involved in columns I and II of the table. We may be certain that the Siwalik region does not cover a deepening of the trough; but whether the floor continues underneath it with very little change of level, or whether there is a marked drop, and deepening of the trough just outside the limits of the Siwaliks, cannot be determined from the latitude observations alone.

The gravity stations in the Siwalik region of the Dehra Dun are seven in number, and for two of these only, Rajpur and Dehra Dun, has the Hayford anomaly been published. A list of these stations is given in table No. 27, where two other stations to

TABLE 27.—*Gravity stations in and south of the Dehra Dun.*

STATION.	Distance from main boundary.	Bouguer anomaly.	Hayford compensation of Imaginary Range.	Residue expressed as depth of Trough.
Rajpur	0	— ·124	— ·073	15,000
Kalsi	0	— ·098	— ·073	7,500
Dehra Dun	2	— ·126	— ·067	12,000
Fatehpur	6	— ·100	— ·056	7,500
Hardwar	7	— ·114	— ·053	10,000
Asarori	9	— ·112	— ·048	10,000
Mohan	14	— ·104	— ·039	10,000
Roorkee	25	— ·107	— ·024	13,000
Nojli	38	— ·095	— ·015	12,000

the south are included, in order to bring the series into connection with the stations in the alluvial plain, which have already been dealt with. As before, the first column gives the name of the station, the second its distance from the main boundary, the Bouguer anomaly of gravity is given in the third column and the gravitation effect of the compensation of the Imaginary Range in the fourth. Finally the depth of the trough is given, to the nearest 500 feet, on the supposition that the whole of the unexplained residue of the anomaly is due to the defect in density of the material contained in the trough. These depths were obtained from table No. 18, where the effect of a 15,000 feet deep trough is given, the depth in table No. 27 bearing the same proportion to 15,000 feet as the unexplained anomaly to the deficiency of gravitation which should be met with at a station similarly situated on a trough 15,000 feet in depth.

The first point to be noticed in the table is that the depth of the trough at Rajpur is given as 15,000 feet, which happens to be exactly the figure assumed at the outset as somewhere near the actual throw of the main boundary fault, but, as has been explained, no great importance can be attached to the precise figure. The second point to be noticed is that the western stations of Kalsi and Fatehpur give much smaller depths of the trough and, at first sight, seem to indicate that the throw of the main boundary fault in this section is only about one half as great as on the Rajpur-Dehra Dun section. The correctness of this conclusion is, however, open to doubt, owing to the unknown effect of the break in the general course of the main boundary just east of Rajpur, and this doubt is confirmed by a consideration of the Hayford anomalies. These have positive values, of + ·003 at Dehra Dun and + ·022 at Rajpur, thus following the general rule that the Hayford anomaly has a positive value as compared with the Bouguer, but the amount of the difference is greater than at stations further removed from the Himalayas; and, moreover, the anomaly is greater at Rajpur than at Dehra Dun. There are two possible explanations of these differences, between the Hayford anomalies at Rajpur and Dehra Dun and between the Bouguer anomalies at these and stations further west; they may be due, either to a variation in the depth, and consequent effect, of the trough, or to a difference between the real and the calculated effect of the compensation of the range, for all other changes, introduced by the difference in the method of calculation, as well as by the effect of any cause not considered in the calculations, would affect both stations in exactly, or very nearly exactly, the same degree and direction.

From this it appears that these stations, close to the main boundary, cannot be used with any degree of safety in determining the form of the trough, or in other words, they belong more properly to the region of the range and will be more profitably dealt with in that connexion. It also follows that the gravitation observations close to the main boundary cannot be used to confirm or qualify the results obtained from the deflections.

Southwards of the stations just considered, and now at a sufficient distance from the edge of the range proper to make it probable that the difference between the actual and the calculated effect of the compensation will not be great, come the three stations of Asarori, Hardwar, and Mohan, all situated on the line of the Siwalik Hills, and all indicating a depth of about 10,000 feet. Southwards of these again come the two stations in the alluvium indicating a depth of 13,000 and 12,000 feet. Here again it is not the exact figures which are important, although it has been shown that they are probably of much the same order of magnitude as the actual depths, but the very definite indication of an increase in depth of the trough to the south of the edge of the Siwalik Hills. The amount of this difference is 3,000 feet as between the stations in the Siwaliks and Roorkee, but Roorkee is separated by about 15 miles of plain from the Siwalik Hills, and the stations to the southward indicate a progressive decrease in depth at the rate of about 250 feet per mile for some forty miles from Roorkee. If this average slope continues northwards from Roorkee towards the hills, the actual rise in the floor of the trough may well amount to the 5,000 feet assumed when dealing with the deflection of the plumb-line.

The gravity observations may also be treated in another manner. At the four stations of Rajpur, Dehra Dun, Roorkee, and Kaliana, we have both the Bouguer and Hayford anomalies, from which it is easy to obtain the correction from the one to the other at those stations. If, then, these corrections at the four stations are plotted on squared paper, the stations being ranged according to their distances from the main boundary, a curved line can be drawn through the four points which will approximately indicate the correction which would be applicable to a station at some other distance from the main boundary, and by applying this correction to the published Bouguer anomalies, we can get an approximate value for the Hayford anomaly, which should be correct to the first two places of decimals. The values obtained by this method are given below, where an asterisk means that the anomaly is an estimated one; the figures are :—

	Distance.	Anomaly.
Rajpur	0 miles	+ ·022
Kalsi	0 ,,	+ ·047
Dehra Dun	2 ,,	+ ·033
Fatehpur	6 ,,	+ ·01*
Hardwar	7 ,,	— ·01*
Asarori	9 ,,	— ·01*
Mohan	14 ,,	— ·02*
Roorkee	25 ,,	— ·043
Nojli	38 ,,	— ·04*

Here, as before, the irregularity shown by the first four stations is probably connected with the distribution of the compensation of the range, and will be dealt with in the next chapter. At the other stations the anomalies show the same feature as the Bouguer values, and indicate an increase in the negative anomaly of about ·03 dyne as between stations in the Siwaliks and the nearest ones on the alluvial plain. Interpreted as an effect of the alluvium, this means an increased depth of about 4,500 feet.

The general result, then, of an examination of the geodetic observations in the Dehra Dun is that the observations of the deflection of the plumb-line require that the magnitude of the main boundary fault shall be of the order of near 10,000 feet vertical throw; they suggest the possibility, though they cannot establish the existence, of a rise in the floor of the trough coincident with the outer limit of the Siwalik Hills; they show that if such a step exists it must mean a rise of some thousands, probably near 5,000 feet; that in this case the throw of the main boundary fault will be near the lower limit indicated, but will be near the upper limit if the floor of the trough continues under the Siwalik area with no material change in level. Finally, they exclude the possibility of a deepening of the trough under the Siwalik area as compared with its depth under the plains to the south.

The gravity observations, on the other hand, do not enable us to determine the depth of the trough at the main boundary; though they indicate that the main boundary fault has a throw of several thousand feet, they do not enable us to decide, directly, between the two alternatives presented by the observations of the deflection of the plumb-line. Indirectly, however, they do give an answer, for they indicate most unmistakeably that there is a very considerable drop in the level of the floor of the trough at, or near, the southern edge of the Siwalik Hills, amounting to something like 5,000 feet in vertical difference, with a depth of somewhere about 10,000 feet on the one side and about 15,000 feet on the other, of the step.

Taken together, these observations indicate that the boundary of the outer hills, if we could obtain a deep section, would be of very much the same character as the main boundary fault, thus confirming the suggestion, first made by Mr. H. B. Medlicott [1] and subsequently worked out in much greater detail by Mr. C. S. Middlemiss,[2]

[1] *Mem. Geol. Surv. Ind.*, Vol. III, pt. 2 (1864).
[2] *Mem. Geol. Surv. Ind.*, Vol. XXIV, pt. 2 (1890).

that the series of longitudinal faults, traversing the Siwalik region, represent successive positions of the boundary between hill and plain, and that the outermost boundary of the hills marks the position of a similar fault, the latest in date of the whole series.[1]

It is now possible to summarise the conclusions drawn from the separate groups of observations and to draw a generalised cross-section of the trough, as is shown in figure 7. This does not represent any one cross-section, for no one cross-section is complete, but, by a combination of the geodetic and geological evidence of different sections, it is possible to represent diagrammatically the general type of section which would be met with, subject to minor variations, at almost any part of the length of the trough. On the north we have the range of the Himalayas proper, and near the southern edge of it a series of faults, which mark the successive boundaries between hill and plain. The outermost and latest of these faults traverse the region where the deposits of the plain have been compressed, folded and elevated into the foot-hills of the Siwalik zone, the outer limit of which is probably marked by a similar fault.

[1] In Vol. VII of the *Records of the Survey of India*, p. 151, particulars are given of the deflection of the plumb-line at two stations between Rajpur and Mussoorie. The deflections, in the meridian and the prime vertical, are

Mussoorie	36″·5 N	28″·2 E.
Jharipani	52″·5 N	33″·6 E.
Spur Point	53″·2 N	31″·3 E.
Rajpur	47″·7 N	31″·3 E.

It will be seen that the deflections at Jharipani and Spur Point are distinctly greater than at Rajpur; part of this excess is doubtless due to the effect of quite local topography, but these stations are situated rather less than a mile and about half a mile, respectively, from the outcrop of the main boundary fault, that is, in positions where the effect of the trough would be markedly less, and lesser deflections looked for, were the plane of the boundary fault vertical. Not so, however, if the fault had a hade towards the hills, as is indicated by the surface geology; in this case the maximum effect of the trough would be met with to the northwards of the outcrop, and there would not be the same rapid falling-off of the deflections as in the case of a vertical plane of separation between the denser and the less dense rocks. Seeing that a hade of 30° from the vertical would bring the fault directly under Jharipani at a depth of 7,000 to 8,000 feet, figures in good accord with the geological and the geodetic observations, the effect of the trough would be at least as great at Jharipani and Spur Point as at Rajpur, the effect of the range would not be materially different and that of the quite local topography perhaps a little greater. The large deflections at the new stations are, therefore, in complete accord with what was to be expected, and confirmatory of the structure which had been deduced from geological examination.

These observations did not reach me in time to be embodied in the text; the absolute deflections are liable to modification in the manner which has been indicated, and are actually different from the figures printed above, but this does not affect the differences between the deflections at the different stations.

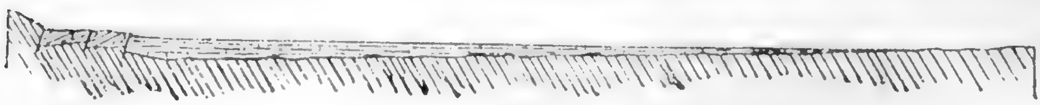

FIG. 7.—Generalised cross-section of the Gangetic trough. This does not represent any individual cross-section but is a diagrammatical representation of the general type; to the left is the Siwalik region with its successive boundary faults, which now forms part of the mountain system of disturbance; to the right is the alluvial trough proper, the floor of which at first slopes downwards to the point of maximum depth, and then gradually upwards to the southern limit of the alluvium.

Leaving the hills, the section enters the area of the alluvial plain and there is an increase in depth of deposit; beyond this the section becomes uncertain for a while and there are two possibilities, one that the floor of the trough slopes upwards from a maximum depth at the edge of the hills, the other that the trough gradually increases in depth for a while before the upward slope of the floor commences, as is indicated in the figure. In either case the greater part of the width is occupied by a sloping floor, rising to the southwards and ending in a rock area, rising above the level of the plain in some sections, and in others covered by a layer of alluvium.

The position of the southern boundary has been referred to when dealing with the different groups of observations. At the eastern end the boundary seems to bend round to the northwards, and the trough to terminate where the Assam range impinges on the boundary of the Himalayas. The next locality where the boundary of the deep trough can be fixed is to the south of Jalpaiguri, where it evidently runs near to the stations of Chanduria and Ramchandpur; the exact position here is doubtful as the deflection suggests that the boundary lies to the southward of, and the anomaly of gravity that it lies very nearly under, or a little to the northward of, Ramchandpur. The distinction between the deep trough and the shallow covering of alluvium must in any case be an indefinite one and cannot be defined with accuracy, but the trough here has a width of certainly 80, and possibly over 100, miles.

In a westward direction the southern boundary of the trough is fixed by the boundary of rock and alluvium at Monghyr and thence sweeps across to Sasaram, the stretch of alluvium to the southward of this line, with rock islands rising from it, being evidently of only shallow depth. From Sasaram westwards the boundary of the trough follows the general course of the boundary of the peninsular rock area, keeping clear of the irregularities and deep indentations of the alluvial boundary, till, west of the 80° meridian, it trends more northwards and from Agra to Delhi runs about north-north-west. In this part of the course the latitude stations help but little as the effect of the trough on the plumb-line would be in a nearly westerly direction, but the gravity observations enable us to place the boundary not far west of Hathras, Chandaos, and Gesupur; the great spread of alluvium, with rocky hills rising from it, to the westward of this line being merely a covering, of a few hundreds of feet at most, over the rocky floor.

From Delhi, where the last outlier of the Aravalli Hills disappears below the alluvium, the boundary of the trough must bend nearly west, for we find it running south of Rakhi and close to Ferozepore and Lahore; the further course cannot be traced with certainty, but the trough appears to be represented as far west as the station of Ranjitgarh, and probably terminates on the west as the Salt Range is reached, just as it ends up on the east where the Assam Range impinges on the Himalayas.

From the southern edge of the trough the floor slopes downwards towards the hills, reaching a depth of probably over 20,000 feet in the broadest part of the trough between 80° and 84°. Near 78° the greatest depth has sunk to not more than 15,000 feet, but further west the maximum depth of alluvium seems to increase again and may rise to as much as 20,000 feet under the plains of the upper Punjab.

We have, therefore, a fairly symmetrical trough, ranged along the whole of that part of the length of the Himalayas which is not complicated by the junction or contact of other ranges; and it is to be noted that the symmetry is in reality greater than appears on the map, for the very marked break in the even sweep of the boundary, and the prominence culminating near Delhi, are not entirely, and need not be in any way, connected with an irregularity in the displacements by which the trough was produced. The prominence lies on the direct continuation of the Aravalli hills, which still stand out, in the southern portion, as a distinct range of hills, rising above the general level of the country on either side, and the termination of the range to the northwards is not in any way connected with its structure, but solely due to a gradual lowering of the general elevation, which has allowed the alluvium to invade the valleys to a greater and greater extent, leaving the higher peaks standing out as rocky inliers in the alluvium, till the range finally disappears in the last exposure of rock at Delhi. There is, however, nothing to suggest that the range does not continue northwards under the alluvium, with the same irregular surface and general elevation above the rock surface on either side, and the geodetic observations indicate the same conclusion. The northerly deflections at Datairi and Bostan occur on the direct continuation of the line of the main range of the Aravallis, and beyond them the gravity observation at Meerut indicates a smaller negative anomaly, which may be interpreted as a lesser depth of alluvium than is found in other similarly situated stations. Still further in the direction of the Himalayas the comparatively small northerly deflection at Sarkára suggests a lesser depth of alluvium under this station than under similarly situated stations further east; and if the line is continued into the Himalayas it strikes a region where the geological structure has suggested the possibility of an original extension of the Aravalli range into what is now the Himalayan region[1]; the geodetic observations have supported this suggestion and converted what was only a bare possibility into something more than a probability.

The existence of a structural feature of such magnitude as the Aravalli Range, extending across the region where the Gangetic trough was subsequently brought into being, would have a twofold effect. In the first place it would introduce a variation in the strength of the earth's crust, and so a difference in the resistance which it would offer to the forces by which the trough was produced, and in the second place the mere fact of the original greater surface elevation of the range would result in the country on either side being soonest brought below the level of the formation of alluvium, and so give rise to an indentation in the boundary and a projection of rock into the alluvial area, quite apart from any possible difference in the amount of the surface warping, by which the trough was produced. In this way the northerly deflections at Datairi and Bostan, which it must be remembered are only northerly if the deflection at Kalianpur is assumed to be as much as 4″ to the south, represent the absence of a regular shallowing of the alluvium to the southwards, or the presence of very considerable irregularities of the under surface, no less than a deficiency of depth, so that the influence of uneven distribution of density in the underlying crust ceases to be masked by the effect of the trough.

[1] *Manual*, 2nd ed, p. 483.

To the eastwards there seems to be a much smaller interruption of the regular sweep of the boundary of the trough in the north-eastern extremity of the peninsular area, to the south of Monghyr, which may be due to an original greater elevation of the land surface as compared with the regions on either side.

