Art. LXI.—*The Tasmanian Earthquake of the 27th January, 1892.**

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Plate LXII.

This earthquake was felt over almost the whole of Tasmania; in Victoria, as far west as Melbourne; and in the south-east part of New South Wales. I am indebted for the data to the late Captain Shortt, R.N., who was kind enough to send me the whole of his official returns; to Mr. A. B. Biggs, of Launceston; to Professor Hutton, F.R.S., of Canterbury College, New Zealand; and to Professor Liversidge, F.R.S., of Sydney, who happened to be at Launceston at the time: to R. J. Ellery, Esq., C.M.G., for Victoria; and to H. C. Russell, Esq., C.M.G., for New South Wales. Further details I owe to the *Launceston Examiner*, *Tasmanian News*, and *Telegraph* of the 28th January, 1892. I have also read Mr. A. B. Biggs's letters in the *Launceston Examiner* of the 23rd February, 1892, and the 5th April, 1892. To these papers I would refer any one who wishes to know the more picturesque details of the earthquake.

The Tasmanian returns give the reported times for the beginning of the earthquake from sixty-one different places; but the majority of them give the time only to the nearest multiple of five minutes—perhaps a natural thing for an inexperienced observer to do, yet a kind of observation which one is inclined to suspect in a calculation which requires for its success observations correct at least to within a half-minute—that is, to the nearest minute. All such times, therefore, must be rejected unless we have evidence to show that they were actually correct to the desired degree of accuracy, and checked by Hobart mean time. The rest, except where obviously at variance with any theory of the origin, were included in the normal equations for finding the origin of the earthquake. As a consequence of that investiga-

* This paper was handed to the Tasmanian Royal Society in January, 1893, but the manuscript was lost, and has only now (1898) been found.

tion, I was led to reject all the times from Tasmania except those of Hobart and Launceston. These I place in the first class, as comparatively good times; one or two others—*e.g.*, St. Mary's, Eagle Hawk Neck, Branxholm, and Campbell-town—are probably within about a minute of the true time, but not exact enough to be relied upon, or to be classed with Hobart and Launceston.

One thing is clear from the reports from the various Tasmanian observers—namely, that the earthquake was a compound one, consisting of four (or perhaps five) shocks, three near together (Captain Shortt gives 2.48, 2.49, and 2.50 at Hobart) and one about seven or eight minutes later. In other respects besides the time—as regards the intensity and direction of the shocks—much valuable information can be gleaned from these reports, and there is a general agreement in the conclusions to which they point.

The Victorian returns are eleven in number. The times are shown by the normal equations to be inferior in value to the times for Hobart and Launceston; I have accordingly not put any of them in the first class. Two of the times, however, may be assigned to the second class—Wilson's Promontory (2.49½) and Sorrento (2.51½). These, with Bairnsdale, are set down in Mr. Ellery's list as the most reliable of the Victorian times. Bairnsdale must be rejected unless it refers to the last of the four shocks; even then it is probably two or three minutes out. It may be remarked that Mr. Ellery expresses a fear that the times from Victoria are not exact enough for use in calculations of the origin. Only four times were received from New South Wales; three of these are fairly good, and must be put in the first class. The other—Green Cape (2.56½)—would probably be correct for the last shock.

The second shock was the chief one, and the one noticed most by ordinary people. At several places where the first three shocks were felt their character was clearly distinguished. I propose briefly to discuss the earthquake under the heads—(I.) Origin of shock; (II.) velocity of propagation; and (III.) intensity of shock.

(I.) For the purpose of finding the epicentrum, or point on the earth's surface immediately above the origin of the disturbance, we may use—(*a*) the directions observed at the various places; (*b*) the times of beginning, or any other marked phase of an earthquake; or (*c*) the degree of the intensity of the shock as felt at different places. Of the various methods, those depending on good times—(*b*)—are by far the best, and the indications given by the impressions or observations of direction are the least reliable. I am, however, very far from holding with Mr. Biggs that they are

quite unreliable. In the great majority of New Zealand earthquakes I find that most of the observations of direction, when properly used, give a very fair rough idea of the position of the origin, especially if that is not too far away. A direction-circle drawn as below, for instance, prevents us from hunting on a false track, and in the present case, after drawing that, I should not expect to find the origin anywhere else but east of Tasmania.

