R. D. OLDHAM.

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ON THE ORIGIN OF THE OCEANS.

The CONSTITUTION *of the* INTERIOR *of the* EARTH, *as* REVEALED *by* EARTHQUAKES: (SECOND COMMUNICATION). *Some* NEW LIGHT *on the* ORIGIN *of the* OCEANS. By RICHARD DIXON OLDHAM, F.G.S.

THE origin of the great oceanic basins has been the subject of numerous speculations, more or less plausible, but none convincing: for the reason that we have no knowledge as to whether these depressions are mere surface-phenomena, or whether they are accompanied by, and related to, differences in the constitution of the interior of the earth beneath them. It is known that the attraction of gravity is, as a rule, greater at island-stations than on the continents, and that the plumb-line at coast-stations is frequently deflected towards the sea; but these facts do not help, for they are easily explicable by differences which may be regarded as superficial, seeing that they need not extend to a depth of even as much as one hundredth of the earth's radius. As regards greater depths, mathematical deductions can help us but little, for any deductions drawn in this way are subject to the logical objection that, while showing the possibility of one explanation of known facts, they do not exclude the possibility of some other. Direct or positive evidence is therefore desirable, and this I propose to offer: not indeed amounting to proof, but still strong enough to merit serious consideration, that the ocean-basins of the Northern Atlantic and Northern Pacific are not mere surface-departures from the perfect spheroid, but are accompanied by differences in the constitution of the matter underlying them, which extend to a considerable portion of the whole radius of the earth.

In a previous communication[1] I showed that the study of the rate of transmission of earthquake-waves enabled us to reach some positive conclusions regarding the constitution of the interior of the earth. In that paper only the constitution of the earth as a whole came into consideration, and only average values for all the available earthquakes were dealt with; this method is no longer permissible when the detection of variations from the average is aimed at, and it will be necessary to compare the rates of propagation along different wave-paths with each other. The investigation has been much simplified, and practically made possible, by the fact that in 1906 there were two great earthquakes, both of which were large enough to give very complete records at distant stations; both of which originated at about the same distance from the group of seismological stations in Western Europe, but in such positions that the wave-paths differed radically in type. From the San Francisco earthquake of April 18th the wave-paths ran under the continent of North America, crossed the Northern Atlantic not far south of Iceland, and approached the observatories from the north-west. Almost the whole of the course of

[1] Quart. Journ. Geol. Soc. vol. lxii (1906) pp. 456–73.

these wave-paths ran under continents or the continental shelf, so that they may be regarded as essentially continental. From the origin of the Colombian earthquake of January 31st the wave-paths ran under the north-western corner of South America and the Antilles, and then crossed the broadest and deepest part of the North Atlantic basin, being as essentially oceanic as those from San Francisco were continental.

Time and place of origin of the latter earthquake are both known with great accuracy, unfortunately the same cannot be said of the Colombian one; this certainly originated under the sea, and, as the greatest destruction seems to have taken place at Esmeralda, we may assume the centre as somewhere about 79° long. W., and 2° lat. N. Seeing that the origin was probably quite as extended as that of San Francisco, which is known to have had a length of over 200 miles, this assumption is sufficiently near the truth; the time is not known with accuracy from direct observation, and though it may be approximately determined from the distant records of the earthquake, this cannot, justifiably, be used for deducing absolute values for the rate of propagation. Although no comparison of the absolute rates of propagation of these two earthquakes is possible, the relative rates of propagation of the first and second phases in each case may be compared one with the other; for, these two phases being due to wave-motion of different kinds, propagated at different rates, it is evident that any difference in the length of the interval between the arrival of the one and of the other will indicate a difference in the relative rates of propagation.

The data at my disposal are summarized in the tabular statement appended to this paper (Table II, pp. 348–49), and from this a briefer and more manageable table may be compiled, of the intervals at those stations where good records of both earthquakes are available:—

TABLE I.

DISTANCES AND INTERVALS BETWEEN FIRST AND SECOND PHASES OF THE CALIFORNIAN AND COLOMBIAN EARTHQUAKES OF 1906.