Excluding these departures from symmetry, for which quite obvious and adequate causes are apparent, the trough forms a remarkably symmetrical structure extending along the southern face of the Himalayas, from the Salt Range on the west to the Assam Range on the east. A structural feature exhibiting a symmetry and dimensions so closely coincident with those of the Himalayan range can hardly be wholly independent in its origin, and any attempt to account for the formation of one must take cognisance of the origin of the other. This is a matter which will be dealt with further on, but it must be pointed out that the trough, whose form and dimensions have been investigated, is something apart from the great spread of alluvium, stretching from the delta of the Ganges to that of the Indus. To this spread of alluvium the term Indo-Gangetic may be applied with perfect propriety, but it would evidently be incorrect to apply that name to the trough seeing that in no part of its course does the river Indus touch or even approach the deep alluvial trough along the foot of the Himalayas.

There is some reason to suppose that a deep trough filled with alluvium, similar to that which has been dealt with, though smaller in size, runs along the foot of the hill ranges of the western frontiers of India proper, which might be called the Indus trough, as that river traverses it from end to end. The other may be appropriately described as the Gangetic trough, seeing that three-quarters of its length and more than that proportion of its area lie within the drainage of the Ganges, but there is no reason to suppose that the two troughs are connected. Apart from the observations which have been dealt with, the outcrops of old rocks in the Chiniot, and other, hills which rise from the alluvium, point to the presence of a rock barrier, stretching under the plains of the Punjab to the Salt Range and separating the two deep troughs.

CHAPTER V.

THE SUPPORT OF THE HIMALAYAS.

The geodetic stations in the Himalayas, with the exception of a few isolated observations which will be dealt with separately, are ranged along the southern edge of the hills, covering some ten degrees of longitude and a distance of forty miles in from the edge of the hills. The latitude stations are given in table No. 28, arranged in a series of groups, in order of groups from west to east, and, in each

TABLE 28.—*Deflections which would be produced at Latitude Stations in the Himalayas on the assumption used in the text.*

Station.	Miles from main boundary.	Deflections normal to the range due to			
		Range.	Siwaliks.	Trough.	Total.
Kidarkanta	40	— 19	+ 1	— 5	— 23
Lambatach	36	— 19	+ 1	— 5	— 23
Bahak	26	— 20	+ 1	— 8	— 27
Bajamara	18	— 21	+ 2	— 11	— 30
Mussooree	3	— 31	+ 8	— 21	— 44
Banog	3	— 31	+ 8	— 21	— 44
Rajpur	0 & 5	— 41	+ 11	— 23	— 53
Birond	2	— 32	+ 10	— 26	— 48
Kaulia	32	— 19	+ 1	— 5	— 23
Mahadeo Pokra	30	— 20	+ 1	— 5	— 24
Phallut	32	— 19	0	— 5	— 24
Tonglu	20	— 21	0	— 7	— 28
Senchal	9	— 25	0	— 11	— 36
Kurseong	4	— 29	0	— 15	— 44

group, of their distance from the main boundary. In this table is also given a calculation of the deflections which should be expected at each station, in accordance with the assumptions of imaginary topography which have been used in the preceding chapters. These deflections are given in three elements; firstly the effect of the attraction of the Imaginary Range, supposed to be compensated according to Mr. Hayford's factors for a uniform compensation extending to a depth of 113·7 km.; secondly, the effect of the attraction of the Siwalik plateau, where it exists; and, thirdly, the effect of the Gangetic trough, using in each case the cross-section which has been adopted in Chapter IV as most appropriate to the position of each station. The combined effect of these three separate causes is given as the deflection, normal to the range, which should be expected at each station. This deflection requires a further correction, as the general course of the range varies, at the different stations, from nearly east and west to nearly north-west and south-east, and, before the calculated deflections can be compared with those actually observed in the meridian, it is necessary to make an allowance for the direction of the course of the range at each station. This has been done in table No. 29, where the calculated deflections, in the meridian, are compared with those actually observed by the Great Trigonometrical Survey and the difference given in the last column, a minus sign meaning that the northerly deflection, which is found at every station, is in excess, and a plus sign that it is in defect of the calculated deflection.

TABLE 29.—*Latitude Stations in the Himalayas.*

Station.	Distance from main boundary.	Calculated Deflections.	Observed Deflections.	Difference.
Kidarkanta	40	— 18	— 26	— 8
Lambatach	36	— 18	— 30	— 12
Bahak	26	— 22	— 24	— 2
Bajamara	18	— 24	— 24	0
Mussooree	3	— 35	— 32	+ 3
Banog	3	— 35	— 29	+ 6
Rajpur	0 & 5	— 42	— 44	— 2
Birond	2	— 38	— 40	+ 2
Kaulia	32	— 21	— 29	— 8
Mahadeo Pokra	30	— 22	— 34	— 12
Phallut	32	— 24	— 33	— 9
Tonglu	20	— 28	— 38	— 10
Senchal	9	— 36	— 31	+ 5
Kurseong	4	— 44	— 47	— 3

In interpreting these figures it must be remembered that the observed deflection at any station may depart from the average deflection, at a similarly situated station on an average range, by some seconds of arc, owing to the effect of the irregularity of topography in the immediate vicinity of the station. The stations furthest in the hills are situated on peaks, and are not so much affected by this cause as those near the outer edge of the hills, where the effect is considerable. The stations of Mussooree and Banog, for instance, are situated on a ridge with a deep-cut valley on the north, and would therefore show a southerly deflection as compared with similarly situated stations on an imaginary representative of an average Himalaya, and the difference in the observed deflections at the two stations seems sufficiently accounted for by the local topography, which makes the effect of the valley to the north greater at Banog than at Mussooree. At Rajpur, which is situated at the southern foot of this ridge, the effect of the valley to the north is less, and here we have a northerly difference; the mean of the three gives a small southerly difference, or residual, if the effect of the trough has been correctly estimated.

The most conspicuous characteristic of the figures is the excess of observed over calculated deflection in a northerly direction, exhibited at all the stations in the interior of the hills, amounting to from 8″ to 12″, and the smallness of the differences at the outer stations, where the positive differences are as numerous as the negative. Though these characteristics are common to all the groups, it will be well to examine each separately.

In the western group we have first the two stations of Kidarkanta and Lambatach, at a mean distance of a little under 40 miles from the main boundary and giving a difference, or residual, of northerly deflection amounting to about 10″; next the two stations of Bahak and Bajamara, at about 20 miles from the boundary, give a difference of 2″ and 0″ respectively, and thirdly the three stations of Mussooree, Banog, and Rajpur, all within 3 miles of the main boundary, give a mean difference of about 3″ southerly. In all these cases the differences depend in part on the effect of the trough, and the dimensions adopted for this were those which have been deduced as probable ones, namely, 10,000 feet depths under the Siwalik area and 15,000 feet under the plains beyond. The adoption of these figures was largely governed by the fact that tables had been calculated for those depths, and the estimate is probably somewhat in excess of reality; if this excess amounted to as much as 25 per cent., probably an extreme value, the northerly deflections at the three outer stations would be reduced by about 4″ and the mean difference, or residual, altered from + 2″ to — 2″. This change would also affect the stations further in, whereby the differences at Bahak and Bajamara would be altered by — 2″, and at Lambatach and Kidarkanta by — 1″, but there would still remain a difference of about — 3″ as between the outer and the central, and about — 10″ as between the outer and the inner, stations of this group. So, too, a change in the estimate of the effect of the range would alter the estimated deflections at all stations, and only change the value of the differences, of the estimated residuals, by a small fraction of their total amount.

In this group of stations Major Crosthwait's calculation of the effect of the actual complicated topography surrounding two of the stations gives us a good check on the correctness of the conclusions drawn from the method of investigation which has just been outlined. At Lambatach he found a residual of — 18″, using the Bessel-Clarke spheroid, after allowing for the effect of the visible topography and its compensation, but not for the effect of the trough. This latter would account for about — 4″ of Major Crosthwait's residual, leaving — 14″ still unaccounted for, as compared with — 12″ in table No. 29. At Mussooree the residual was — 18″; the effect of the trough, as estimated in table No. 28, is — 17″ in the meridian, leaving a residue unaccounted for of — 1″ as against the + 3″ indicated in table 29. Major Crosthwait's figures thus make the northerly residual of deflection at Lambatach greater by 5″ than at Mussooree, a difference which is increased by some 10″ to 12″ if the effect of the trough is included, bringing it into fair agreement with the difference of — 15″ in table 29. We may therefore conclude that the increase in the unexplained residual of northerly deflection is a real one and amounts to about 10″ at 40 miles into the hills on this section.

The two stations in Nepal show an excess of northerly deflection amounting to about 10″, at a distance of 30 miles from the main boundary, and the same is noticeable in the more complete section in Sikkim, where the difference between the observed and the calculated deflections amounts to — 9″ at Phallut and — 10″ at Tonglu. At the station of Senchal the difference between calculated and observed deflections is + 8″, but the situation of this station is altogether exceptional, and the observed deflection departs largely from the average of similarly situated stations from purely a local cause. Due north of Senchal the deep-cut valley of the Rangit penetrates the range of the Himalayas, and about N.N.E. of the station is the larger valley of the Tista, similarly penetrating the range. I am unable to determine the exact amount of the defect of attraction due to these valleys, but an approximate estimate, made from the 32-mile contoured map of India, shows that the northerly deflection at Senchal is in defect by an amount which is of the order of 10″ to 12″ of arc, as compared with the average of stations at the same distance from the outer boundary of the hills, or with what would have been found at a station situated twenty miles or so west of its actual position. Applying this correction to the observed deflection we find that there remains a small northerly residual of unexplained deflection at this station, instead of the considerable southerly difference shown in table 29.

The effect of these deep-cut river valleys must be felt, though to a lesser degree, at Kurseong, but is there neutralised by the purely local topography, which gives an excess of attraction amounting to about — 4″ of arc, and at this station the difference between the estimated and observed deflections amounts to — 3″.

In this group we have only a single check on the estimates, in Major Crosthwait's calculation of the residual at Kurseong, where he made it amount to — 23″, of which — 15″ would be accounted for by the estimate of the effect of the trough adopted in table 28, leaving an unexplained residue of — 8″ to be accounted for in some other way. In part this is doubtless due to the estimate of the effect of the trough being too small, but the difference between the actual and the assumed dimensions cannot possibly amount to 50 per cent., as would be required if this was a complete explanation, and part of the northerly residual must remain unexplained after full allowance has been made for any possible effect of the trough.

In both the eastern and the western series of stations we have the same feature of only small differences between the actual and the calculated deflections at stations near the outer edge of the hills, if we allow for the effect of the lesser density of the material filling the Gangetic trough, and a high northerly residual of unexplained deflection at stations situated 30 to 40 miles in. This difference amounting to 10″ to 12″ is repeated in the three stations situated between the two groups and may be accepted as not only real, but directly connected with the structure and compensation of the range, rather than with four independent, fortuitous, variations in the density of the rocks which in every case act in the same direction and to the same amount.

In searching for an explanation of these peculiarities it is natural to turn in the first place to a modification of the hypothesis of compensation and a reference to table 8 shows that no help is to be got from supposing an alteration in the depth to which uniform compensation extends, for an increase in depth leads to a larger northerly residual at stations near the edge of the hills than at those further in, and a lesser depth merely gives a nearly uniform southerly residual. Table 9 shows that the adoption of an hypothesis of support by flotation gives some help, for it would give a northerly residual, as compared with calculations from Mr. Hayford's tables, of some 3″ greater than at a station situated outside the range, but as regards stations within the range, situated as are Lambatach and Mussooree, it would merely give a nearly uniform residual of about — 3″. It is obvious, therefore, that the explanation must lie in a departure from a locally complete compensation, and table No. 10 shows that, without going beyond the bounds of an easily accepted departure from the conditions assumed in the other tables, we can account for all the difference which is actually found between stations some thirty or forty miles apart. A supposition of this sort also allows of the passage from northerly to southerly residuals, which is suggested by the figures in table No. 29; but it is useless to pursue this matter further till the gravity observations have been dealt with.

Meanwhile it can be said that the measurements of the deflection of the plumb-line show that, northwards of about 30 miles from the edge of the Himalayas proper, the hills are superelevated, or, otherwise, that the compensation is in defect; but the amount of this departure from normal conditions depends largely on the manner in which it is distributed between the surface topography and the compensation, and this will be considered further on.

Besides the latitude stations, which have been considered, there are three others, separated by a long interval and situated in the north-western extremity of the range. Two of these are in the interior of the hills, on the southern edge of the valley of Kashmir, and will be more conveniently considered further on, the third is the station of Murree, situated near the edge of the Himalayas proper, but separated from the alluvium of the Punjab by some 80 miles of low hills. At this station a northerly deflection of 16″ was observed, of which 10″ are accounted for by the effect of the visible topography and its, Hayford, compensation, leaving a residual of 6″ of northerly deflection, which is reduced to 2″ if the Bessel-Clarke is substituted for the Everest spheroid. Here we find a very different condition from that met with in the stations further east, such as Mussooree, where the Hayford residual is 11″ greater than at Murree, and the difference may reasonably be attributed to the difference in geological conditions. The station of Murree is situated on rocks of the lower part of the Tertiary system, as developed in the Himalayas, and in the deep embayment of the exposure of these rocks, which marks the junction of the Himalayan system of disturbance with that of the ranges beyond the western frontier. The main boundary is not of the same sharply defined character as further east, but south of Murree is a broad expanse of middle and upper Tertiary rocks, and the eastern extremity of the Salt Range. The effect of the trough would be much smaller than on the eastern sections, so far as the deflection of the plumb-line is concerned, and in the absence of other stations for comparison, it is impossible to discover how far the small northerly residual, actually found, is due to the effect of the trough, and how far to an excess of the actual over the calculated attraction of the range, such as was suggested by the eastern stations. In either case the isolated position of the station, with none others near it for comparison, or as a check, makes it impossible to make any further use of the observation, which is, at least, not inconsistent with the conclusions drawn from the stations further east.

A list of the gravity stations in the Himalayan and Siwalik regions is given in table No. 30 (page 106), arranged in groups from west to east, as in the case of the latitude stations. It will be convenient to begin with the eastern group, where the station Sandakphu at about 26 miles in from the main boundary, gives a Hayford anomaly of + ·048 dyne, equivalent to the effect of the attraction of about 1,500 feet of rock at the surface, or of the equivalent of about half as much again, if the effect is due to a deficiency of compensation. At the other two stations we have only the Bouguer anomalies, but an approximate estimate can be made of the Hayford anomalies at these stations, either by applying the Hayford compensation of the Imaginary Range, as given in table No. 11, or by plotting the corrections to the Bouguer anomaly at Sandakphu, and the two stations of Siliguri and Jalpaiguri, and drawing a curve

TABLE 30.—*Gravity Stations in the Himalayas.*

Station.	Distance from the		Elevation.	Bouguer anomaly.	Hayford anomaly.
	Main Boundary.	Boundary of hills.			
Moré	110 N.	150	15,427	— ·435 ?	
Simla	16 N.	34	7,043	— ·119	
Kalka	1 S.	11	2,202	— ·085	
Mussooree	3 N.	21	6,924	— ·110	+ ·049
Rajpur	0	18	3,321	— ·124	+ ·022
Kalsi	0	18	1,684	— ·098	
Dehra Dun	2 S.	12	2,239	— ·126	+ ·003
Fatehpur	6 S.	10	1,434	— ·100	
Hardwar	7 S.	0	949	— ·114	
Asarori	9 S.	8	2,467	— ·112	
Mohan	14 S.	0	1,660	— ·104	
Sandakphu	26 N.		11,766	— ·150	+ ·048
Darjeeling	15 N.		6,966	— ·143	
Kurseong	3 N.		4,915	— ·130	

through the three points, from which the correction at intermediate stations can be estimated. Either method gives a Hayford anomaly of between + ·02 and + ·03 dyne at Darjeeling and of between ·00 and + ·01 dyne at Kurseong. These results are necessarily approximate, but they are sufficiently near the values which would be derived from detailed computation to show that there is an increase in the force of gravity at Sandakphu, as compared with Kurseong, amounting to a departure of + ·05 dyne from the difference which should result from the hypothesis of compensation adopted in the calculations.

The northerly residual of deflection at the two latitude stations of Phallut and Tonglu, situated about 6 miles on either side of Sandakphu, makes it almost certain that the gradient of increase in the anomaly of gravity will continue to the northwards beyond Sandakphu, and that stations further into the hills would show even higher positive anomalies, though it is impossible to say for what distance this increase would continue. Now a gradient of increase in the excess of gravity of ·05 dyne in 30 miles, if continued, would give rise to a deflection of about 9″, if the anomaly were produced by a want of adjustment in the compensation. The actual residual deflection being about 10″, there is as close an agreement between the result of the gravity observations and of the deflection of the plumb-line as can be expected, and the want of adjustment between topography and compensation in this part of the range may be accepted as a fact, the consideration of its interpretation and origin being deferred for the present.

