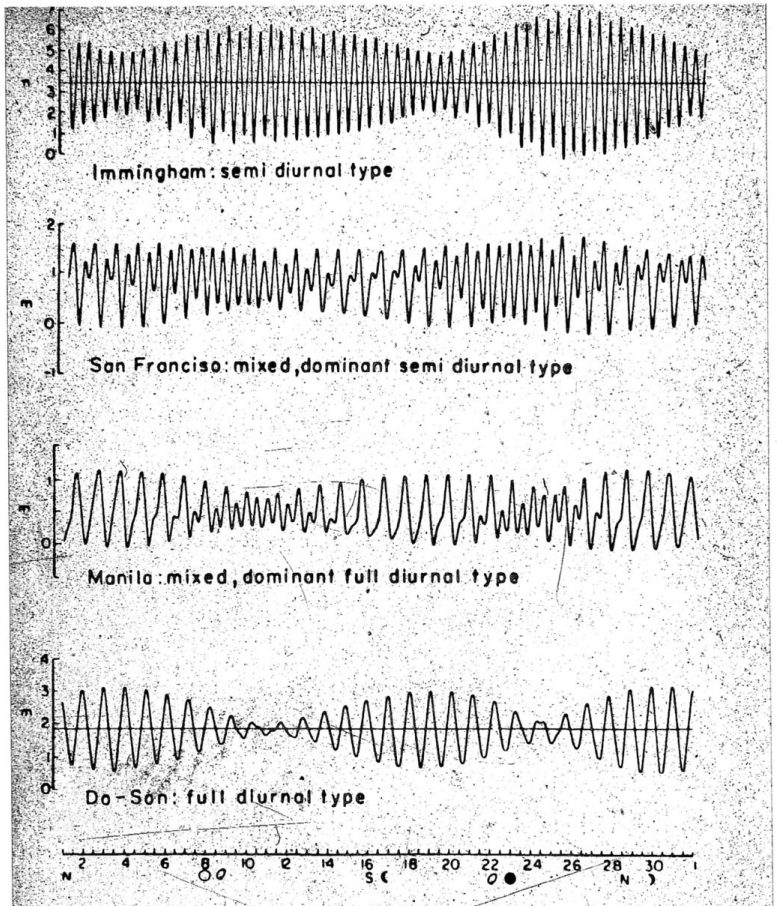


Figure 11.4 Tides at Immingham, San Francisco, Manila and Do San. The time in days for March 1936 is given on the bottom of the figure. The phases of the moon are also shown. *N* shows the maximum northern declination of the moon; *S*, the maximum southern declination, and *Q* the time when the moon crosses the equator. [From Defant (1961).]

4/7

DIALOGO
DI
GALILEO GALILEI LINCEO
MATEMATICO SOPRAORDINARIO
DELLO STVDIO DI PISA.
E Filosofo, e Matematico primario del
SERENISSIMO
GR. DVCA DI TOSCANA.

Doue ne i congressi di quattro giornate si discorre sopra i due

MASSIMI SISTEMI DEL MONDO
TOLEMAICO, E COPERNICANO;

Proponendo indeterminatamente le ragioni Filosofiche, e Naturali tanto per l'vna, quanto per l'altra parte.

CON PRIVILEGI.

IN FIORENZA, Per Gio: Batista Landini MDCXXXII.

CON LICENZA DE' SVPERIORI.


DIALOGO
di
GALILEO GALILEI LINCEO
AL SER.mo FERD. II. GRAN. DVCA DI
TOSCANA
Stefan. Della Bella

THE FOURTH DAY

First general conclusion: No ebb and flow if the terrestrial globe were immovable.

SAGREDO. I do not know whether you are really arriving later than usual for our accustomed discussion or whether it just seems so to me because of my desire to hear Salviati's thoughts on such an interesting matter. I have been watching through the window for a long time, hoping from one moment to the next to see the gondola come into view which I sent to fetch you.

SALV. I believe it is only your imagination that has made the time drag, rather than any tardiness on our part. But in order not to stretch it still further it will be good for us to get to the matter in hand without wasting any more words.

Nature's whim to make the flow and ebb of the seas endorse the earth's mobility.