Station.	California.		Colombia.		*Difference corrected for Distance: Minutes.*
	Distance: Degrees.	*Interval: Minutes.*	*Distance: Degrees.*	*Interval: Minutes.*	
Bidston	75	10·4	80	11·3	+0·4
Shide	78	9·9	81	11·9	+1·7
Leipzig	78	10·8	82	11·4	+0·2
Strassburg	83	10·4	86	11·6	+0·9
Laibach	88	9·5	91	10·7	+0·9
Quarto	89	10·7	91	11·5	+0·6
Catania	96	11·3	92	11·4	+0·5
MEAN	84	10·4	86	11·4	+0·8

From the foregoing table it will be seen that the intervals are distinctly greater in the case of the Colombian earthquake and oceanic wave-paths, the mean difference being 1·0 minute in time for an excess of only 2° in distance; as the time-interval increases by almost exactly 0·1 minute per degree at about 90° from the origin, the observed difference is 5 times as great as that which would be due to the increased distance if the rate of transmission had been the same in each case, and the excess (being about 7 per cent. of the whole interval) is greater than can be accounted for by errors of record or interpretation of the seismograms. In other words, the substance through which these waves of the Colombian earthquake travelled transmitted the second phase at a slower rate —as compared with the rate of transmission of the first phase— than that traversed by the corresponding waves of the San Francisco earthquake.

It may be a mere accident that the wave-paths in the one case lie under a continental and in the other case under an oceanic area, but the coincidence is certainly noteworthy and suggestive, and the notion that it is not merely accidental derives some support from the Japanese records of the San Francisco earthquake. According to Prof. Omori the mean interval derived from the records of four distinct stations in Japan was 9·7 minutes for a mean distance of 75°, the wave-paths running under the Northern Pacific and being, therefore, oceanic. The European records of the earthquakes of Japan, August 9th, 1901, and Assam, June 12th, 1906, give mean intervals of 10·6 minutes for a mean distance of 83·3° in the first case, and 8·3 minutes for a mean distance of 64·2° in the second, from which we may deduce an interval of about 9·4 minutes for a distance of 75° when the wave-paths lie under the continents of Asia and Europe. The interval as deduced from the average-curves on p. 462, vol. lxii (1906) of this Journal, which are practically based on continental wave-paths only, is 9·0 minutes; so here again we find that the material under the Pacific Ocean transmits the second-phase waves at a slower rate, as compared with the first-phase waves, than does the material under the Eurasian continent.

The exact depth to which this difference extends is not, at present, determinable with accuracy, but the figures in Table I (p. 345) allow us to form an approximate estimate. It will be noticed that the distances range from 75° to a little over 90°; now, the maximum depth of the chord from the surface is 0·21 of the radius for an arc of 75°, and 0·29 for an arc of 90°, and the wave-paths descend somewhat below the direct line of the chords. We may, therefore, take it that the wave-paths under consideration reached a maximum depth of from one-quarter to one-third of the radius. A consideration of the difference between the intervals for the two shocks at the same station shows that it does not appear to increase with an increase of distance, but rather tends to decrease in amount, suggesting the conclusion that the deeper wave-paths entered a region where there was no difference, or at any rate a smaller difference, in the rate of propagation of the two phases. From this we may conclude that the difference, in whatever it consists, does not extend to a depth of one-third, but that it does extend to something like a quarter of the radius from the surface.

We may conclude, therefore, that there is good ground for supposing that the oceanic basins and continental elevations are not merely irregularities of surface-form, but are accompanied by, and probably related to, differences in the constitution of the substance beneath them which extend inwards to a distance of about one-quarter of the radius. It is not possible to state exactly the nature of this difference, beyond that it is such as to cause a slowing-down of the rate of propagation of the second-phase waves under the oceans.

More data are required before these conclusions can be positively accepted; but, if not amounting to proof, the evidence is too strong to be ignored, and its confirmation or refutation must depend on the accident of the occurrence of great earthquakes originating at suitably situated localities.

Appendix.

Data utilized in the foregoing Paper.