In the western group we have no gravity determinations, of which the Hayford anomaly has been calculated, further into the hills than Mussooree, three miles in from the main boundary, and the same distance in from the outer edge of the Himalayas proper. At this station the Hayford anomaly amounts to + ·049 dyne; at Rajpur, close to the main boundary, the same anomaly was found to amount to only + ·022 dyne, a remarkable difference to find in so short a horizontal distance. Part of this difference is the result of the method of calculation, combined with the fact that Mussooree is situated on the crest, and Rajpur at the foot, of a steep-sided hill, with a difference of level amounting to over 3,500 feet. In the method of calculation adopted, each separate small compartment is supposed to be separately compensated, but it is highly improbable that the compensation can vary as rapidly as the topography in a case like this, and if it varied more slowly the amount would not be largely different in the near-by compartments at each station; the result being that the actual calculation makes the effect of compensation too great at Mussooree and too small at Rajpur, thus increasing the difference between the anomalies at the two stations. Though part of the difference may be explained away in this manner, it is insufficient to account for more than a part, and probably a small part, and so we are driven to find another explanation, which is provided by the defect of density in the Siwalik rocks. If the trough in which they lie is supposed to be 10,000 feet deep, it would produce a difference of about — ·03 dyne at Rajpur as compared with Mussooree, and about — ·02 dyne at Dehra Dun as compared with Rajpur, or about the same differences are found in the calculated anomalies, which take no cognizance of the effect of the trough. We may conclude, therefore, that the actual excess of gravity at Mussooree and Rajpur is much the same and, interpreted as a defect of the compensation, appropriate to the averaged topography of the region, amounts to something less than ·05 dyne.

At Dehra Dun the anomaly is very small, but at this station a negative anomaly should have been expected, on account of the effect of the lesser density of the Siwalik rocks, which certainly extend for some thousands of feet under this station. If the thickness is taken at 10,000 feet and the distance of the station from the boundary of the trough at between 2 and 3 miles, the defect in the attraction of gravity would amount to about ·05 dyne, or much the same as the excess at Mussooree. It will be shown that the excess of gravity, which may be attributed to the want of adjustment of the compensation, decreases in the stations southwards of Dehra Dun, and so we may reasonably conclude that it will be less at that station than at Mussooree, but if the trough is 10,000 feet deep under Dehra Dun, there would need to be an excess of gravity apart from the effect of the trough of not less than the anomaly at Mussooree, and so again we find that the depth of the trough under the Dehra Dun is somewhat under 10,000 feet.

To the southwards of Dehra Dun are some gravity stations at which the Hayford anomaly has not been calculated, but can be estimated approximately by comparison of the corrections at the stations already considered, with those in the plains to the south. Accepting the figures given on p. 92, we find that at Asarori and Hardwar there is an anomaly of — ·1 dyne; as the effect of the trough would amount to at least — ·04 to — ·05 dyne, there is left an excess of gravity of from + ·03 to + ·04 dyne at these stations. At Mohan the anomaly, exclusive of the effect of the trough, is about — ·02, and the effect of the trough will be much the same as at Hardwar, leaving an excess of gravity of about + ·02 to + ·03 dyne. At Roorkee, the Hayford anomaly has been calculated as — ·043 dyne, and if this is directly interpreted in terms of the depth of alluvium necessary to produce the same effect, it represents a thickness of about 6,500 feet, but if interpreted in the terms of difference from Dehra Dun, indicates a depth of about 6,000 feet greater than at the latter station. In the last chapter a figure of 13,000 feet was indicated as the approximate depth indicated by the geodetic data, a figure which agrees very well with that indicated by deduction from the geological structure, and a comparison of this figure with those given in the last sentence suggests that the defect of compensation, found in the stations to the north, still exists under Roorkee, though the effect is reduced in amount to not more than + ·02 dyne. Here, however, we have reached a region where too many corrections of unknown amount have to be applied for the result to be of any real value, but the stations to the northward, in the Dehra Dun district, indicate a gradually increasing excess, as the range is neared, of gravity, which may be interpreted as an increasing defect of compensation.

Northwards of Mussooree there are no gravity stations, but in the group to the westward we have the station of Simla, situated about 13 miles further into the hills than Mussooree, whether we measure the distance from the main boundary or the outer limit of the hills. At Simla the Bouguer anomaly only has been calculated, which is negative and larger in amount than at Mussooree by ·009 dyne; as has been explained, the various corrections required to convert this into the Hayford anomaly would be very much the same at both stations, with the exception of the effect of the compensation of the range itself, and a reference to table No. 11 shows that this effect should be greater at Simla than at Mussooree by somewhere about ·035 dyne. From this it results that we should have expected the Bouguer anomaly at Simla to be greater than at Mussooree by not less than about ·035 dyne, whereas the excess of negative anomaly is just short of ·01 dyne, and it is, consequently, reasonable to conclude that the Hayford anomaly at Simla would certainly be positive and larger in amount than at Mussooree, probably somewhere near + ·08 dyne.

From this it will be seen that the progressive increase in the defect of compensation, as compared with the hypothesis on which the Hayford tables are based, is repeated in this part of the outer Himalayas, and that the magnitude and rate of increase is not very largely different in the two regions if we take the outer edge of the hills as the starting point for measuring distances. If, on the other hand, we take the position of the main boundary as the zero datum for distance, the anomalies are larger in the western group by close on ·05 dyne. Here we have a distinct suggestion that the main boundary, which may be regarded as a dominant feature of geological structure, is not continued into the region of compensation, but is confined to the outer portion of the crust.

This suggestion is an important one, and an attempt was made to test it by a detailed examination of the observations in the Dehra Dun district; the result showed that the apparent discrepancies between the observations were distinctly diminished if the compensation was regarded as distributed with reference to the general course of the range, rather than if it was distributed with reference to the sinuosities of the course of the main boundary; but the result showed that there were also variations in the force of gravity which must be attributed to some other cause, one of which might be a variation in the depth of the trough. There are in fact too many corrections of unknown amount to justify a detailed discussion of the inconclusive results, from which only one conclusion could be drawn, that neither the course of the main boundary, nor that of the outer boundary between hill and plain, coincided in detail with the limit of the compensation of the range.

We have seen that from the outer edge of the hills inwards, there is an excess of gravity, or a defect of compensation, which increases continuously as far as the observations extend, and that these show no indication of the progressive increase coming to an end. Yet it cannot go on for ever, and sooner or later the excess of gravity must diminish and ultimately disappear, and the principle of general isostasy requires that the excess of gravity, which has been established, should be balanced by a corresponding defect on one or both sides, of the under supported tract. To the southwards we can get no direct evidence, owing to the preponderating effect of the defect of density in the alluvial trough, the amount of which cannot be estimated with accuracy. To the northwards we shall have precise information when the observations made by Dr. F. de Filippi's expedition are published, but in the meanwhile we have a good indication of what the nature of these results is likely to be in Capt. Basevi's determination of the force of gravity at Moré. The results obtained by this observer, after having been discredited, have been reinstated and, the cause of the discrepancies between his values and those of later observers having been detected, it is once more possible to make use of his results. Every correction which has to be applied was used by Basevi, with the exception of that for flexure of the stand, the necessity for which had not been recognised, nor means devised for measuring its amount. Had he followed the usual practice of having pillars built at each station it would have been impossible to allow for this correction, but instead he used a strongly braced wooden stand, which was transported from station to station, and later observations, at stations where this stand was used, have so far indicated a fairly constant flexure correction of about ·04 dyne, with variations up to ·01 dyne on either side of the average. Had this stand been used at Moré we should be able to determine the force of gravity, within a limit of ·01 dyne, but it was replaced at this station by a lighter tripod, whose flexure would be different, and greater in amount than in the case of the standard stations; fortunately, however, the same stand was used at Mian Mir, and a later observation by Col. Lenox Conyngham showed that Basevi's determination was in defect by ·109 dyne at that station, a difference which may be attributed to the flexure of the stand used at that station and at Moré.

The published discussion of Capt. Basevi's observation indicates a defect of gravity, or negative anomaly, amounting to 24·11 swings of a pendulum which would beat seconds at the equator, after allowing for the effect of latitude, altitude and attraction of the visible masses above sea level.[1] Converted into modern standards the anomaly becomes ·545 dyne, to which the correction found at Mian Mir may be applied, making the actual anomaly about — ·434 dyne. As the formulæ on which this result is based have been superseded by others, believed to be more accurate, it will be safer to use the more modern value published in the Report of the 1909 meeting of the International Geodetic Association, where the anomaly is given as — ·433 dyne, an allowance of ·107 dyne being made for the flexure of the stand.[2] The two values of the anomaly differ by only ·01 dyne and we may take it that the deficiency at Moré is not far from ·43 dyne, omitting the third decimal figure as meaningless in the circumstances of the case.

This deficiency of gravity represents the effect not only of the compensation of the range but also that of the distant topography. The exact amount of this last has not been calculated in detail, but some estimate can be based on the fact that at Dehra Dun the effect of topography beyond a radius of 104 miles from the station amounts to — ·055 dyne on the Hayford hypothesis, and will not be materially different on any other admissible hypothesis of compensation. At Moré the effect of distant topography would certainly be greater than at Dehra Dun, but is not likely to be twice as much; if it should be as much as — ·100 dyne it would leave — ·33 dyne for the effect of the compensation of the range, a value which is not materially different from the effect of compensation within 100 miles of a station situated 150 miles from the edge of the Imaginary Range, namely about — ·33 dyne if the Hayford

[1] Account of the Operations of the Great Trigonometrical Survey of India, V, p. 147, 1879.

[2] *Comptes Rendus de la seizième conférence générale de l' Association géodésique Internationale.* Vol. III, pp. 222 & 236 (1911).

tables, and about ·29 dyne if the Fisher constants, are used. The compensation of the actual range should somewhat exceed that of the imaginary, for the average level of the ground round Moré is more than the 15,000 feet assumed, but the difference cannot be great, and we may conclude that if the effect of distant topography is as much as —·100 dyne the range is just about completely compensated if the Hayford hypothesis is used, but that if the Fisher constants are adopted it is distinctly over-compensated. If the effect of distant topography is less than ·100 dyne, as seems more probable, then the defect of gravity becomes greater than can be accounted for on either hypothesis, and we reach the conclusion that the range is over-compensated at Moré, just as it is under-compensated at the stations in the outer hills.

Whether compensation is or is not in excess at Moré it is evident that the defect of compensation, which was so conspicuous in the outer hills, has disappeared, and that the station is either within, or on the borders of, the region of excess of compensation which is required to balance the defect met with further south.[1]

The conclusion drawn from the gravity observation at Moré is to some extent supported by the observations at two latitude stations situated on the southern border of the valley of Kashmir. These latitude stations were not included in the final account of the Operations of the Great Trigonometrical Survey, on account of a small uncertainty in their accuracy, due to unfavourable weather conditions, but, as this inaccuracy is certainly less than one second of arc, the results may be safely used for the purpose of this investigation.[2] The western station, Poshkar, is described as situated on a well-marked peak at the end of a spur that projects into the Kashmir valley from the Pir Panjal range, and is evidently situated on the small inlier of Panjal rocks, marked

[1] It may be pointed out that, when discussing the Hayford anomalies of gravity in the alluvial plain, it was necessary to apply, what was in effect, a correction of —·02 dyne, to avoid the obtaining of a negative value for the depth of alluvium. It is not impossible that this represents a real correction to the method of calculation made use of, in which the ocean basins are assumed to be compensated in the same manner, and within the same depth, as the continental elevations, an assumption which is by no means necessarily correct. All that need be considered here is, that any correction of this character would change very slowly in amount, at stations in the interior of a continental area, and would have the effect of increasing the negative value of the anomaly at Moré.

[2] See Operations, etc., XI, 1890, pp. 18 &27, and Synopses of the Results of the Operations, etc., Vol. VII, 1879.

on Mr. Lydekker's map, in the position ascribed to the latitude station. The eastern station, Gogipatri, is described as being on one of the long slopes from the Panjal range. Both stations are in the region of the Karewah deposits, south of the newer alluvium of the valley, and the observations gave a deflection of + 11″ at Poshkar and — 1″ at Gogipatri, using the Everest spheroid and a deflection of + 4″ at the reference station of Kalianpur; deflections which become + 15″ and + 3″ respectively if the Bessel-Clarke spheroid is adopted.

These southerly deflections were attributed by the Trigonometrical Survey to the effect of the southerly attraction of the Pir Panjal range, yet it is doubtful whether this cause would, in itself, be sufficient to produce an actual southerly deflection, though it would necessarily reduce the amount of the northerly deflection due to the Himalayas as a whole. An approximate estimate, based on the 32-mile contoured map of India, gives the outward attraction of the mass between the stations and the plains as about + 20″ and the inward attraction of the masses towards the main range as about — 22″, allowing for the Hayford compensation of the visible masses in both cases, the greater proximity of the hills in the former case about counterbalancing the greater mass in the latter, with the result that only a small deflection in either direction is to be expected.

From this it is evident that the northerly residual of deflection, found at stations up to about 30 miles in from the main boundary further east, has disappeared at these two stations, and this suggests that they lie in the region where the northerly residual, resulting from the defect of compensation in the outer hills, is passing into the region where the excess of compensation in the central part of the range would give rise to southerly residuals. This deduction derives some support from the indications of a general recent uplift of the hills to the north of the valley, but any such inference is rendered unsafe by the fact that the southerly deflection, at both stations, may be due to the effect of the alluvium filling the depression of the valley of Kashmir, which, as in the case of the Gangetic alluvium, would cause an apparent repulsion, or southerly deflection, of the plumb-line. This cause is, indeed, the only obvious explanation of the great difference in the deflections observed at the two stations, for the Poshkar station is just south of the greatest development of the alluvial deposit, which is not only narrower to the north of Gogipatri, but probably shallower also; as suggested by the inliers of rock in the Karewa region to the west, and in the alluvium east of Srinagar.

The unknown amount to be attributed to this cause makes it impossible to determine the amount or direction of the residual of deflection, if the alluvium is taken out of consideration; but the observations do throw some light on an interesting point of geological structure, for they enable us to form some estimate of the depth of the depression of the valley of Kashmir. If we take the difference in the deflections to be entirely due to the effect of the alluvium we find that this is 12″ in the meridian, which is equivalent to about 17″ at right angles to the direction of the boundary of the alluvial deposit, and this, adopting the same density of deposit as in the Gangetic trough, would necessitate a depth of about 10,000 feet, or more. The estimate must be taken as very approximate, and subject to several qualifications, the most important of which are, firstly, the fact that the alluvium will not be altogether without effect at Gogipatri and, as the estimate is of a difference, this would necessitate an increase in the absolute depth; and secondly, the possibility that the southerly attraction of the Pir Panjal range may be greater at Poshkar than at the other station, thus lessening the amount of the difference in deflection which should be attributed to the effect of the alluvium, and so diminishing the thickness to be attributed to it. These two qualifications, therefore, introduce corrections in opposite directions and, as it is probable that both must be considered, they will, to a certain extent, neutralise each other, yet after making every reasonable allowance, there remains the conclusion that the depth of the depression under the valley of Kashmir is of such an order of magnitude as to bring its floor down to, if not below, sea level.

We can now summarise the separate conclusions which have been reached, and attain an understanding of the general distribution of the compensation of the Himalayas. In the central part of the range the compensation is in excess of the load which it is supposed to support; in the outer Himalayas, at a distance of 30 to 40 miles in from the edge of the hills, it is in very considerable defect; and somewhere between these two regions must come a tract where the compensation and topography are in adjustment with each other, where, in other words, the anomaly of gravity should be zero, proper allowance being made for the effect of compensation. Towards the outer edge of the hills the defect of compensation diminishes and the anomaly must ultimately become zero once more.