What is observed is, as Mr. Biggs says, undoubtedly the direction of the movement of the earth-particle, or of what depends thereon—the movement of the ground or of objects resting upon it. But this movement is by no means arbitrary, nor can the movement of the earth be compared to the rolling of a ship on the waves. The earth's crust is an exceedingly rigid and highly elastic mass, not homogeneous certainly, but so nearly so in effect that, as Major Dutton has shown in his celebrated memoir upon the Charleston earthquake, we shall not go far wrong if we treat it as homogeneous. Then, the vibrations from a shock at any point within it must obey the ordinary laws of vibrations. The vibrations set up will in general be of two kinds—longitudinal (that is, to and fro along the line of propagation of the wave, like the vibrations of the air in a tube along which a sound-wave is sent) and transverse (that is, at right angles to the line of propagation, like the small vibrations set up in a stretched string by a blow upon it). For instance, if an earthquake were sent from A to B, the longitudinal vibrations would be backwards and forwards in the directions of the arrow-heads, and the transverse vibrations would be to and fro across the line AB, as CO (see Plate LXII.).

At any distance from the origin, considerable compared with the depth of the actual centrum, the longitudinal vibrations will be nearly horizontal; while the transverse vibrations will give rise to up-and-down movements, to horizontal movements at right angles to those of the longitudinal vibrations, and to movements in directions between those of the up-and-down movements and those of the horizontal transverse vibrations, but always at right angles to the longitudinal vibrations, unless there has been reflexion or some other cause of disturbance of the direction of the earthquake-waves. The seismograph record of almost any considerable earthquake will show these several movements more or less distinctly. The disturbing causes are not likely in the majority of cases to make much difference for an earthquake like the present, of intensity vi. or vii., unless the formation of the underlying strata be very peculiar indeed.

Generally speaking, the longitudinal waves seem to reach any given place first; but often only the one kind of vibration

is felt, or only one direction is observed. To use the directions, then, we evidently have the following rule: Draw two lines through each place, one in the direction named in the report, the other at right angles to it; one of these two lines will be very possibly that of the direction of the shock. In the diagram, for instance, the shock felt at O might have come from any of the four directions, AO, BO, CO, DO, but it could not have come from X.

The apparent directions were given for twenty-one places in Tasmania as follows: Launceston, E. to W. (second shock); Scottsdale, N. to S.; St. Mary's, E. to W. (second shock); Swansea, W. to E.; Eagle Hawk Neck, N.E. to S.W. (second shock); Boobyalla, S.E. to N.W.; Cape Portland, S.E. to N.W.; Ormley, W. to E.; Avoca, E. to W. (second or third shock); Franklin, S.W.; Beaconsfield, E. to W.; Sorell, S. to N.; Geeveston, N.W. to S.E.; George's Bay, N.E. by N. to S.W. by S.; Buckland, E. to W.; Oaks, E. and W.; Campbelltown, S.E. to N.W.; Karoola, N.W. to S.E.; East Devonport N.W. to N.E.; Blessington, from N.W.; St. Helen's, E. to W.

The directions for Australia were given as follows: Omeo, S.E. to N.W.; Bairnsdale, W. to E.; Grant, N. to S.; Forster, S.W. to N.E.; Genoa, W. to E.; Cape Everard, S.W. to N.E.; Gabo, E. to W.; Walhalla, N. to S.

Now, drawing lines in the directions indicated, we find we can describe a circle to cut or touch lines through twenty out of the twenty-nine places. The centre of this direction-circle is D. Its radius is large (eighty miles); so that the indication is only rough. The effect of the direction-lines of two or three places of the nine whose lines do not cut the circle O would be to throw the origin somewhat further to the east. We should therefore expect to find the origin either within or somewhat to the east of the circle D.

The indication, if any, given by the directions reported by ordinary observers is only rough, and I should not have dwelt so long upon it but for the circumstance that it is the custom to despise it altogether, a prejudice which experience in the calculation of a very large number of earthquake origins in New Zealand has shown me to be wrong. One cause of error in observing the direction must be noticed: When the method fails the failure generally is not due to eccentricity in the movement of the earth-particle, but to the neglect of the observer to take into account any peculiarity in the method of support of disturbed objects which would tend to make them move, whatever the direction of the disturbing force might be, in certain directions only.

I. (*b.*) The determination of the origin by means of the observed times of the same phase of the earthquake is far

more exact. The time I have taken is that of the beginning of the second shock (or maximum). The times in Class I. are: Launceston, 2.48½ a.m.; Hobart, 2.49 a.m.; Kiama, 2.52½ a.m.; Kiandra, 2.52½ a.m.; Bombala, 2.49½ a.m.: all Hobart mean time.