The following table (II) embodies the data utilized in the paper. Each line refers to the record of a distinct instrument or pendulum.

The first column gives the name of the station.

The second column indicates the nature of the instrument. These are classified into types, irrespective of variations in detail, of construction, represented by letters as under:—

- M. = Light horizontal pendulum, with photographic registration, of the Milne pattern.
- R. = Light horizontal pendulum, with photographic registration, of the Rebeur-Paschwitz type.
- H.P. = Heavy horizontal pendulum, with mechanical registration.
- V.P. = Vertical pendulum, with mechanical registration.
- Vert. = Instrument designed for recording the vertical component of the motion.
- W. = Inverted astatic pendulum of the Wiechert type.

In the two groups of three columns referring to the Californian and Colombian earthquakes the first column gives the approximate distance, in whole degrees, from the origin, while the other two give the time of arrival of the first- and second-phase waves. In the case of the Californian earthquake they represent minutes after $13^h\ 12^m$ of April 18th, 1906; in the case of the Colombian earthquake minutes after $15^h\ 36^m$ of January 31st, 1906: these times being those of origin in each case, as near as they are known.

Figures underlined indicate that the times were determined in the observatory on the original record; the figures not underlined represent times determined by myself on copies and, therefore, necessarily, of somewhat less accuracy.

Table II. Station.	Instrument.	California.			Colombia.		
		Distance.	First Phase.	Second Phase.	Distance.	First Phase.	Second Phase.
		Degrees.	Minutes.	Minutes.	Degrees.	Minutes.	Minutes.
Paisley	M.	73	11·2	21·0	80	12·5	......
Bidston	M.	75	11·7	22·1	80	10·6	21·9
Edinburgh	M.	73	11·5	21·2	80	12·5	......
Kew	M.	77	(13·7)	22·2	82	12·9	24·0
Shide	M.	78	11·7	21·6	81	12·8	25·0
"	"	"	......	......	"	(11·3)	24·5
Mean		"	**11·7**	**21·6**	"	**12·8**	**24·7**
Leipzig	W.	78	12·8	23·6	82	13·2	24·6
Strassburg............	W.	83	......	......	86	13·1	24·6
"	V.P.	"	12·9	23·3	"	13·3	24·8
"	Vert.	"	13·2	......	"	13·0	......
"	H.P.	"	12·8	23·3	"	13·2	24·7
"	Vert.	"	12·7	......	"	......	......
"	R.	"	13·1	23·5	"	......	......
"	R.	"	12·9	23·3	"	......	......
Mean		"	**12·9**	**23·3**	"	**13·1**	**24·7**

Laibach	V.P.	88	13·6	23·5	91	13·4	24·1
"	Vert.	"	13·6	23·5	"	13·9	24·3
"	H.P.	"	14·9	(24·8)	"	13·7	(22·1)
"	H.P.	"	14·5	(24·4)	"	13·2	(23·4)
"	R.	"	13·4	23·6	"	13·0	......
"	"	"	13·6	23·3	"	13·5	......
"	"	"	13·8	23·3	"	13·8	......
MEAN		"	**13·9**	**23·4**	"	**13·5**	**24·2**
Quarto	H.P.	89	15·3	26·0	91	13·1	24·7
"	"	"	15 2	26·0	"	13·2	24·7
MEAN		"	**15·3**	**26·0**	"	**13·2**	**24·7**
Rocca di Papa	V.P.	90			90	14·2	24·8
"	H.P.	"			"	13·5	25·3
"	"	"			"	14·5	25·1
MEAN		"			"	**14·1**	**25·1**
Catania	V.P.	96	14·1	25·4	92	13·5	24·9

Figures enclosed in parentheses represent times which are regarded as doubtful and have, therefore, not been used.

The data from Strassburg and Laibach have been included, although I have not been able to see either originals or copies of the seismograms, as these observatories are equipped with a number of instruments of different types, serving as a check on each other and preventing the mistakes which may easily arise in the interpretation of isolated records. In every other case I have examined either the original or a copy of the seismogram.