A variation of this kind in the adjustment between topography and compensation, or between load and support, is with difficulty intelligible, except on the supposition of a support of the range by flotation, and certainly finds easiest expression in terms of that hypothesis. In the centre of the range the downward protuberance of the crust is over-developed and there is an excess of buoyancy, tending to make the range rise, the excess of load in the outer hills would then be an indication that such rise has taken place, carrying with it the outer hills, till the load thrown on the central tract became large enough to check the further uplift and leave the main range at a lower elevation than that which would result from the protuberance beneath it, while, on the flank of this central tract, the outer hills are upraised beyond the height which they would attain by the effect of the support immediately below them. The general distribution of the stresses set up in the mountain range, by this want of adjustment between load and support, would be as shown by the arrows in fig. 8; in this diagram the points O O represent the points at which there is a complete adjustment of the

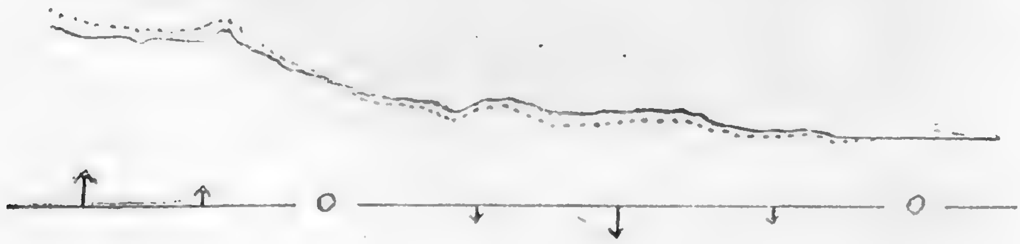

Fig. 8.

Fig. 8.—To illustrate the adjustment between topography and compensation in the Himalayas. In the central region, to the left of the diagram, the compensation is in excess of the load, producing an upward stress, as indicated by the arrows; in the outer region compensation is in defect, and there is a downward stress. The firm line represents the actual contour of the ground, the dotted line, that which it would have if the adjustment between topography and compensation, of load and support, were everywhere exact and complete.

compensation to the topography, not necessarily coincident with the zero points of the Hayford anomaly; to the left there is an excess of compensation, resulting in a tendency of the range to rise as indicated by the arrows; between the two zero points the compensation is in defect and the excess of load results in a tendency for the hills to sink. The same conclusions may be otherwise depicted in the outline of the topography where the firm line represents the section of the range as it actually exists, and the dotted line that which it should be if the topography were everywhere adjusted to the compensation.

One more conclusion may be drawn from the distribution of stresses indicated in the diagram. If the crust has sufficient strength to bear the load imposed on it by the superelevation of the outer hills, it is improbable that the adjustment would cease at the right hand zero point; the load on the tract between the two zero points would tend not only to hold down the central portion of the range from rising but also to bear down the crust on the right into the plastic, denser, layer below, and so we might expect to find a defect of gravity outside the range, quite apart from that due to the defect in density of the alluvium. It will be shown, further on, that there is some indirect evidence of the existence of such a depression of the under side of the crust, but there is no possibility of getting any direct confirmation of it from observations in the alluvial area, for the effect would be masked by that of the trough; and as our only estimate of the depth of the trough, except close to its margins, is derived from the geodetic evidence, any attempt, based on this evidence, to separate out the one effect from the other would be merely arguing in a circle.

The local departures from a condition of equilibrium between topography and compensation, which have been found in the Himalayas, indicate a degree of rigidity, and strength, of the crust greater than that which has sometimes been attributed to it, and this might lead to doubt as to the correctness of the inferences which have been drawn. On this point we have, fortunately, the recent elaborate investigation of the rigidity of the earth's crust by Prof. J. Barrell,[1] in which, after dealing with geological and geodetic data in the United States and elsewhere, he concludes that the crust is strong enough to support a load of over 3,000 feet of rock, har-

[1] *Journal of Geology*, Vols. XXII and XXIII *passim*, 1914-15.

monically distributed over a wave-length of nearly 400 miles,[1] a degree of strength which is much greater than is needed to allow of the local departures from equilibrium which are met with in the Himalayas.

It will be of interest to find where the position of the right hand zero point of fig. 8 lies with regard to the outer edge of the Himalayas. In this connexion we have a suggestion in the fact that the Hayford anomaly near the outer edge of the hills, after allowing for the effect of the Gangetic trough, seems to have a small positive value, of the order of ·01 dyne, on both the Dehra Dun and the Sikkim sections. Too much weight must not be attached to this coincidence, as the actual compensation will not be identical with that adopted in the tables computed by Messrs. Hayford and Bowie, but it is suggestive of the conclusion that the zero point, where the uplift of the outer Himalayas comes to an end, lies beyond the edge of the hills, and under the northern part of the alluvial plain.

This conclusion receives some support on the geological side. Everywhere along the foot of the hills there is a gravel slope, composed as a rule of much coarser material, and having a steeper surface gradient, than the alluvial plain beyond. This gravel slope known in part of Upper India as the *bhabar*, is the result of deposit of coarser material by the streams as they leave the hills, and the steeper surface gradient has generally been attributed to the steeper slope of deposit of this coarser material, as compared with the finer silt of the plain proper. On some sections, however, the increase of surface gradient towards the hills results in a slope too steep to be accounted for in this way, and almost everywhere we find the streams cutting their way through the old gravel deposits at a lower level, and on a lower gradient, than the general slope of the surface. To some extent this may be due to climatic change, but this explanation does not seem adequate, and there remains a distinct suggestion, even where there is not a practical certainty, that there has been a general tilting of the surface and an uplift on the side towards the mountains. It is important to note that this surface tilt is too even and regular to be referred to any compression, folding, or similar process; it is not analogous

[1] Vol. XXIII, p. 30. Not, be it observed, in addition to the weight of the crust itself. This is supposed to be everywhere isostatically supported; it is only the unsupported excess or defect which is borne by the strength of the crust.

to the disturbance which the strata have undergone in the Siwalik hills, but is a general tilt, which may reasonably be attributed to a general displacement of the crust, and to a continuation of the general uplift which is indicated in the outer hills, which, in this case, must extend beyond the limits of the hills into a region where its further progress can only be traced by inference from the geodetic data. It may also be pointed out that this interpretation is in accordance with, and may in some respects be regarded as a confirmation of, the conclusions, independently reached, that the great boundary faults of the sub-Himalayan region are the result of tectonic processes in the outer part of the crust, and do not extend downwards to its lower limit.

The conclusions which have been elaborated, as to the excess of support in the central part of the Himalayas, and the uplift which has thereby been superimposed on the mountain building processes in the outer hills, are of great importance in attaining an understanding of what these processes are, and to what causes they may be attributed. In one respect the question of the origin of the mountains may be regarded as having been put in a new light, for, hitherto, it has been usual to regard the visible range as the primary problem and the provision of support, or compensation, as a secondary one; but, in the light of the results of geodetic work in the Himalayas, the order must apparently be reversed, the primary phenomenon being the production of an excess of buoyancy under the range, in virtue of which the range is uplifted, and the range itself becomes but a secondary, though the most conspicuous, effect of the processes at work.

CHAPTER VI.

SUMMARY AND CONCLUSIONS.

The various groups of geodetic stations have now been considered in detail, and the conclusions, which may be drawn from each, have been indicated, but it is still necessary to review these as a whole and to consider how far they help in the solution of the problems, still in doubt, which were indicated in the opening chapter as those in which the geodetic evidence might help.

These questions will most conveniently be taken in the reverse order to that adopted in stating them, and it may be said that the geodetic observations fully support the two conjectures, that a rock barrier extends, at no great depth below the surface of the alluvium, from the peninsular rock area to that of the Assam Range to the east, and to the Salt Range to the west.

We have also found complete confirmation of the geological deduction that the depth of the alluvium along the outer edge of the Himalayas is great, amounting to about 15,000 to 20,000 feet towards the northern boundary of the alluvial plain, figures which are in complete accord with those deduced from the geological examination of the Siwalik hills.

This agreement, between the results of two wholly independent and different lines of research, leaves little room for doubt that we have reached a correct interpretation of the underground form of the Gangetic trough from near its northern limit to the southern boundary, and that its maximum depth is about 15,000 to 20,000 feet, possibly more on some sections, probably less on others, but in most cases lying within the limits named. From this maximum depth, at a distance of from 10 to 30 miles from the northern edge of the plain, the floor slopes upwards, with a fairly uniform slope, to the southern limit, whether this is marked by the reappearance of solid rock, at the northern boundary of the Peninsular area, or by the hidden barriers under the alluvial plains, over which the drainage of the Ganges and Brahmaputra reaches the Bay of Bengal on the one hand, or the rivers of the Punjab flow down to the Indus and so into the Arabian Sea on the other.

The underground form of the trough in its northern portion, along the edge of the Himalayas, is less clearly defined. On only one section, that of the Dehra Dun, do the observations extend across the Siwalik area to the Himalayas proper, and here they indicate that the maximum depth of the alluvium lies not far from the outer edge of the Siwalik hills, but whether actually at the boundary or at some distance from it is not established. Under the Siwalik area there is a distinct shallowing of the trough, probably abrupt and coincident with the outer edge of the hills, and, at the northern boundary of the Siwalik region, the floor of the trough rises abruptly along the main boundary fault, the throw of which is indicated as something less than 10,000 but probably over 7,000 feet.

Another section, which traverses the whole width of the alluvium near the 81° meridian, but stops short at the foot of the hills, indicates much the same conclusions, that the floor of the trough rises rapidly under the Siwalik area, though here the maximum depth may be 50 miles or more from the edge of the hills. A third section, near the eastern end of the trough, where the Siwalik zone is unrepresented, or covered by alluvium, indicates an increase in depth from south to north almost up to the outer edge of the hills, though a larger number of observations might put the maximum depth somewhat south of the station nearest the hills, at which the largest depth is indicated.

The structure indicated on these sections may reasonably be extended to others, and in it we find a confirmation of the deduction, which had been drawn from geological data, that the underground form of the trough near its northern limit, as well as the nature of the northern boundary, is radically different from what is to be found under the southern part of the trough. To the south of the present line of maximum depth the trough has been formed by simple subsidence and the alluvium deposited on an old land surface, preserved with little or no change in its original form. To the north, the rise is not only more rapid, but more irregular and determined mainly by tectonic processes, connected with the origin of the hills, which have profoundly altered the original form of the floor of deposition, and involved some of the originally undisturbed deposits in the folding and faulting of the process of mountain formation.

Incidentally we find a confirmation of the interpretation which had been accepted, rather than demonstrated, that there is a rise in the floor of the trough under the Siwalik area, and indirectly of the deduction that the outer edge of the hills marks the position of a structure similar in character to the faults which traverse the Siwalik area, and form its northern boundary for a large portion of the length of the Himalayas.[1]

There remains only the question of whether the compression, which the rocks of the Himalayas have unquestionably undergone, is the cause, or merely the accompaniment, of the elevation of the range. The treatment of this question is impossible without considering that of the origin of the Himalayas and a discussion, which need not be detailed, of the explanations which have been offered, of the origin of the Himalayas, and of the closely connected problem of the origin of the Gangetic trough.

It has already been shown that there is some suggestion of the boundary faults, and with them of the tectonic processes which have modified the underground form of the floor of the trough, being phenomena of the upper part of the crust alone, and independent of the more deep-seated changes in the distribution of density on which the compensation depends.[1] This being so, it is obviously possible that the same conclusion might be extended to the whole of the trough, and its existence be regarded as due to processes which were confined to the upper part of the crust proper, with the result that there would be neither need nor reason to look for any more deep-seated cause of origin. The magnitude and extent of the trough seem to make any such localised cause inappropriate, and the radical difference in the form and boundary of the southern part, as compared with the northern fringe, makes it probable that an entirely different set of processes have been at work, and that the trough as a whole may be due to deep-seated and widespread forces, involving the crust, as a whole, and the material which underlies it. In this case we cannot ascribe the trough to any deformation of a part of the crust, such as has profoundly modified the form, and defined the boundary, on the north, but rather to a general subsidence of the crust, increasing in amount from south to north.

In searching for a cause, which could have produced this depression, we must first of all reject the notion that it can be a direct downward pressure due to the weight of the alluvium. The notion

[1] *Supra* p. 109.

that the deposit of sediment on the surface of the earth must cause a subsidence, in consequence of the additional load, is one which has had some vogue; it is unnecessary here to discuss the justification of this idea, it is sufficient to point out that the cause is obviously inapplicable in the case of the Gangetic trough. Not only is the surface of the alluvium at a lower level than that of the rock areas to the north and the south, but the density of the material is very considerably less than that of the rocks on either side; consequently the load borne by the crust in the region of the Gangetic trough must be less than in the Himalayas to the north, or in the peninsular rock area to the south, as is proved by the result of gravity observations in the alluvial plain. But though the weight of the sediment cannot have been the originating cause of the depression of the Gangetic trough, it may well have had considerable influence in determining the magnitude of its dimensions, for if there had been some other cause capable of forcing down the level of the crust to a given depth before the resistance to further movement became equal to the force, then the addition of a load of alluvium would enable the same force to lower the level to a greater extent than if the hollow had been left empty or only filled with water. The amount of this extra depression would depend on the balance between the force and the resistance; if both remained appreciably constant, within the limits of movement involved, the weight of the alluvium would enable this to be carried about five times further than would otherwise be the case, so that the Gangetic trough, taken as 15,000 feet deep, would only have had a depth of about 3,000 feet had it not been filled with alluvium as fast as it was formed.

One such possible cause has been indicated by Mr. Fisher. He pointed out that if material is removed by denudation from the surface of a range, and deposited by its side, the centre of gravity of that portion of the crust comprising the two regions would be shifted laterally, and, on the assumption of a crust supported by flotation, there would be a disturbance of the condition of equilibrium, so that the centres of gravity and of buoyancy would no longer lie on the same vertical line. As a result, a couple would be set up, tending to raise the range and depress the crust alongside it, till the loss of buoyancy under the range, and the gain under the plain, led to a re-establishment of a condition of equilibrium and, as a further result, a depression of the surface would be formed along the foot of the range, which would grow in depth, and in breadth, as the range increased in height. The reasoning is perfectly sound from a mechanical point of view ; given a crust of some degree of strength and rigidity, supported by flotation, the processes conceived will follow with logical necessity, and it is interesting to note that the results of this purely mathematical investigation agree remarkably with the deductions which result from geological examination as to the character of the southern margin of the alluvium, the history of its gradual extension to the south, and the radical contrast in character between the southern and northern margins of the trough. The only doubt is as to whether the cause invoked by Mr. Fisher would be quantitatively sufficient to produce the results, and with regard to this it may be pointed out that the action, which he conceived, would be reinforced by the effect of an increase in the buoyancy under the range, such as has been indicated in the preceding chapter, so that it is possible for the combined effect of the two causes, working in the same direction, to have given rise to the depression of the Gangetic trough, though neither of them would, independently, have been sufficient.

The only test which we can apply to this interpretation is to be derived from the geodetic data. It is evident that a depression of the lower surface of the crust, with the consequent displacement of denser by less dense material, would produce an effect on the plumb-line and the pendulum, it would cause a northerly deflection to the north of the trough, and a southerly deflection to the south, and would give rise to a defect of gravity, greatest along the line of maximum depression and decreasing on either side. These effects, it will be noticed, are similar in kind to those produced by the alluvial trough, but, being much smaller in amount, are so effectively masked by those due to the alluvium itself that it is difficult to disentangle them. An attempt was made, by a comparison of the results derived from the deflections and the gravity observations, to separate out the effect of a possible depression of the crust as a whole from that of its upper surface, the attempt led to an apparent confirmation of the hypothesis, but it involved too many considerations of very doubtful validity to justify the space necessary for its exposition. There are, however, within the area of the alluvium some observations, otherwise difficult to understand, which find an easy interpretation in this way, namely, the very considerable defect of gravity at Monghyr and the lesser defect at Sasaram, which cannot be attributed to the alluvium, but could find an explanation in a depression of the crust into the denser material below, though whether this explanation is valid cannot be established.

It is outside the alluvial area that the test of the hypothesis must be looked for; the boundary of the alluvium would not necessarily coincide with that of the trough, for south of the alluvium the general level of the surface continues to rise, and in this region we may look for effects to be recognisable, which would be masked by others, of greater magnitude, in the alluvial plain. Now the investigation by Sir S. G. Burrard of the deflection of the plumb-line in India, published in 1901,[1] showed that along the northern edge of the peninsular area the deflections were all to the southwards, and that further south comes a belt in which northerly deflections prevail. His investigation established the conclusion that these facts could only be explained by the existence of a belt of excess of gravity, or as he expressed it a Hidden Range, traversing the Peninsula in a direction approximately parallel to the Himalayan Range, and having its crest directly under the station of Kalianpur. This conclusion has since been supported by the gravity observations, and by Major Crosthwait's determination of the residuals of unexplained deflection at a number of stations in India. The highest positive anomalies of gravity are at Kalianpur and Seoni; between these stations and the alluvial plain, positive anomalies prevail, but of lesser amount; and the line of separation between those stations at which Major H. L. Crosthwait obtained a southerly, and those which show a northerly, residual, also runs through these two places and follows almost exactly the course of the "Hidden Range" as indicated by Sir S. G. Burrard in 1901. In the diagrammatic representation, reproduced in fig. 9, of this belt of greater density it is shown as comparatively narrow and steep-sided, and in this form the result would not accord very well with observation, a mass of the form indicated would produce effects distributed very much as shown by the figures in table No. 1, immediately over the crest there would be no deflection, then a gradual increase to a maximum and a gradual dying out again as the distance increased. Actually, however, the observations suggest the existence of local

[1] Survey of India, Prof. Paper No. 5, Dehra Dun, 1901.

irregularities of deflection superimposed on a general southerly deflection, which remains fairly constant over a wide tract of country ; this condition would be satisfied if we supposed the belt of greater density to have the form indicated by the dotted lines in fig. 9, that is to say, instead of being narrow and steep-sided, to be broad with a gentle slope downwards on either side. If the excess of gravity along the crest of the range is taken as equivalent to about ·04 dyne, and the zero point at a distance of about 200 miles, the southerly deflection would be about 3″; and if the slope of the Hidden Range were continued into the depression under the Gangetic alluvium, in the manner which will be suggested immediately, this deflection would continue in fairly constant amount up to and beyond the boundary of the alluvium.