For Launceston I had three returns: Mr. A. B. Biggs, 2.48½; Captain Shortt, 2.49; Professor Liversidge, 2.48. The time sent to Captain Shortt is noted as probably not quite at the beginning, so it is a little too late; that given by Professor Liversidge is probably too early—there was a little delay in finding the matches, and allowance made for such delay during an earthquake is generally rather too great. Mr. Biggs took the time by a chronometer at once. All the times were verified as soon as possible afterwards by standard time. I think we may say, in taking 2.48½ as the right time, we are correct to the nearest half-minute. At Hobart three shocks were noted—two slight and one sharp. Three were also noted at Carnarvon and other places, and in each case the middle shock—that is, the "second" shock referred to above—was the severe one: Hobart, therefore, 2.49. Great care seems to have been taken in checking the New South Wales times, and they are at least correct to the nearest minute.

The times which at first I placed in Class II. were: Glenora, 2.51; St. Mary's, 2.49½; Eagle Hawk Neck, 2.49; Fingal, 2.50; Branxholm, 2.47; Campbelltown, 2.47½; Sorrento, 2.51½; Wilson's Promontory, 2.49½.

Method of Co-ordinates.—After some preliminary trials by the methods of straight lines* and circles, I formed the equations of observation for all the places in Classes I. and II. as in Milne's "Earthquakes," p. 206, and then the normal equations from them (see "Merriman's Method of Least Squares," chap. iii.). No good result was obtained, however; but the conclusion could plainly be drawn that the times in Class II., being more or less inconsistent with one another, were less reliable than those of Class I.

The weights assigned for the several observations were: For Hobart, 25; for Launceston, 16; Kiama, 9; and for the rest, 4, 2, or 1.

I then returned to the method of circles, which, with data of the kind we have, and for an earthquake whose origin is not near any of the places of observation, is as good as the method of co-ordinates. C_{20} is the epicentrum obtained by

* S was obtained by the method of straight lines from the two pairs, Kiama-Kiandra (2.52½), Hobart-Launceston (2.48½). It corresponds to a surface-velocity of about twenty-six miles per minute. Subsequent comparison of the records, however, for reasons already given, led me to believe that 2.49 was the true time for Hobart, or as near as we could get to it. S remained as a rough first approximation.

taking the times for Kiama, Kiandra, Launceston, Hobart, with a velocity of twenty miles per minute. Bombala, Launceston, Hobart give C_{35}, with a velocity of thirty-five miles per minute. This also agrees to about a minute with Campbelltown, Wilson's Promontory, Kiama, and Kiandra. Still more nearly do C_{30} and C_{25} agree with the times in Class I., though still not exactly. I then, with varying velocities from twenty miles to thirty-five miles per minute, attempted to find some small area (or comparatively small area) a simultaneous shock from which would reach the five places in Class I. at the several times observed. With a velocity of about twenty-six miles per minute we can get such an area, marked EE′ on the map. The degree of agreement with the data may be tested by the time at the origin, as calculated from the different places. This time should, of course, be the same from whatever place we calculate it. We get the same time—2 hours 35 minutes a.m.—from each of the five places in Class I.

The places in Class II. give this time as follows: St. Mary's, 2.38; Glenora, 2.36·4; Eagle Hawk Neck, 2.35·8; Fingal, 2.37·9; Branxholm, 2.34·7; Campbelltown, 2.34·5; Sorrento, 2.32·3; Wilson's Promontory, 2.33·8. The average or arithmetical mean of these is 2 hours 35.4 minutes a.m., which certainly does not contradict the evidence of the best times.

The epicentrum I therefore take to have included the whole or part of the shaded strip EE′, and not to have extended nearer to any of the places of observation than EE′. How far it may have extended to the south-east it is, of course, impossible to say, as no observations were made on that side—probably not very far. EE′ is about forty-eight miles long and four miles wide in the widest part. It lies between 153° 56′ and 154° 36′ east longitude, and between 41° 13′ and 40° 46′ south latitude. E is 353 miles from Launceston and 365 from Hobart.

V_{35} is the position I have found for the epicentrum of a previous well-marked earthquake—that of the 13th May, 1885. V_{35} is only seven miles from the boundary of EE′, and the two results seem thus to confirm one another in a remarkable manner. The confirmation is all the greater as the area over which the two earthquakes were felt was practically the same.

S, T is the position assigned for the same earthquake (13th May, 1885) in the late Captain Shortt's map (as corrected by himself), of which he kindly allowed me to take a tracing. He seems afterwards, in a paper read before the Royal Society of Tasmania, on the 16th November, 1885, to have expressed an opinion that the origin lay rather further to the north, and thus, I presume, not very far from V_{35}, my own result.

