EARTHQUAKES ON THE PHILIPPINES IN THE YEAR 1876, ACCORDING TO THE PUBLICATION OF THE "ATENEO MUNICIPAL" IN MANILA. COMMUNICATED BY DR. A. B. MEYER, DRESDEN.

Date.		Hour.	Place.	Province or District.	Island.	Direction.	Remarks.
January	19	1 A.M.	Vigan	Ilocos sur	Luzon	—	—
February	7	4–5 A.M.	Iba	Zambales	,,	—	—
,,	10	7 A.M.	Laoag	Ilocos norte	,,	—	—
March	18	12.15 A.M.	Vigan	Ilocos sur	,,	—	—
,,	18	11–12 P.M.	Benguet	Benguet	,,	—	—
,,	21	5–6 A.M.	Batangas	Batangas	,,	—	—
,,	31	2.25 P.M.	Laoag	Ilocos norte	,,	N.–S.	—
April	14	2–3 A.M.	Iba	Zambales	,,	—	—
June	12	12.45 A.M.	Nueva-Cáceres	Camarines, S.	,,	—	—
,,	12	11–12 P.M.	Albay	Albay	,,	—	—
,,	18	? A.M.	Laoag	Ilocos norte	,,	N.–S.	—
July	13	10.30 P.M.	Iba	Zambales	,,	—	—
,,	13	,,	Cavite	Cavite	,,	N.–S.	—
,,	13	10–11 P.M.	Bulacan	Bulacan	,,	—	—
,,	13	10.34 P.M.	Manila	Manila	,,	N.N.E.–S.S.W.	Intensity 3°, sismometer 2 mm.
,,	26	? A.M.	Tacloban	—	Leyte	—	Strong.
,,	26	4 A.M.	Surigao	—	Mindanao	E.–W.	—
,,	27	10 A.M.	Baler	Com. P. M. d. Principe	Luzon	N.–S.	—
August	10	5.45 A.M.	Nueva-Cáceres	Camarines, S.	,,	W.–E.	—
,,	21	12–1 A.M.	Iba	Zambales	,,	—	—
,,	22	10–11 P.M.	,,	,,	,,	—	—
,,	23	12.30 A.M.	Vigan	Ilocos, S.	,,	—	—
September	13	10 A.M.	Nueva-Cáceres	Camarines, S.	,,	—	—
,,	15	11.30 P.M.	Surigao	—	Mindanao	W.–E.	—
November	15	7–8 A.M.	Iba	Zambales	Luzon	—	—
,,	17	11.30 P.M.	Vigan	Ilocos, S.	,,	—	—
,,	17	night.	Benguet	Benguet	,,	—	—
,,	17	,,	Cayan	Lepanto	,,	—	—
,,	18	4–5 A.M.	Iba	Zambales	,,	—	—
,,	19	8 P.M.	Mobo	—	Masbate	—	—
,,	22	noon.	,,	—	,,	—	—
,,	26	—	Albay	Albay	Luzon	—	Great eruption of Mount Tacbacon.
,,	27	11.5 P.M.	Manila	Manila	,,	—	One shock, intensity 3 mm.
December	12	4.5 P.M.	,,	,,	,,	N.E.–S.W.	Intensity 1°, sismometer 1 mm.
,,	12	9.45 P.M.	Zamboanga	—	Mindanao	—	—
,,	13	4 P.M.	Baler	Com. P. M. d. Principe	Luzon	N.–S.	—
,,	13	11.45 P.M.	Zamboanga	—	Mindanao	—	—
,,	18	? P.M.	Iba	Zambales	Luzon	—	—
,,	20	4–5 A.M.	Batangas	Batangas	,,	—	—
,,	25	3 A.M.	Calapan	—	Mindoro	N.–S.	—
,,	25	9.23 A.M.	Manila	Manila	Luzon	S.E.–N.W.	Intensity 1°.

If we take, with Dr. von Drasche ("Fragmente zu einer Geologie der Insel Luzon," Vienna, 1878), North Luzon to a little north from 16° N., Central Luzon from there to about 14° 30′ N., and South Luzon on the south of this line, we have 11 earthquakes in North Luzon, 15 in Central Luzon, 8 in South Luzon; and on the islands mentioned—1 on Mindoro, 2 on Masbate, 1 on Leyte, and 4 on Mindanao.

There were recorded in the year 1876, altogether 41 earthquakes on the Philippine Islands.