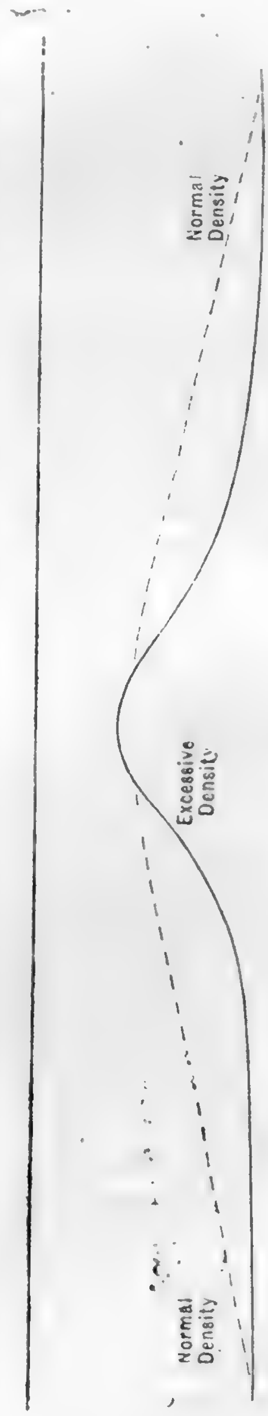

Fig. 9.—Diagram representing the "Hidden Range" of excessive density in the northern part of the Peninsula. The firm line reproduces the original diagram ; the dotted line the modification suggested as being in better accord with the observations.

So far as I know, the only suggestion, which has yet been made, to account for the origin of this Hidden Range, is that the excess of density is due to an intrusion, or series of intrusions, of dense basic or ultrabasic rocks.[1] To this the same objection applies as to any ascription of the effect to a comparatively narrow belt of excessive density, and we must look elsewhere for an explanation of the origin of this feature, which seems marked out, by its courses and position, as in some way connected with the origin of the Himalayas. One such explanation follows, as a natural consequence from Mr. Fisher's interpretation of the origin of the Gangetic trough. Granted the existence of a floating

[1] T. H. Holland. Presidential address to section C. *British Association Report* 1914, p. 358.

crust, of sufficient strength to enable it to be forced downwards into the denser matter underlying it, in the manner which has been outlined, it is improbable that so large a depression would at once die out into a condition of equilibrium on the further side from the hills. The very strength of the crust which enabled the depression to be formed would be likely to uplift the crust, on the further side, beyond the point of equilibrium, before it finally sank down into a normal condition, unaffected by the exceptional circumstances connected with the Himalayan range. In this way the depression of the Gangetic trough would be bordered on the south by a tract where the crust was uplifted, as a whole, with the consequence of the rise of the denser matter from below into the hollow formed in the under surface of the crust, and so give rise to precisely the phenomenon which Sir S. G. Burrard found necessary to invoke, in order to account for the observed deflections of the plumb-line.

The argument of the last paragraph may be made clearer by reference to fig. 10, where a cross-section is depicted, from the centre of the Himalayas to about the centre of the Peninsula, covering about 10° of latitude or a distance of some 700 miles. In this figure the actual relief of the surface is indicated on a somewhat exaggerated vertical scale, in order to make it recognisable; below is represented, on an equally reduced scale, the under surface of the crust, adopting Mr. Fisher's constants of a thickness of 25 miles for the undisturbed crust, and a ratio of 9·6 : 1 between the prominences on the under and upper surface of the crust, respectively.[1] In this part of the figure there are two lines, one firm and the other dotted, of these the dotted line represents the under surface of the crust as it would be if there was at every point a complete compensation of the surface irregularity, the firm line represents the form of the under surface of the crust as it would have to be in accordance with the departures from exact compensation which have been established or inferred. The treatment is in fact the reverse of that adopted in fig. 8, in which the adjustment was made by an alteration of the surface level, and the hills supposed to be either held down or uplifted.

[1] It is obvious that the dotted line, which represents what the under surface should be, were the inequalities in the surface and the Gangetic trough completely compensated under every point, may also be regarded as representing the proportionate amount of the compensation, irrespective of any theory of how it is brought about.

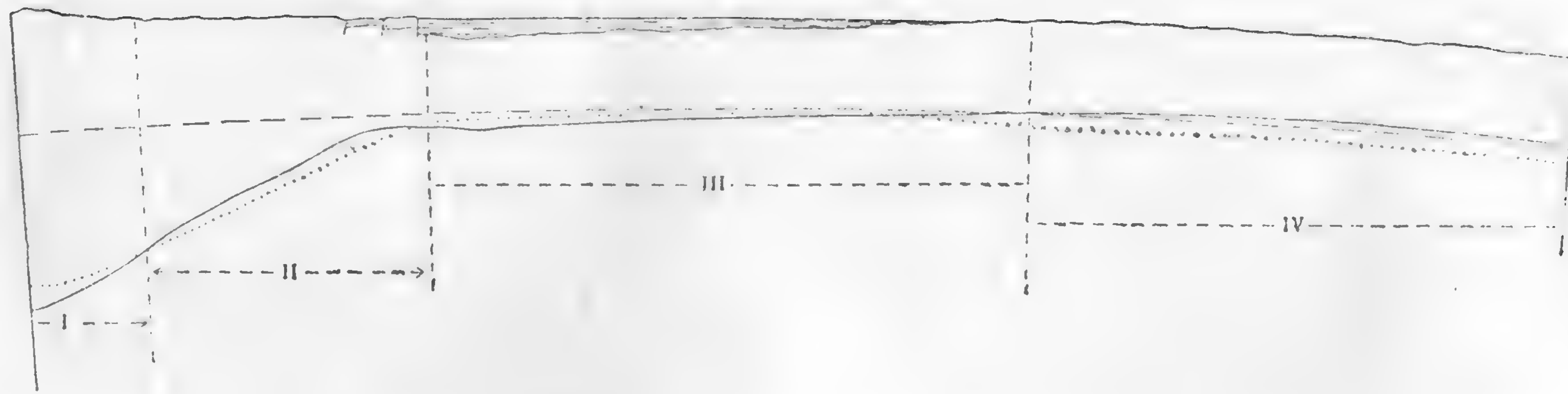

FIG. 10.—Cross section of the Himalayas, Gangetic trough and part of the Peninsula. Above is represented the actual form of the ground and the cross section of the Gangetic trough on a natural scale of curvature of the earth. Below, the broken line represents the assumed original lower surface of the undisturbed crust; the dotted line represents the form of the under surface as it would be if the balance between load and support were everywhere exact, and no local departures from average density in the crust; the firm line represents the actual form of the under surface according to the interpretation elaborated in the text. I is the region of excess of support; II the region of defect of support, where the surface is superelevated by the surplus buoyancy of region I, which is held down by the excess of load in the region II; III is the region of depression of the crust caused by tilting due to the overload of region II; IV is the region where the hills are nearly uncompensated and the crust is uplifted by the downward tilt of region III, to form the "Hidden Range" of Burrard. The length of the section represents a distance of about 700 miles; vertical scale of the upper surface is exaggerated by about one half, of the lower surface reduced by about one-third.

Turning now to the interpretation of these two lines, we see on the extreme left of the figure, that the firm line is below the dotted one, representing the greater depth of "root" required to produce the excess of compensation which exists in this region. To the right, but still within the region of the hills, this excess of compensation disappears and we enter a region where the crust is uplifted, as a whole, by the excess of buoyancy to the left, the hills are still compensated to a large extent, but not completely, and the defect may reach a maximum of about the equivalent of 2,000 feet of rock, or one-sixth to one-fifth of the whole amount of what would be complete local compensation of this portion of the range. Further to the right, this uplift gradually dies out and a condition of equilibrium is reached, at a point somewhat beyond the outer limit of the visible hills, but not maintained, for the weight of the tract which has been uplifted by the excess of buoyancy in the central region bears down the crust on the side towards the plains, and causes the crust to be depressed below the level of equilibrium, giving rise to the depression of the Gangetic trough. This depression reaches its maximum limit and then the buoyancy of the crust, further away from the hills, causes it to bend upwards, till a condition of equilibrium is again reached, at a point which seems to lie not far from the southern boundary of the alluvium, where it attains its greatest development and width, but to lie south of the boundary in the region of the Aravalli hills, and where the Rajmahal hills project into the alluvial area west of the Gangetic delta. Further to the right the condition of equilibrium is, once more, not maintained, but the downward tilt of the crust to the left is continued as an upward tilt to the right, with a corresponding rise of the under surface of the crust, till the weight of the unsupported crust beyond puts an end to this uplift, and the crust bends downwards again into a condition where the influence of the Himalayan range is no longer felt.

It will be seen that this development of the consequences which would result from the hypothesis of a floating crust, supported on a denser, plastic, but not necessarily liquid, substratum, is in close accordance with the larger features of the structure of the country south of the Himalayas. It provides for the trough, for the elevation of part of the earlier deposits formed from the waste of the hills on the north of this trough, and for a gradual extension, by progressive regular subsidence, to the southwards, as the range itself grew in magnitude; it provides also for that belt of positive anomaly of gravity, traversing the Peninsula, with its comcomitant effect on the plumb-line; and it may be added that the strength of the crust, required to produce these effects, is much the same as that deduced by Prof. Barrell from the geodetic work in North America.[1] This agreement, between the results of conclusions drawn from observation and those obtained by deduction, lends considerable support to the hypothesis on which the deductions were based, but it must be confessed that the Himalayas are the only range where anything like this agreement has been found, yet even this may rather strengthen than weaken the support, for it may well result from the magnitude of the range, which is not attained by any other mountains of the world. It is conceivable that only in the mountain system, of which the Himalayas form the culminating member, do the gravitational stresses set up by the processes of mountain formation reach a magnitude which enable them to dominate all other influences, and to produce a simplicity and magnitude of structure, obscured in other cases by the action of other influences and resistances, which become more prominent with the decrease in the magnitude of the gravitational stresses.[2]

We have seen that, the phenomena actually observed, in the region lying in and to the south of the hills, are in agreement with, and are easily explained by, the hypothesis of a solid and somewhat rigid crust supported by flotation on a substratum of denser material; but when we come to consider more especially the range itself, difficulties arise in the acceptance of Mr. Fisher's explanation of a simple thickening of the crust by compression. In his investigation the crust is supposed to be compressed as a whole and, recognising that the resistance of the lower part would be less than that of the upper, the neutral zone was put at two-fifths of the thickness from the upper surface, so that all above this would be thickened upwards and all below in a downward direction. In these circumstances the downward protuberance would be half as large again as the upward one, which would give an insufficient

[1] *Journal of Geology*, XXIII, p. 30 (1915).

[2] Too little is known of the Andes, the only other mountain system of comparable magnitude, to admit of comparison with the Himalayas. [Since this was written, some particulars of deflection of the plumb-line in the Andes have been published, indicating that it varies in much the same manner, and to about the same extent, in these two ranges, which are of very much the same magnitude, in the portions which have a predominating share in the effect on the plumb-line. *Geog. Jour.* XLVII, 464-467, & XLVIII, 180-181, (1916).]

support by flotation, and the range would sink, carrying with it the crust on either side till a condition of equilibrium was attained. This explanation carries with it the necessity of a depression on both sides of the range; it renders the elevation of the marginal deposits almost impossible, and is in contradiction to the excess of support which is actually found in the central Himalayas. The latter condition could, however, easily be met by putting the neutral zone at a higher level. If placed so that the amount of the crust below were ten times that above, which would correspond to a depth of about two and one-third of a mile in a crust of 25 miles in thickness, the downward protuberance would exceed the upward one in just about the proportion necessary to provide a small excess of flotation.

In some respects a neutral zone so near the surface would be welcome, for some of the complicated structures, which have been revealed by geological survey of the more highly disturbed regions of the earth, certainly seem easier of explanation if we can consider the relief from compression as having taken place in a downward, rather than an upward, direction, and it is equally easier to accept these structures as having been brought upwards from a depth of a couple of miles than from five times that depth. On the other hand, a neutral zone so near the surface seems to give an inadequate cover for the production of a complicated folding of hard rocks, such as could only take place, without crushing and fracture, under a heavy superincumbent load of rock. A more important objection to this explanation is the fact that, though it would provide an adequate amount of support, it would not provide for the alternate defect and excess of compensation, which is revealed by observation, for, so long as the neutral zone is maintained at the same absolute level, preserving the same proportion between the thickness of crust above to that below it, the relative dimensions of the upward and downward protuberance would remain unchanged, and the hills would be uniformly over- or under-compensated, as the case might be.

A relief from this difficulty may be obtained in several directions. In the first place if the neutral zone maintained a nearly constant depth from the surface, instead of the same fraction of the total thickness of the crust, the downward protuberance under the central range would be developed in greater proportion to the upward one, and the excess of buoyancy attained. The distribution of resistance to compression, needed to bring this condition about, would be somewhat peculiar, but by no means impossible, yet it must remain merely a suggestion, in the absence of any means of testing it. Another possibility is that, in addition to the thickening of the crust by compression, its density is actually reduced in some way or other, and here Dr. Fermor's suggestion of the passage of rocks, belonging to the same norm, from a mode of greater density to one of lesser, affords a feasible explanation, but, like the previous one, it must remain a mere suggestion.

Neither of these suppositions involves the implication of any fresh material, from outside the portion of the crust covered by the hills, in the process of mountain formation, but the excess of support under the main range might equally be accounted for by an invasion, of the tract under the hills, by material from outside, whether by the injection of acid intrusions, or by a differential movement of the lower and upper parts of the crust, such as could be described indifferently, according to the point of view, as an over-thrust of the upper portion towards the south, or an under-thrust of the lower towards the north.

It is in the last-named direction that the easiest relief occurs from the difficulties arising from a limitation of the cause to the area actually covered by the range. The attribution of part of the downward prominence to an invasion of material from outside the limits of the range, would enable the neutral zone to be brought down to a level which would remove any difficulty in explaining the production of complicated folding of the rocks, but it is important to note that any process of this sort can only be subsidiary to the effect of compression, and that we cannot, on the hypothesis under consideration, attribute the whole, or even the major part, of the elevation of the range, to the invasion of material from outside. The case can be put simply enough : using Mr. Fisher's constants, the total thickness of the crust under the range would have to be just about twice as much as the normal thickness of the undisturbed crust, but these constants, as has been pointed out,[1] represent what may be regarded as a minimum value for the thickening, which may amount to three times the normal thickness ; the hypothesis, therefore, demands a compression of from one-half to two-thirds of the original horizontal extent of the crust. The actual amount of compression, indicated by geological structure, cannot be estimated with

[1] See p. 48.

accuracy but, allowing for all possible over-estimates, it cannot be put lower than one-third, and is probably not much over one-half, of the original extent. It will be seen that the two estimates overlap, so that it is just possible to account for the support of the range, by compression limited to the area covered by the hills; on the other hand, if we take the highest estimate derived from the hypothesis and the lowest possible from observation, the downward prominence produced by compression would have to be reinforced by an equal bulk of material, of similar density, to provide sufficient support for the visible range. These may be regarded as the extreme limits, and the most natural conclusion is that, although simple compression might account for the whole of the support, or might be unable to account for more than one-half, the conditions lie somewhere between these two limits, and probably nearer to the first than the second, so that we may take it that, on the hypothesis which is being considered, the greater part of the support of the range would be provided by the compression, which it has certainly undergone, though a small portion may be attributable to the invasion of material from outside.