I have also examined the data for two of the other well-known earthquakes—the 13th July, 1884, and 19th September, 1884; they are scarcely exact enough for a good determination of the epicentrum, but in both cases point to an origin about fifty miles north-north-west of V_{35}. These estimates, again, rough though they may be, are not widely at variance with the more exact results of the present investigation. Mr. A. B. Biggs, of Launceston, has assigned a different position altogether for the epicentrum of the earthquake of the 27th January, 1892—namely, a point 730 miles due east of Hobart. (See *Launceston Examiner*, 23rd February, 1892.)

This is totally inconsistent with the data, even as given by Mr. Biggs himself. It is always assumed that an earthquake-wave travels with nearly the same velocity throughout; indeed, since Major Dutton's report on the Charleston earthquake, already alluded to, this is taken to be practically settled.

If, then, d_1, d_2 be the distances of two places from the supposed origin, t_1, t_2 the time of the same phase at those places, v the velocity of propogation, evidently we have

$$\frac{d_2 - d_1}{t_2 - t_1} = v.$$

Applying this formula to different pairs of places with Mr. Biggs's origin we get the following values for v: Hobart and Kiama give $v = 11{\cdot}4$ miles per minute; Hobart and Kiandra $= 24{\cdot}3$ miles per minute; Hobart and Bombala $= 30$ miles per minute; Launceston and Kiama $= 8{\cdot}3$ miles per minute; Launceston and Kiandra $= 23{\cdot}3$ miles per minute; while Launceston and Bombala would agree with any velocity whatever.

When we remember, as just stated, that all these values of v should be the same, or very nearly the same, we shall see, I think, that it is impossible to accept Mr. Biggs's theory of the origin.

N.B.—I have used Mr. Biggs's version of the data, though they differ slightly from mine. As a matter of fact, the data he has used give an epicentrum within twenty miles of mine — not one where he has placed it. Moreover, Mr. Biggs puts the origin much nearer to New Zealand—where the earthquake was not felt at all—than to Tasmania or Australia.

The maximum intensity of the earthquake of the 27th January, 1892, was vii. or viii. on the Rossi-Forel scale, as appears from the following summary of the observed effects, which I put here for future reference, though they do not seem to call for any special remarks:—

Place.	Effects.	Intensity Degree on Rossi-Forel Scale.
Hobart	Stopped clocks; overturned flowers; threw down fowls; rang bells; rocked beds; windows rattled; dislodged rocks	vii.
Launceston ..	House shaken considerably; two or three chimneys shaken down or shifted; bells rung violently; furniture shifted; ornaments dislodged; clocks stopped; inhabitants rushed out of houses. (Professor Hutton says bells rung on hill, not on flat)	vii. or viii.
Scottsdale ..	Strongest ever felt; clocks stopped	vi.+
St. Mary's ..	Houses rocked; window-frames and slight articles violently shaken	v.+
Carnarvon ..	Three shocks at 2.50. Pillars of church thrown out of perpendicular	vii.+
Avoca	Loose bricks knocked off chimney (by second and slighter shock at 3)	vii.
George's Bay ..	People frightened	vi.
Buckland	Windows violently shaken ..	vi.
Moorima	Cattle and people alarmed, some rushing out of doors	vi.
Coppington ..	Furniture moved out of its place ..	v.
Ouse	Furniture and curtains shaken. Most severe for thirty-five years	v.
Evandale	Furniture rocked	v.
Longford	Clocks stopped and bell set ringing	vi.
Devonport ..	People complained of nausea; many awakened	vi. (v.)
Blessington ..	Houses shaken	iv. (v.)
Boobyalla ..	Heavy surf broke on bar	vi.
Fingal	Clocks stopped; clocks started; bells rung; plaster fell from walls. Greater than the 13th July, 1884	vii.+
Carrick	Doors and windows rattled ..	iv.
Tartleton	All sleepers awakened	vi.
Ulverstone ..	Windows rattled; persons awakened	..
Penguin	Nearly every one awakened ..	vi.
Stanley	A regular panic occurred ..	vii. (vi.)
Beaconsfield ..	Houses shaken; doors banged; furniture rattled; in mine (Tasmania), 486 ft. from surface, water agitated; pumping-engine rattled violently; post-office clocks stopped; swallows alarmed, and left nests	vii.-vi.
Wilson's Promontory	Light-tower vibrated violently ..	vii.-vi.
Foster	Chimney fell	vii. (viii.)