SOME RESULTS OF THE SUPPOSITION OF THE VISCOSITY OF THE EARTH[1]

SIR W. THOMSON'S investigation of the bodily tides of an elastic sphere has gone far to overthrow the idea of a semi-fluid interior to the earth, yet geologists are so strongly impressed by the fact that enormous masses of rock have been poured out of volcanic vents in the earth's surface, that the belief is not yet extinct that we live on a thin shell over a sea of molten lava. It appeared to the author, therefore, to be of interest to investigate the consequences which would arise from the supposition that the matter constituting the earth is of a viscous or imperfectly elastic nature. In this paper these hypotheses were followed out, and the results were fully as hostile to the idea of any great mobility of the interior of the earth as are those of Sir W. Thomson.

It is first shown that every problem about the strains of an incompressible elastic solid has its analogue touching the flow of an incompressible viscous fluid, and that the solution of Sir W. Thomson's problem of the bodily tides of an elastic sphere may thus be adapted to give the bodily tides of a viscous spheroid. The state of internal flow of a viscous spheroid is then found, under the joint influence of any external disturbing force and of the mutual gravitation of the parts of the spheroid.

When there is no disturbing force this gives the law of the subsidence of inequalities on the surface of a viscous globe under the influence of simple gravitation; and it is suggested that some light may possibly be thrown thereby on the laws of geological subsidence and upheaval. It appears that inequalities of wide extent will subside much more quickly than wrinkles, as might have been expected from general considerations.

The rate is found at which a rotating spheroid would adjust itself to a new form of equilibrium, when its axis of figure is not coincident with that of rotation; and the law is established which

[1] Abstract of a paper on the bodily tides of viscous spheroids, by G. H. Darwin. Read before the Royal Society, May 23.

was assumed in a former paper.[1] The case is next considered where the disturbing force is regularly periodic in time; this is the assumption appropriate for the tidal problem. The forces which act on the spheroid in this case do not form a rigorously equilibrating system; but there is a small couple called into existence, the consideration of which is deferred to a future paper.

It appears that the bodily tide lags, and is less in height than it would be if the spheroid were perfectly fluid; also the ocean tides on such a spheroid are accelerated, and are less in height than they would be on a rigid nucleus.[2]

This theory is then applied to the lunar semi-diurnal and fortnightly tides, and numerical tables of results are given.

A comparison of the numbers given with the viscosity of pitch at near the freezing temperature (as roughly determined by the author) shows how enormously stiff the earth must be to resist the tidally distorting influence of the moon. It may be remarked that pitch at this temperature is hard, apparently solid and brittle; and if the earth was not very far stiffer than pitch, it would comport itself sensibly like a perfect fluid, and there would be no ocean tides at all. It follows, therefore, that no very considerable portion of the interior of the earth can even distantly approach the fluid condition.

This does not, however, seem conclusive against the existence of bodily tides in the earth of the kind here considered; for, under the enormous pressures which must exist in the interior of the earth, even the solidest substances might be induced to flow to some extent like a fluid of great viscosity.

The theory of the bodily tides of an "elastico-viscous" spheroid is next developed. The kind of imperfection of elasticity considered is where the forces requisite to maintain the body in any strained configuration diminish in geometrical progression, as the time increases in arithmetical progression. There are two constants which define the mechanical nature of this sort of solid: first, the coefficient of rigidity, at the instant immediately after the body has been strained; and second, "the modulus of the time of relaxation of rigidity," which is the time in which the force requisite to maintain the body in its strained position has diminished to ·368 of its initial value. The author is not aware that there is any experimental justification for the assumption of such a law; but after considering the various physical objections which may be raised to it, he concluded that the investigation was still of some value.

The laws of flow of such an ideal solid have been given (with some assistance from Prof. Maxwell) by Mr. Butcher,[3] and they are such that the solutions already found might easily be adapted to the new hypothesis. The results of the application to the tidal problem are not quite so simple as in the case of pure viscosity. By a proper choice of the two constants, the solution becomes either that for a purely viscous spheroid or for a purely elastic one. This hypothesis is therefore intermediate between those of pure viscosity and pure elasticity.

Sir William Thomson worked out numerically the bodily tides of elastic spheres with the rigidities of glass and of iron; and tables of results are given for those rigidities, with various times of relaxation of rigidity, for the semi-diurnal and fortnightly tides.

It appears that if the time of relaxation of rigidity is about one-quarter of the tidal period, then the reduction of ocean-tide does not differ much from what it would be if the spheroid were perfectly elastic. The acceleration of high tide still, however, remains considerable; and a like observation may be made in the case of pure viscosity approaching rigidity. This leads the author to think that perhaps one of the most promising ways of detecting such tides in the earth, would be by the determination of the periods of maximum and minimum in a tide of long period in a high latitude.

The second part of the paper contains a dynamical investigation of the ocean tides in an equatorial canal running round a yielding nucleus, and the results are confirmatory of the previous ones.