The specific question which had been put, of how far the elevation of the Himalayas is the direct result of the compression which they have undergone, seems to have been answered. An hypothesis has been found which is in accord with observation, not only within the limits of the range itself, but in the regions outside the range, where structures closely related to it in geographical extent and, presumably, in origin, are met with. But before this hypothesis can be accepted as in any degree satisfactory, it is necessary to examine the other explanations which have been offered at various times, and it will be of interest to pursue the hypothesis which has been discussed somewhat further, to see whether a satisfactory explanation can be found of the compression which it makes mainly responsible for the elevation of the Himalayas.

To take this last question first, it must be confessed that Mr. Fisher's investigation gives no conclusive answer. He rejected the obvious suggestion that it was due to the contraction of the earth by cooling; the cause may be a real one, it provides a force very many times more than adequate to produce the effect required, but the possible range of motion is almost equally in defect of that necessary to account for the compression which has taken place.

He next investigated the possibility of an expansion of the crust by the injection of dykes; this process seems just about able to produce the amount of force required, but here again the range of motion is inadequate. He finally suggested the existence of convection currents, rising under the ocean beds, flowing outwards along the under surface of the crust towards the continents, and giving rise, by a drag on the under surface of the crust, to compression in the continental areas. This cause, granted the existence of the currents, would produce an ample range of movement, but it is doubtful whether it could produce sufficient force to give rise to a yielding and compression of the crust. The drag exerted by such a current on the underside of the crust would be proportionate to three factors, the co-efficient of friction, the rate of flow, and the length of the tract along which the flow takes place; of these the first would be small, the second probably also small, but the third would be some hundreds of miles, and therefore large, so that the stress, accumulated along a length of the crust, might attain a magnitude sufficient to give rise to compression of the weaker portions of the crust.[1] It seems that, granted the existence of the currents postulated, the effect might be produced, but the conclusion is by no means established, and the postulate has by no means been accepted, very largely on account of the nomenclature adopted.

The notion of convection currents connotes, and was certainly intended to imply, a degree of fluidity which appears difficult to grant, but it is important to observe that similar movements might take place in a material which exhibits none of the properties associated with a fluid, as it exists on the surface of the earth. A material having the properties of the asthenosphere of Prof. Barrell,[2] would have sufficient power of yielding, to long continued stresses, to permit of the existence of movements analogous to convection currents, and so provide the motive power required. Though possible, however, this explanation can hardly be regarded as probable, or even satisfactory, but it is at least a feasible one, and not more unsatisfactory than any other which has been offered as yet.

Of these the first to be considered is that of Prof. Suess which, being incorporated and developed in his great work on the

[1] *Physics of the Earth's Crust*, 2nd ed., 1889, p. 320.
[2] *Journal of Geology*, XXII, 1914, p. 655.

Face of the Earth, has attained a certain vogue, and a considerable amount of influence on geological thought and speculation. This explanation is based on the hypothesis of an originally highly heated solid globe gradually cooling by radiation from the surface, and the effects of surface deformation are attributed to the compression, to which the outer layers of the earth would be subjected, by the gradual contraction of such a globe. In explaining the actual forms, assumed by the surface, great stress is laid on the supposed directions from which pressure was applied, and to which movement took place. In the case of the Himalayas it is specially argued [1] that the form of the range, and of the associated ranges on the eastern and western frontiers of India, can only be explained if pressure was applied from outside towards the steady mass of the Peninsula, and is inconsistent with the supposition that the pressure and movement came from the south. On this view of the case the peninsular area naturally became a foreland, and the Gangetic trough a foredeep; but the whole of the reasoning, on which the conclusion is based, is permeated by two mechanical fallacies.

The first is the possibility of a one-sided application of pressure; but pressure can only exist if there is some resistance, and the resistance necessarily gives rise to an equal and opposite pressure. If these opposing pressures exceed the resistance of the material, compression, and consequent movement, will take place, but the direction and form, which this yielding will assume, is dependent solely on the nature of the resistances, and the amount of movement needful to relieve the pressure. The other fallacy is the possibility of absolute movement, and this will be most easily explained by reference to a diagram; in fig. 11 let A B be two

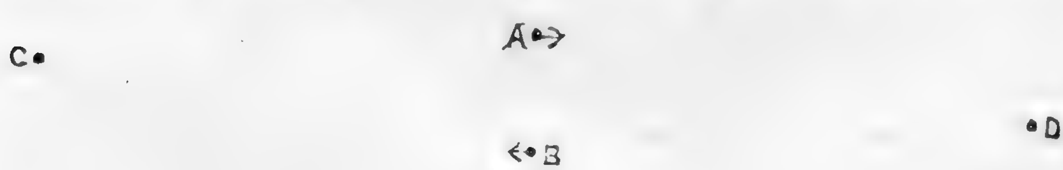

FIG. 11.

points near the outer limit of the Himalayas, C a point well away to the northwards and D one well away to the southwards, and

[1] *Das Antlitz der Erde*, III (2), p. 707. English translation IV, p. 614.

suppose the distance between C and D to be reduced. Then, in the first place, we can only determine the change in distance, and cannot say whether C has moved to the right or D to the left, except by reference to some more distant point, such as the north pole, which again can only be fixed by reference to some still more distant points such as the sun or stars, which obviously have nothing to do with what goes on between C and D. Next, as regards this tract, we may suppose the tract to be uniformly compressed, in which case all the distances are proportionately reduced and the positions of A and B relative to each other are unchanged; or we may suppose the distances from C to A and from D to B to remain unchanged, those from C to B and from D to A being shortened, and in this case the effect will have a different aspect according as it is viewed from C or D. From the side of C it will seem that A has been unmoved while B has been underthrust to the left, but from the side of D the reverse action will seem to have taken place, and A to have been overthrust to the right; so far, however, as A and B are concerned it is only the relative movement which comes into consideration, and the result in either case is the same. From this we see that, as regards the processes which take place within the hills themselves, the question of whether the surface has been overthrust to the south or the lower layers underthrust to the north, is meaningless; the form of the range, and of the structures developed in the rocks of which it is composed, depends on the power of resistance, and the direction in which yielding takes place most easily, and not on the supposed direction from which pressure is applied. In other words the form of the range depends entirely on the distribution of resistances within the hills themselves, and the answer to the question of the direction in which this relief has taken place, depends entirely on the point of view from which it is regarded.

This matter has been dealt with as it seems important to clear it up, for the fallacies referred to are widespread and deep-seated and permeate a great deal of geological and other reasoning. The whole of the arguments based upon them are meaningless, so far as the origin of mountain ranges is concerned, but the fundamental objections to Prof. Suess' theory are, that it fails to provide a sufficient range of movement, and is incompatible with the existence of compensation. The first of these objections can be put simply; given a solid, heated globe, cooling into space, it is possible to calculate the amount of contraction which it has undergone, if certain constants are known. These are, the original temperature of solidification, the co-efficient of contraction, the conductivity, and the temperature gradient; none of these are known exactly, but they are known to lie within certain possible limits, and calculation, based on these, shows that, on this hypothesis, the total decrease in the circumference of the globe, since it became solid, might be as small as a couple of miles and cannot be more than about ninety. In other words the whole of the contraction, which could have taken place throughout geological time, is not greater than the compression of the Himalayas alone, within the limit of the Tertiary epoch.

The other objection is an even more important one; it was foreseen by Prof. Suess, and anticipated by a denial of the existence of compensation. In the case of the Himalayas he must be credited with a greater intuition than many of his successors and followers, for he recognised the fact that an alluvial trough, of the form which had been inferred from geological examination, would account for a large part of the facts on which the concept of the compensation of the range had been based; from this it was not a long step forward to the suggestion that the whole of the facts might be accounted for in this manner, and the absence of any compensation of the range asserted.[1] The position, though difficult, was still tenable at the time when he wrote, but in the light of subsequent observations, and of the investigation of the form and dimensions of the trough in chapter IV, must now be definitely abandoned. There can be no doubt, at the present time, that the Himalayas, as a whole, are compensated, though there are local departures in one direction or the other from exact equilibrium. This being so the only hypothesis of mountain formation which is consistent with a solid, rigid, globe is one of tumefaction, all hypotheses which refer the origin of mountains to compression, due to contraction, being excluded by the impossibility of providing for compensation.

Another explanation of the origin of the Himalayas and the Gangetic trough, which has attracted some attention of late years, is that offered by Sir S. G. Burrard.[2] Like that of Prof. Suess

[1] *Das Antlitz der Erde* III (2), p. 707, English translation IV, p. 614.

[2] On the Origin of the Himalaya Mountains. *Survey of India, Prof. Paper*, No. 12, Calcutta, 1912.

it is based on the hypothesis of a solid heated, cooling globe, but differs in recognising that this hypothesis necessitates the existence of a zone of tension underneath the outermost layers of the crust. The fact that this consequence follows inevitably from the hypothesis, was first pointed out by Mr. Mellard Reade,[1] and once stated is so axiomatic that it immediately met with general acceptance. If we suppose a cooling globe, in which the cooling has only reached a certain distance down from the surface, we have an outer shell, which is contracting and so reducing its circumference, surrounding a central core, which remains unaltered in dimensions, and in these circumstances the outer shell must be thrown into a state of tension. Only in the outermost layers will the general reduction of the bulk of the globe, under the layers which, being already fully cooled, are incapable of further contraction, lead to the existence of compression, and it has been abundantly shown that the zone of tension must be of much larger dimensions than that of compression.[2] Sir Sidney Burrard, however, makes a somewhat different use of this deduction from his predecessors, and considers that the depression of the trough was produced by a withdrawal of material towards the Himalayas, and the range to have been produced by the invasion of the material so withdrawn. Such, eliminating the details of the mechanism invoked, is the essential character of the hypothesis; it seems to involve a greater tensile strength in the zone of extension than can easily be granted, greater certainly than that of any known rocks, as met with near the surface of the earth; but so little is known, or can be known, of the physical properties of the material of the earth, when subjected to the temperatures and pressures which exist in its interior, that we cannot summarily reject the explanation, on this ground alone.

In developing his explanation Sir S. G. Burrard is as insistent on the direction of movement as Prof. Suess, though he insists on the exact opposite, and maintains that the Himalayas are due to an underthrust of the sub-crust from the southwards, instead of an over-thrust of the upper layers from the north. This matter has been dealt with already and it has been shown that the distinction is meaningless, so far as the processes which have taken place within the range itself are concerned; but it is not meaningless

[1] Origin of Mountain Ranges. 1886, p. 123.
[2] *Cf.* O. Fisher, *Physics of the Earth's Crust*, 2nd ed., 1889, ch. VIII, for a discussion of this matter and references to earlier literature.

as regards the region to the south of the range, now occupied by the Gangetic trough, and if this trough is really due to a withdrawal of material towards the hills, we have a process which is the converse of that suggested by Mr. Fisher. In the one case the crust is supposed to have been borne down, displacing a certain amount of denser material from beneath it, in the other the underlying material is supposed to have been withdrawn, leading to a settling down of the lighter material above, and as the form of the resulting trough, developed in Sir S. G. Burrard's latest exposition of his explanation,[1] is practically identical with that resulting from the present investigation, the geodetic effects would be identical in either case, and we have no criterion for discrimination between the two interpretations.

Nor do we get any help from the geological evidence. There is no indication that the region of the Gangetic trough is one of tension, as suggested by Sir S. G. Burrard, but equally there is no certainty that it is not; within the region of the alluvium all evidence, one way or the other, has been obliterated, and only by consideration of the associated phenomena can a criterion be obtained. It has been shown that the view which regards the origin of the Gangetic trough as a consequence of the process of the elevation of the range, and the disturbance produced in the equilibrium of a floating crust, is in agreement with the geological and geodetic observations along the border of the alluvium and in the country beyond; the same cannot be said of the alternative explanation. On the southern side it is not incompatible with the facts, and might give rise to the phenomenon of the Hidden Range of excess of gravity; on the northern, in the region of the Himalayas, there are the same fundamental objections, which were pointed out in dealing with Prof. Suess' explanation, that the hypothesis does not admit of a sufficient range of movement to account for the structure, and that it is inconsistent with the existence of compensation, and more especially of the alternate excess and defect of compensation, of the range. So far, however, as the explanation refers the origin of the Himalayas to an invasion of the region of the hills by the lower layers of the crust, independent of the deformation which has taken place in the upper layers, it is in accord with the investigation which has been developed in this memoir; for it has been shown that the facts, as they are known, seem

[1] *Proc. Roy. Soc.*, Series A, XCI, 1915, p. 233.

incapable of complete explanation without invoking some such action, though the ultimate cause to which it is due has not been established.

The same action is provided for by Mr. Bailey Willis, who attributed the origin of the mountain ranges of Asia to the greater density, and weight, of the crust under the Pacific and Indian Oceans, and to an underground transfer of material, from the oceanic to the continental regions, in consequence of the pressure set up by this difference of weight.[1] At a later date a similar explanation was adopted by Mr. J. F. Hayford, who puts the action as taking place within narrower horizontal limits.[2]

So far as this undertow is supposed to occur at a depth below that in which the contortion of the rocks, now lying near the surface, took place, it is in effect similar to that of Mr. Fisher's convection currents; but while these supply a continuous action, ample to provide for all the range of movement required, the alternative process only provides for a limited and insufficient range of movement, and in both cases it is questionable whether the pressure requisite to produce compression could be communicated to the upper layers of the crust. If, on the other hand, the compression is supposed to take place within the layer involved in the movement of the undertow, the range of motion might be sufficient, but the pressures developed, especially when supposed to be transmitted, through a long horizontal column of material, appear to be utterly inadequate. As has been pointed out before, we know too little of the conditions actually existing in the interior of the earth to reject this explanation as impossible, but, in view of the many difficulties in the way of acceptance, it cannot be regarded as a satisfactory and sufficient explanation of the facts revealed by observation.

One more explanation of the origin of mountain ranges, which may be referred to, is the suggestion of Mr. Mellard Reade.[3] He pointed out that if the average temperature of a tract of the earth's crust was raised, it would expand, not merely in a vertical but also in a horizontal direction, and that the cubical expansion of the whole tract would most naturally find relief by yielding along a

[1] *Research in China*, Vol. II, Chap. VIII, 1907.
[2] *Science*, new series, XXXIII, 1911, pp. 199-208; *Journ. Geol.*, XX, 1912, 562-578.
[3] The Origin of Mountain Ranges. London, 1886.

line of weakness, where the rocks would be compressed, and thickening of the crust take place. If the temperature then sank, the material would not return to its original position, but the contraction be relieved by a general subsidence of the superincumbent rocks and a compressive extension of the lower layers. On an increase of temperature again taking place, relief would once more be found along the original lines, and the disturbance and thickening of the crust accentuated, till, by a repetition of the process, the largest mountain ranges might be formed.

There can be no question that this cause is capable of producing much more than the pressure required, and a sufficient range of movement. It is a cause which might quite conceivably act, but, with the masses involved, the process would be slow, so slow in fact that even the vast periods, which have been deduced from the study of radioactive minerals, would seem insufficient for the production of the effect.

The explanations which have been passed in review do not by any means complete the list of those which have been proposed, but they serve as types, and the difficulties which lie in the way of the acceptance of each of them apply equally to the variants of the type. The general result of the examination is that, while the general distribution of the excesses and defects of gravity agrees best with the supposition of a somewhat rigid crust, supported by flotation on a denser yielding layer, we can, neither on this nor any other hypothesis of support, find an explanation of the origin of the Himalayas, which can be regarded as complete and satisfactory; nor does it seem possible to offer any alternative which can be accepted. In spite of this negative result the investigation has not been in vain; it was undertaken with no expectation of attaining a solution of the problem of the ultimate cause, to which the elevation of the Himalayas is due, and it has not failed this want of expectation; but it has yielded a fresh criterion, which must be met before any hypothesis can be regarded as acceptable. The conclusions, however, must not, at present, be extended to other ranges of a different type of structure, without corroboration of independent observations, and even in the case of ranges of similar general geological structures, but very different magnitude, such as the Alps, it is not impossible that the difference of scale may seriously vitiate an application of the conclusions, drawn from a study of the greatest range on the surface of the earth. If the conclusions, drawn from a study of the Himalayas, are corroborated by the study of other mountain ranges, an important step forward will have been made, and the problem will become one of accounting for the excess of support, of which the mountains themselves are but a secondary result and manifestation.

INDEX TO GEODETIC STATIONS.

In this list L signifies a latitude, G a gravity, station. Latitudes and longitudes are given to the nearest whole minute. There is some confusion in the longitudes, as the old and revised values of the longitude of the Madras Observatory differ by nearly 3′. The published longitudes of gravity stations are all referred to the revised value; those of the latitude stations usually, but not in every case, to the old values. The published longitudes are given without correction, except in those cases where the latitude and gravity stations are identical, or so close to each other that the use of a different reference for the longitude would lead to confusion. In these cases the longitude of the latitude stations has been revised to the new value; in all others the published figure has been retained, as the small discrepancy is immaterial.