The author states as the chief practical result of this paper that it is strongly confirmatory of the view that the earth has a very great effective rigidity; but that its chief value is, that it forms a necessary first chapter to the investigation of the precession of viscous and imperfectly elastic spheroids—an investigation which he hopes to complete very shortly.

[1] On the Influence of Geological Changes on the Earth's Axis of Rotation. *Phil. Trans.*, vol. clxvii. Pt. I.

[2] The law is as follows:—If $\frac{v}{2\pi}$ be the frequency of the tide, μ the coefficient of viscosity, g, gravity, a, earth's radius, w, earth's density, and if $\tan \epsilon = \frac{19\mu v}{2gwa}$, the tide of the viscous spheroid is equal in height to the equilibrium tide of a perfectly fluid spheroid multiplied by $\cos \epsilon$, and the tide is retarded by $\frac{\epsilon}{v}$. Also the equilibrium tide of a shallow ocean overlying the nucleus is equal to the like tide on a rigid nucleus multiplied by $\sin \epsilon$, and there is an acceleration of the time of high water equal to $\frac{\pi}{2v} - \frac{\epsilon}{v}$.

[3] *Proc.* Lond. Math. Soc., December 14, 1876, pp. 107–9.

PHYSICAL GEOLOGY[1]

A Geological Proof that the Changes of Climate in past times were not due to changes in the position of the Pole; with an attempt to assign a minor limit to the duration of Geological Time.

IF we examine the localities of the fossil remains of the Arctic regions, and consider carefully their relations to the position of the present North Pole, we find that we can demonstrate that the Pole has not sensibly changed its place during geological periods, and that the hypothesis of a shifting pole (even if permitted by mechanical considerations) is inadmissible to account for changes in geological climates.

We are thus driven to the conclusion that geological climates are due to the combined cooling of the earth and sun; and on comparing the rates of cooling of such a body as the earth with the maximum measured thicknesses of the several strata, we find a remarkable proportion between them, which leads towards the conclusion that the maximum thicknesses of the strata are proportional to the times of their formation; and so I deduce a minor limit of geological time.

Climate of the Parry Islands in the Jurassic Period.—Capt. M'Clintock found in the Parry Islands, on the north coast of America, at Point Wilkie, in Prince Patrick's Island, lat. 76° 20′, tropical shells, and drew the attention of geologists to the difficult task of providing a tropical climate inside the Arctic Circle, to accommodate the habits of the animals that lived there in jurassic times. The tropical fossils found in the Parry Islands were:—

Ammonites M'Clintocki (M'Clintock).
Monotis septentrionalis ,,
Pleurotomaria sp. ,,
Nucula sp. ,,
Ichthyosaurus sp. (vertebræ) (Sir Edward Belcher).[2]
Teleosaurus sp. (vertebræ) (Capt. Sherard Osborne).[3]

The *Teleosaurus* was a reptile closely resembling the gavial of India, which is found nowhere outside the Tropics, and requires warmer water than the alligator of America. The alligator flourishes in the neighbourhood of New Orleans, whose climate is represented by the following figures:—

Mean Monthly Temperature of New Orleans.

	°		°
January	54·8 F.	July	+ 81·6 F.
February	56·4 ,,	August ...	+ 81·2 ,,
March	62·9 ,,	September ...	+ 78·5 ,,
April	69·0 ,,	October ...	– 69·8 ,,
May	74·8 ,,	November ...	– 60·2 ,,
June	79·9 ,,	December ...	– 56·0 ,,

Yearly mean ... ... 68°·7 F.

Reptiles requiring a climate such as is indicated by the preceding table, lived in the jurassic period within 900 miles of the North Pole, where the present climate is represented by the following figures:—

Mean Monthly Temperature of Melville Island.

	°		°
January	– 31·3 F.	July	+ 42·4 F.
February	– 32·4 ,,	August	+ 32·6 ,,
March	– 18·2 ,,	September ...	+ 22·5 ,,
April	– 8·2 ,,	October ...	– 2·8 ,,
May	+ 16·8 ,,	November ...	– 21·1 ,,
June	+ 36·2 ,,	December ...	– 21·6 ,,

Yearly mean ... ... + 1·2 F.

[1] "Notes on Physical Geology." Paper read at the Royal Society, April 4, by the Rev. Samuel Haughton, M.D. Dublin, D.C.L. Oxon, F.R.S., Professor of Geology in the University of Dublin. No. IV.

[2] Exmouth Island, lat. 77° 12′ N. (only 900 miles from the Pole).

[3] Rendezvous Hill, at north-west extremity of Bathurst Island, lat. 77° N.