Station.		Latitude.		Longitude.		Elevation (feet).	Table.	Page.
		°	′	°	′			
Chanduria . . .	L.	25	44	88	25	160	22	75, 95
Charaldanga . .	L.	24	53	88	26	149	22	74, 75
Chatra . . .	G.	24	13	88	23	64		81
Chendwar . . .	L.	23	57	85	29	2,817	21	73
Dadawra . . .	L.	27	43	81	43	420	19	
Darjeeling . . .	G.	27	3	88	16	6,966	30	106
Datairi . . .	L.	28	44	77	41	767	20	71, 97
Dehra Dun . . .	G.	30	19	78	3	2,239	27, 30	74, 78, 79, 90, 92, 107, 111
,, , Old . .	L.	30	20	78	3	2,289	26	88
,, , New . .	L.	30	19	78	3	2,240	5, 26	88
,, , E. Base .	L.	30	17	78	1	1,958	26	87, 88
Dewarsan . . .	L.	26	16	80	21	439	19	
Dubauli . . .	L.	25	40	85	20	189	21	
Etora	L.	26	54	80	42	429	19	
Fatehpur . . .	G.	30	26	77	44	1,434	27, 30	91, 92
Ferozepore . . .	G.	30	56	74	37	647	25	84, 96
Garinda . . .	L.	27	56	75	4	1,204	24	
Gesupur . . .	G.	28	33	77	42	691	23	96
Ghaus	L.	27	21	83	6	296	19	
Gogipatri . . .	L.	33	52	74	43	7,752		113, 114
Gorakhpur . . .	G.	26	45	83	23	257	23	
Gurmi . . .	L.	26	36	78	33	575	20	
Hardwar . . .	G.	29	56	78	9	949	27, 30	92, 108
Hathras . . .	G.	27	37	78	3	587	23	96
Hatni	L.	30	13	77	52	3,096	26	87, 88
Hurilaong . . .	L.	24	2	84	24	1,378	21	73
Imlia	L.	27	19	81	8	428	19	
Isanpur . . .	L.	30	38	76	9	874	24	
Jalapur . . .	L.	26	4	84	23	232	21	
Jalpaiguri . . .	G.	26	31	88	44	268	23	105
,, ...	L.	26	31	88	44	280	5, 22	76

Station.		Latitude.		Longitude.		Elevation (feet).	Table.	Page.
		°	′	°	′			
Moghalsarai	G.	25	17	83	6	257	23	
Mohan	G.	30	11	77	55	1,660	27, 30	92, 108
Monghyr	G.	25	23	86	28	154		81, 124
Montgomery . .	G.	30	40	73	6	557	25	
Moré	G.	33	16	77	54	15,427	30	110, 111
Murree	L.	33	55	73	27			104
Mussooree	G.	30	28	78	5	6,924	30	107
,, ...	L.	30	28	78	4	6,937	5, 28, 29	94, 101, 102, 104
Muttra	G.	27	28	77	42	562	23	
Muzaffarpur . .	G.	26	7	85	25	179	23	
Nimkar	L.	27	21	80	32	486	19	67
Noh	L.	27	51	77	41	710	20	
Nojli	G.	29	53	77	40	879	23, 27	92
,, ...	L.	29	53	77	40	929	20, 26	
Nuaon	L.	25	35	84	14	251	21	
Pahargarh	L.	24	56	77	44	1,641	20	
Pahladpur	L.	26	4	85	27	175	21	
Parewa	L.	26	38	81	12	380	19	
Pariaon	L.	25	50	81	22	346	19	
Pathankot	G.	32	17	75	39	1,088	25	84, 85
Pathardi	L.	27	26	82	45	320	19	
Pavia	L.	25	27	80	47	481	19	67
Phallut	L.	27	13	88	3	11,815	28, 29	102, 106
Poshkar	L.	34	2	74	32	8,323		112, 113
Potenda	L.	24	37	81	0	993	19	
Rajpur	G.	30	24	78	6	3,321	27, 30	90, 92, 107
. . .	L.	30	24	78	6	3,500	26, 28, 29	87, 88, 94, 101
Rakhi	L.	29	17	76	9	785	24	96
Ramchandpur . .	G.	25	41	88	33	132	23	95
Ram Thal	L.	28	30	75	3	951	24	
Ramuapur	L.	28	22	80	31	541	19	
Ranjitgarh	L.	32	35	74	40	900	24	96
Roorkee	G.	29	52	77	54	867	23, 27	92, 108

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Part 1.—Annual report for 1878. Geology of Kashmir (third notice). Siwalik mammalia. Siwalik birds. Tour through Hangrang and Spiti. Mud eruption in Ramri Island (Arakan). Braunite, with Rhodonite, from Nagpur, Central Provinces. Palæontological notes from Satpura coal-basin. Coal importations into India.

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Part 3.—Geological features of northern Madura, Pudukota State, and southern parts of Tanjore and Trichinopoly districts included within limits of sheet 80 of Indian Atlas. Cretaceous fossils from Trichinopoly district, collected in 1877-78. Sphenophyllum and other Equisetaceæ with reference to Indian form Trizygia Speciosa, Royle (Sphenophyllum Trizygia, Ung.). Mysorin and Atacamite from Nellore district. Corundum from Khasi Hills. Joga neighbourhood and old mines on Nerbudda.

Part 4.—'Attock Slates' and their probable geological position. Marginal bone of undescribed tortoise, from Upper Siwaliks, near Nila, in Potwar, Punjab. Geology of North Arcot district. Road section from Murree to Abbottabad.

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Part 1.—Annual report for 1879. Geology of Upper Godavari basin in neighbourhood of Sironcha. Geology of Ladak and neighbouring districts. Teeth of fossil fishes from Ramri Island and Punjab. Fossil genera Nöggerathia, Stbg., Nöggerathiopsis, Fstm., and Rhiptozamites, Schmalh., in palæozoic and secondary rocks of Europe, Asia, and Australia. Fossil plants from Kattywar, Shekh Budin, and Sirgujah. Volcanic foci of eruption in Konkan.

Part 2.—Geological notes. Palæontological notes on lower trias of Himalayas. Artesian wells at Pondicherry, and possibility of finding sources of water-supply at Madras.

Part 3.—Kumaun lakes. Celt of palæolithic type in Punjab. Palæontological notes from Karharbari and South Rewa coal-fields. Correlation of Gondwana flora with other floras. Artesian wells at Pondicherry. Salt in Rajputana. Gas and mud eruptions on Arakan coast on 12th March 1879 and in June 1843.

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Vol. XIV, 1881.

Part 1 (out of print).—Annual report for 1880. Geology of part of Dardistan, Baltistan, and neighbouring districts. Siwalik carnivora. Siwalik group of Sub-Himalayan region. South Rewah Gondwana basin. Ferruginous beds associated with basaltic rocks of north-eastern Ulster, in relation to Indian laterite. Rajmahal plants. Travelled blocks of the Punjab. Appendix to 'Palæontological notes on lower trias of Himalayas.' Mammalian fossils from Perim Island.

Part 2.—Nahan-Siwalik unconformity in North-Western Himalaya. Gondwana vertebrates. Ossiferous beds of Hundes in Tibet. Mining records and mining record office of Great Britain; and Coal and Metalliferous Mines Acts of 1872 (England). Cobaltite and danaite from Khetri mines, Rajputana; with remarks on Jaipurite (Syepoorite). Zinc-ore (Smithsonite and Blende) with barytes in Karnul district, Madras. Mud eruption in island of Cheduba.

Part 3.—Artesian borings in India. Oligoclase granite at Wangtu on Sutlej, North-West Himalayas. Fish-plate from Siwaliks. Palæontological notes from Hazaribagh and Lohardagga districts. Fossil carnivora from Siwalik hills.

Part 4.—Unification of geological nomenclature and cartography. Geology of Arvali region, central and eastern. Native antimony obtained at Pulo Obin, near Singapore. Turgite from Juggiapett, Kistnah district, and zinc carbonate from Karnul, Madras. Section from Dalhousie to Pangi, *viâ* Sach Pass. South Rewah Gondwana basin. Submerged forest on Bombay Island.

Vol. XV, 1882.

Part 1 (out of print).—Annual report for 1881. Geology of North-West Kashmir and Khagan. Gondwana labyrinthodonts. Siwalik and Jamna mammals. Geology of Dalhousie, North-West Himalaya. Palm leaves from (tertiary) Murree and Kasauli beds in India. Iridosmine from Noa-Dihing river, Upper Assam, and Platinum from Chutia Nagpur. On (1) copper mine near Yongri hill, Darjiling district; (2) arsenical pyrites in same neighbourhood; (3) kaolin at Darjiling. Analyses of coal and fire-clay from Makum coal-field, Upper Assam. Experiments on coal of Pind Dadun Khan, Salt-range, with reference to production of gas, made April 25th, 1881. Proceedings of International Congress of Bologna.

Part 2 (out of print).—Geology of Travancore State. Warkilli beds and reported associated deposits at Quilon, in Travancore. Siwalik and Narbada fossils. Coal-bearing rocks of Upper Rer and Mand rivers in Western Chutia Nagpur. Pench river coal-field in Chhindwara district, Central Provinces. Borings for coal at Engsein, British Burma. Sapphires in North-Western Himalaya. Eruption of mud volcanoes in Cheduba.

Part 3 (out of print).—Coal of Mach (Much) in Bolan Pass, and of Sharigh on Harnai route between Sibi and Quetta. Crystals of stilbite from Western Ghats, Bombay. Traps of Darang and Mandi in North-Western Himalayas. Connexion between Hazara and Kashmir series. Umaria coal-field (South Rewah Gondwana basin). Daranggiri coal-field, Garo Hills, Assam. Coal in Myanoung division, Henzada district.

Part 4 (*out of print*).—Gold-fields of Mysore. Borings for coal at Beddadanol, Godavari district, in 1874. Supposed occurrence of coal on Kistna.

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Part 1.—Annual report for 1882. Richthofenia. Kays (Anomia Lawrenciana, Koninck). Geology of South Travancore. Geology of Chamba. Basalts of Bombay.

Part 2 (*out of print*).—Synopsis of fossil vertebrata of India. Bijori Labyrinthodont. Skull of Hippotherium antilopinum. Iron ores, and subsidiary materials for manufacture of iron, in north-eastern part of Jabalpur district. Laterite and other manganese-ore occurring at Gosulpore, Jabalpur district. Umaria coal-field.

Part 3.—Microscopic structure of some Dalhousie rocks. Lavas of Aden. Probable occurrence of Siwalik strata in China and Japan. Mastodon angustidens in India. Traverse between Almora and Mussooree. Cretaceous coal-measures at Borsora, in Khasia Hills, near Laour, in Sylhet.

Part 4.—Palæontological notes from Daltonganj and Hutar coal-fields in Chota Nagpur. Altered basalts of Dalhousie region in North-Western Himalayas. Microscopic structure of some Sub-Himalayan rocks of tertiary age. Geology of Jaunsar and Lower Himalayas. Traverse through Eastern Khasia, Jaintia, and North Cachar Hills. Native lead from Maulmain and chromite from the Andaman Islands. Fiery eruption from one of mud volcanoes of Cheduba Island, Arakan. Irrigation from wells in North-Western Provinces and Oudh.

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Part 1.—Annual report for 1883. Smooth-water anchorages or mud-banks of Narrakal and Alleppy on Travancore coast. Billa Surgam and other caves in Kurnool district. Geology of Chauari and Sihunta parganas of Chamba. Lyttonia, Waagen, in Kuling series of Kashmir.

Part 2.—Earthquake of 31st December 1881. Microscopic structure of some Himalayan granites and gneissose granites. Choi coal exploration. Re-discovery of fossils in Siwalik beds. Mineral resources of Andaman Islands in neighbourhood of Port Blair. Intertrappean beds in Deccan and Laramie group in Western North America.

Part 3 (*out of print*).—Microscopic structure of some Arvali rocks. Section along Indus from Peshawar Valley to Salt-range. Sites for boring in Raigarh-Hingir coal-field (first notice). Lignite near Rajpore, Central Provinces. Turquoise mines of Nishâpûr, Khorassan. Fiery eruption from Minbyin mud Volcano of Cheduba Island, Arakan. Langrin coal-field, South-Western Khasia Hills. Umaria coal-field.

Part 4.—Geology of part of Gangasulan pargana of British Garhwal. Slates and schists imbedded in gneissose granite of North-West Himalayas. Geology of Takht-i-Suleiman. Smooth-water anchorages of Travancore coast. Auriferous sands of the Subansiri river, Pondicherry lignite, and phosphatic rocks at Musuri. Billa Surgam caves.

Vol. XVIII, 1885.

Part 1 (*out of print*).—Annual report for 1884. Country between Singareni coal-field and Kistna river. Geological sketch of country between Singareni coal-field and Hyderabad. Coal and limestone in Doigrung river near Golaghat, Assam. Homotaxis, as illustrated from Indian formations. Afghan field notes.

Part 2.—Fossiliferous series in Lower Himalaya, Garhwal. Age of Mandhali series in Lower Himalaya. Siwalik camel (Camelus Antiquus, nobis ex Falc. and Caut. MS.), Geology of Chamba. Probability of obtaining water by means of artesian wells in plains of Upper India. Artesian sources in plains of Upper India. Geology of Aka Hills. Alleged tendency of Arakan mud volcanoes to burst into eruption most frequently during rains. Analyses of phosphatic nodules and rock from Mussooree.

Part 3.—Geology of Andaman Islands. Third species of Merycopotamus. Percolation as affected by current. Pirthalla and Chandpur meteorites. Oil-wells and coal in Thayetmyo district, British Burma. Antimony deposits in Maulmain district. Kashmir earthquake of 30th May 1885. Bengal earthquake of 14th July 1885.

Part 4.—Geological work in Chhattisgarh division of Central Provinces. Bengal earthquake of 14th July 1885. Kashmir earthquake of 30th May 1885. Excavations in Billa Surgam caves. Nepaulite. Sabetmahet meteorite.

Vol. XIX, 1886.

Part 1.—Annual report for 1885. International Geological Congress of Berlin. Palæozoic Fossils of Olive group of Salt-range. Correlation of Indian and Australian coal-bearing beds. Afghan and Persian Field-notes. Section from Simla to Wangtu, and petrological character of Amphibolites and Quartz Diorites of Sutlej valley.

Part 2 (*out of print*).—Geology of parts of Bellary and Anantapur districts. Geology of Upper Dehing basin in Singpho Hills. Microscopic characters of eruptive rocks from Central Himalayas. Mammalia of Karnul Caves. Prospects of finding coal in Western Rajputana. Olive group of Salt-range. Boulder-bed of Salt-range. Gondwana Homotaxis.

Part 3 (*out of print*).—Geological sketch of Vizagapatam district, Madras. Geology of Northern Jesalmer. Microscopic structure of Malani rocks of Arvali region. Malanjkhandi copper-ore in Balaghat district, C. P.

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Part 2.—Fossil vertebrata of India. Echinoidea of cretaceous series of Lower Narbada Valley. Field-notes: No. 5—to accompany geological sketch map of Afghanistan and North-Eastern Khorassan. Microscopic structure of Rajmahal and Deccan traps. Dolerite of Chor. Identity of Olive series in east with speckled sandstone in west of Salt-range in Punjab.

Part 3.—Retirement of Mr. Medlicott, J. B. Mushketoff's Geology of Russian Turkistan. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaun, Section I. Geology of Simla and Jutogh. 'Lalitpur' meteorite.

Part 4 (out of print).—Points in Himalayan geology. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaon, Section II. Iron industry of western portion of Raipur. Notes on Upper Burma. Boring exploration in Chattisgarh coal-fields. (Second notice). Pressure Metamorphism, with reference to foliation of Himalayan Gneissose Granite. Papers on Himalayan Geology and Microscopic Petrology.

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Part 1.—Annual report for 1887. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaun, Section III. Birds'-nest of Elephant Island, Mergui Archipelago. Exploration of Jessalmer, with a view to discovery of coal. Facetted pebble from boulder bed ('speckled sandstone') of Mount Chel in Salt-range, Punjab. Nodular stones obtained off Colombo.

Part 2.—Award of Wollaston Gold Medal, Geological Society of London, 1888. Dharwar System in South India. Igneous rocks of Raipur and Balaghat, Central Provinces. Sangar Marg and Mohowgale coal-fields, Kashmir.

Part 3 (out of print).—Manganese Iron and Manganese Ores of Jabalpur. 'The Carboniferous Glacial Period.' Pre-tertiary sedimentary formations of Simla region of Lower Himalayas.

Part 4 (out of print).—Indian fossil vertebrates. Geology of North-West Himalayas. Blown-sand rock sculpture. Nummulites in Zanskar. Mica traps from Barakar and Raniganj.

Vol. XXII, 1889.

Part 1 (out of print).—Annual report for 1888. Dharwar System in South India. Wajra Karur diamonds, and M. Chaper's alleged discovery of diamonds in pegmatite. Generic position of so-called Plesiosaurus Indicus. Flexible sandstone or Itacolumite, its nature, mode of occurrence in India, and cause of its flexibility. Siwalik and Narbada Chelonia.

Part 2 (out of print).—Indian Steatite. Distorted pebbles in Siwalik conglomerate. "Carboniferous Glacial Period." Notes on Dr. W. Waagen's "Carboniferous Glacial Period." Oil-fields of Twingoung and Beme, Burma. Gypsum of Nehal Nadi, Kumaun. Materials for pottery in neighbourhood of Jabalpur and Umaria.

Part 3 (out of print).—Coal outcrops in Sharigh Valley, Baluchistan. Trilobites in Neobolus beds of Salt-range. Geological notes. Cherra Poonjee coal-field, in Khasia Hills. Cobaltiferous Matt from Nepál. President of Geological Society of London on International Geological Congress of 1888. Tin-mining in Mergui district.

Part 4 (out of print).—Land-tortoises of Siwaliks. Pelvis of a ruminant from Siwaliks. Assays from Sambhar Salt-Lake in Rajputana. Manganiferous iron and Manganese Ores of Jabalpur. Palagonite-bearing traps of Rajmahál hills and Deccan. Tin-smelting in Malay Peninsula. Provisional Index of Local Distribution of Important Minerals, Miscellaneous Minerals, Gem Stones and Quarry Stones in Indian Empire. Part 1.

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Part 1.—Annual report for 1889. Lakadong coal-fields, Jaintia Hills. Pectoral and pelvic girdles and skull of Indian Dicynodonts. Vertebrate remains from Nagpur district (with description of fish-skull). Crystalline and metamorphic rocks of Lower Himalayas. Garhwál and Kumaon, Section IV. Bivalves of Olive-group, Salt-range Mud-banks of Travancore coasts.

Part 2 (out of print).—Petroleum explorations in Harnai district, Baluchistan. Sapphire Mines of Kashmir. Supposed Matrix of Diamond at Wajra Karur, Madras. Sonapet Gold-field. Field notes from Shan Hills (Upper Burma). New species of Syringosphæridæ.

Part 3 (out of print).—Geology and Economic Resources of Country adjoining Sind-Pishin Railway between Sharigh and Spintangi, and of country between it and Khattan. Journey through India in 1888-89, by Dr. Johannes Walther. Coal-fields of Lairungao, Maosandram, and Mao-be-lar-kar, in the Khasi Hills. Indian Steatite. Provisional Index of Local Distribution of Important Minerals, Miscellaneous Minerals, Gem Stones, and Quarry Stones in Indian Empire.

Part 4 (out of print).—Geological sketch of Naini Tal; with remarks on natural conditions governing mountain slopes. Fossil Indian Bird Bones. Darjiling Coal between Lisu and Ramthi rivers. Basic Eruptive Rocks of Kadapah Area. Deep Boring at Lucknow. Coal Seam of Dore Ravine, Hazara.

Vol. XXIV, 1891.

Part 1.—Annual report for 1890. Geology of Salt-range of Punjab, with re-considered theory of Origin and Age of Salt-Marl. Graphite in decomposed Gneiss (Laterite) in Ceylon. Glaciers of Kabru, Pandim, etc. Salts of Sambhar Lake in Rajputana, and 'Reh' from Aligarh in North-Western Provinces. Analysis of Dolomite from Salt-range, Punjab.

Part 2.—Oil near Moghal Kot, in Sheráni country, Suleiman Hills. Mineral Oil from Suleiman Hills. Geology of Lushai Hills. Coal-fields in Northern Shan States. Reported Namsèka Ruby-mines in Mainglôn State. Tourmaline (Schorl) Mines in Mainglôn State.—Salt-spring near Bawgyo, Thibaw State.

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Part 4.—Mammalian Bones from Mongolia. Darjiling Coal Exploration. Geology and Mineral Resources of Sikkim. Rocks from the Salt-range, Punjab.

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Part 1.—Annual report for 1891. Geology of Thal Chotiáli and part of Mari country. Petrological Notes on Boulder-bed of Salt-range, Punjab. Sub-recent and Recent Deposits of valley plains of Quetta, Pishin, and Dasht-i-Bedalot; with appendices on Chamans of Quetta; and Artesian water-supply of Quetta and Pishin.

Part 2 (out of print).—Geology of Safēd Kóh. Jherria Coal-field.

Part 3.—Locality of Indian Tscheffkinite. Geological Sketch of country north of Bhamo. Economic resources of Amber and Jade mines area in Upper Burma. Iron-ores and Iron Industries of Salem District. Riebeckite in India. Coal on Great Tenasserim River, Lower Burma.

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Part 1.—Annual report for 1892. Central Himalayas. Jadeite in Upper Burma. Burmite, new Fossil Resin from Upper Burma. Prospecting Operations, Mergui District, 1891-92.

Part 2 (out of print).—Earthquake in Baluchistan of 20th December 1892. Burmite, new amber-like fossil resin from Upper Burma. Alluvial deposits and Subterranean water-supply of Rangoon.

Part 3 (out of print).—Geology of Sherani Hills. Carboniferous Fossils from Tenasserim. Boring at Chandernagore. Granite in Tavoy and Mergui.

Part 4.—Geology of country between Chappar Rift and Harnai in Baluchistán. Geology of part of Tenasserim Valley with special reference to Tendau-Kamauping Coal-field. Magnetite containing Manganese and Alumina. Hislopite.

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Part 1.—Annual report for 1893. Bhaganwala Coal-field, Salt-range, Punjab.

Part 2.—Petroleum from Burma. Singareni Coal-field, Hyderabad (Deccan). Gohna Landslip, Garhwal.

Part 3.—Cambrian Formation of Eastern Salt-range. Giridih (Karharbari) Coal-fields. Chipped (?) Flints in Upper Miocene of Burma. Velates Schmideliana, Chemn., and Provelates grandis, Sow. sp., in Tertiary Formation of India and Burma.

Part 4.—Geology of Wuntho in Upper Burma. Echinoids from Upper Cretaceous System of Baluchistán. Highly Phosphatic Mica Peridotites intrusive in Lower Gondwana Rocks of Bengal. Mica-Hypersthene-Hornblende-Peridotite in Bengal.

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Part 1.—Annual report for 1894. Cretaceous Formation of Pondicherry. Early allusion to Barren Island. Bibliography of Barren Island and Narcondam from 1884 to 1894.

Part 2.—Cretaceous Rocks of Southern India and geographical conditions during later cretaceous times. Experimental Boring for Petroleum at Sukkur from October 1893 to March 1895. Tertiary system in Burma.

Part 3.—Jadeite and other rocks, from Tammaw in Upper Burma. Geology of Tochi Valley. Lower Gondwanas in Argentina.

Part 4.—Igneous Rocks of Giridih (Kurhurbaree) Coal-field and their Contact Effects. Vindhyan system south of Sone and their relation to so-called Lower Vindhyans. Lower Vindhyan area of Sone Valley. Tertiary system in Burma.

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Part 1.—Annual report for 1895. Acicular inclusions in Indian Garnets. Origin and Growth of Garnets and of their Micropegmatitic intergrowths in Pyroxenic rocks.

Part 2 (out of print).—Ultra-basic rocks and derived minerals of Chalk (Magnesite) hills, and other localities near Salem, Madras. Corundum localities in Salem and Coimbatore districts, Madras. Corundum and Kyanite in Manbhum district, Bengal. Ancient Geography of "Gondwanaland." Notes.

Part 3.—Igneous Rocks from the Tochi Valley. Notes.

Part 4.—Steatite mines, Minbu district, Burma. Lower Vindhyan (Sub-Kaimur) area of Sone Valley, Rewah. Notes.

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Part 1.—Annual report for 1896. Norite and associated Basic Dykes and Lava-flows in Southern India. Genus Vertebraria. On Glossopteris and Vertebraria.

Part 2.—Cretaceous Deposits of Pondicherri. Notes.

Part 3.—Flow structure in igneous dyke. Olivine-norite dykes at Coonoor. Excavations for corundum near Palakod, Salem District. Occurrence of coal at Palana in Bikanir. Geological specimens collected by Afghan-Baluch Boundary Commission of 1896.

Part 4.—Nemalite from Afghanistan. Quartz-barytes rock in Salem district, Madras Presidency. Worn femur of Hippopotamus irravadicus, Caut, and Falc., from Lower Pliocene of Burma. Supposed coal at Jaintia, Baxa Duars. Percussion Figures on micas. Notes.

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Part 2 (out of print).—Lt.-Genl. C. A. McMahon. Cyclobus Haydeni Diener. Auriferous Occurrences of Chota Nagpur, Bengal. On the feasibility of introducing modern methods of Coke-making at East Indian Railway Collieries, with supplementary note by Director, Geological Survey of India. Miscellaneous Notes.

Part 3 (out of print).—Upper Palæozoic formations of Eurasia. Glaciation and History of Sind Valley. Halorites in Trias of Baluchistan. Geology and Mineral Resources of Mayurbhanj. Miscellaneous Notes.

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Part 3 (out of print).—Anthracolithic Fauna from Subansiri Gorge, Assam. Elephas Antiquus (Namadicus) in Godavari Alluvium. Triassic Fauna of Tropites-Limestone of Byans. Amblygonite in Kashmir. Miscellaneous Notes.

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Part 2 (out of print).—General report for 1905. Lashio Coal-field, Northern Shan States. Namma, Mansang and Man-se-le Coal-fields, Northern Shan States, Burma. Miscellaneous Notes.

Part 3 (out of print).—Petrology and Manganese-ore Deposits of Sausar Tahsil, Chhindwara district, Central Provinces. Geology of part of valley of Kanhan River in Nagpur and Chhindwara districts, Central Provinces. Manganite from Sandur Hills. Miscellaneous Notes.

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Part 2 (out of print).—Mineral Production of India during 1905. Nummulites Douvillei, with remarks on Zonal Distribution of Indian Nummulites. Auriferous Tracts in Southern India. Abandonment of Collieries at Warora, Central Provinces. Miscellaneous Notes.

Part 3 (out of print).—Explosion Craters in Lower Chindwin district, Burma. Lavas of Pavagad Hill. Gibbsite with Manganese-ore from Talevadi, Belgaum district, and Gibbsite from Bhekowli, Satar District. Classification of Tertiary system in Sind with reference to Zonal distribution of Eocene Echinoidea.

Part 4 (out of print).—Jaipur and Nazira Coal-fields, Upper Assam. Makum Coal-fields between Tirap and Namdang Streams. Kabat Anticline, near Seiktein, Myingyan district, Upper Burma. Asymmetry of Yenangyat-Singu Anticline, Upper Burma. Northern part of Gwegyo Anticline, Myingyan District, Upper Burma, Breynia Multituberculata, from Nari of Baluchistan and Sind. Index to Volume XXXIV.

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Part 2.—Indian Aerolites. Brine-wells at Bawgyo, Northern Shan States. Gold-bearing Deposits of Loi Twang, Shan States. Physa Prinsepii in Maestrichtian strata of Baluchistan. Miscellaneous Notes.

Part 3.—Preliminary survey of certain Glaciers in North-West Himalaya. A.—Notes on certain Glaciers in North-West Kashmir.

Part 4.—Preliminary survey of certain Glaciers in North-West Himalaya. B.—Notes on certain Glaciers in Lahaul. C.—Notes on certain Glaciers in Kumaon. Index to Volume XXXV.

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Part 3 (*out of print*).—Marine fossils in Yenangyaung oil-field, Upper Burma. Fresh-water shells of genus Batissa in Yenangyaung oil-field, Upper Burma. New Species of Dendrophyllia from Upper Miocene of Burma. Structure and age of Taungtha hills, Myingyan district, Upper Burma. Fossils from Sedimentary rocks of Oman (Arabia). Rubies in Kachin hills, Upper Burma. Cretaceous Orbitoides of India. Two Calcutta Earthquakes of 1906. Miscellaneous Notes.

Part 4.—Pseudo-Fucoids from Pab sandstones at Fort Munro, and from Vindhyan series. Jadeite in Kachin Hills, Upper Burma. Wetchok-Yedwet Pegu outcrop, Magwe district, Upper Burma. Group of Manganates, comprising Hollandite, Psilomelane and Coronadite. Occurrence of Wolfram in Nagpur district, Central Provinces. Miscellaneous Notes. Index to Volume XXXVI.

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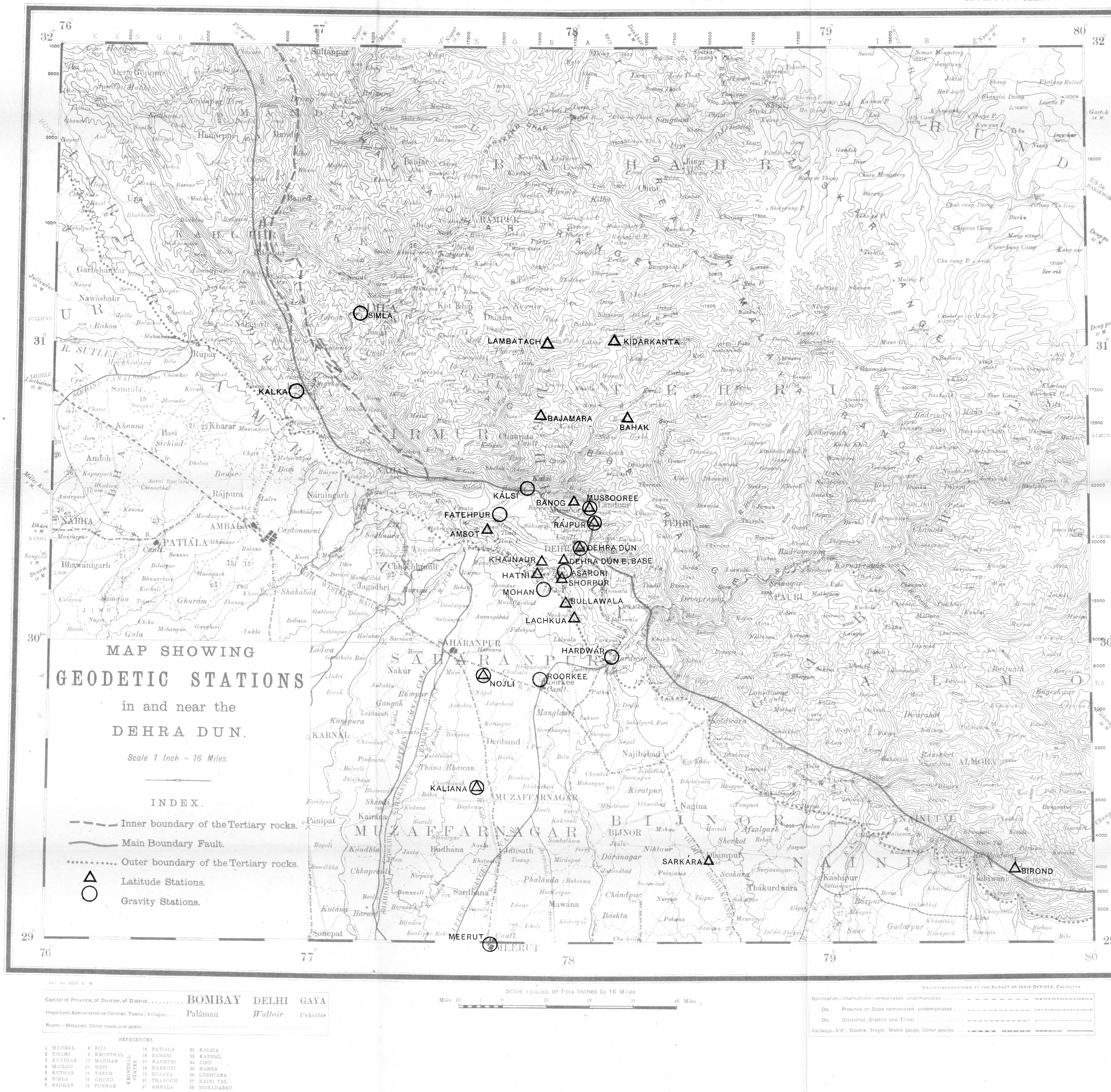
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