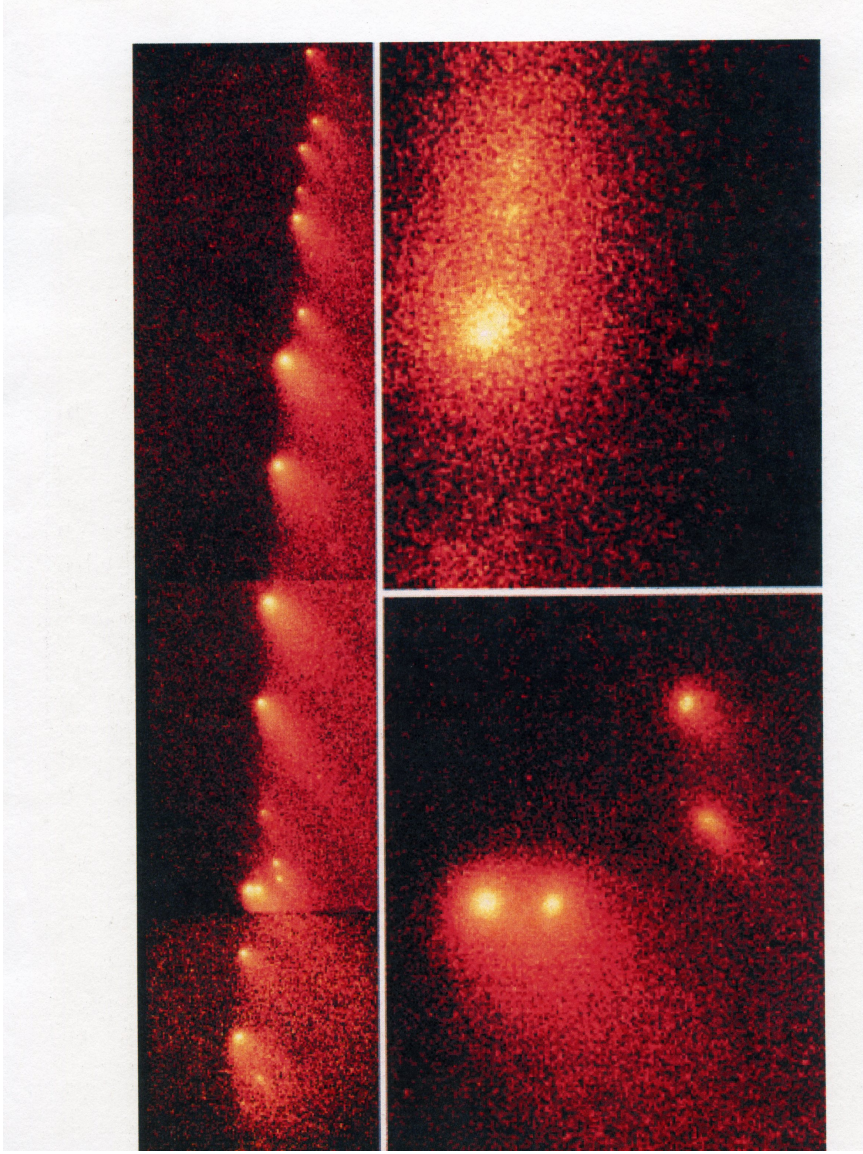
Let us see, then, how nature has allowed (whether the facts are actually such, or whether at a whim and as if to play upon our fancies) — has allowed, I say, the movements that have long been attributed to the earth for every reason except as an explanation of the ocean tides to be found now to serve that purpose too, with equal precision; and how, reciprocally, this ebb and flow itself coöperates in confirming the earth's mobility.†

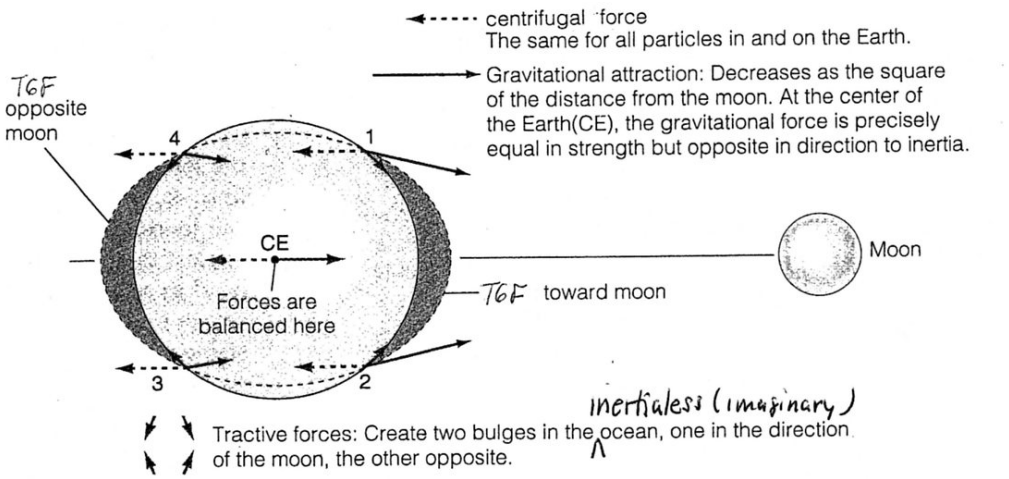
The tides and the earth's mobility reciprocally confirm one another.

Up to this point the indications of that mobility have been taken from celestial phenomena, seeing that nothing which takes place on the earth has been powerful enough to establish the one position any more than the other. This we have already examined at length by showing that all terrestrial events from which it is ordinarily held that the earth stands still and the sun and the fixed stars are moving would necessarily appear just the same to us if the earth moved and the others stood still.

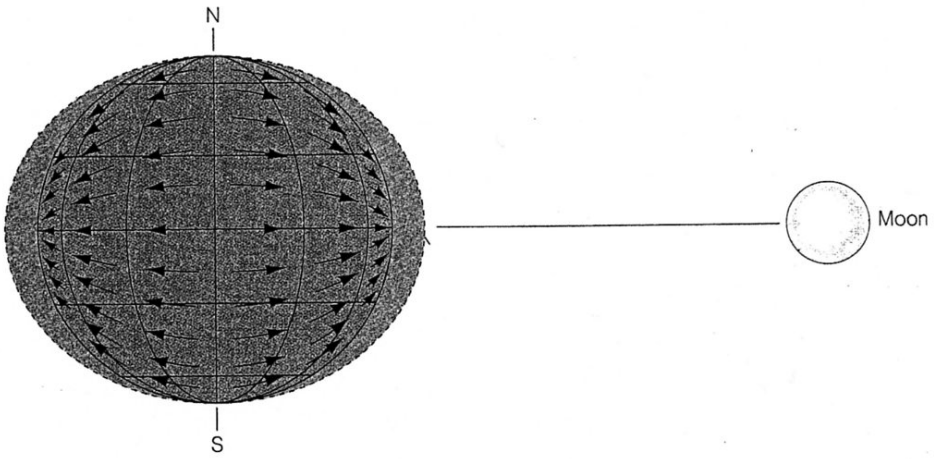
All terrestrial events except the ocean tides are impartial as to the earth's motion or rest.

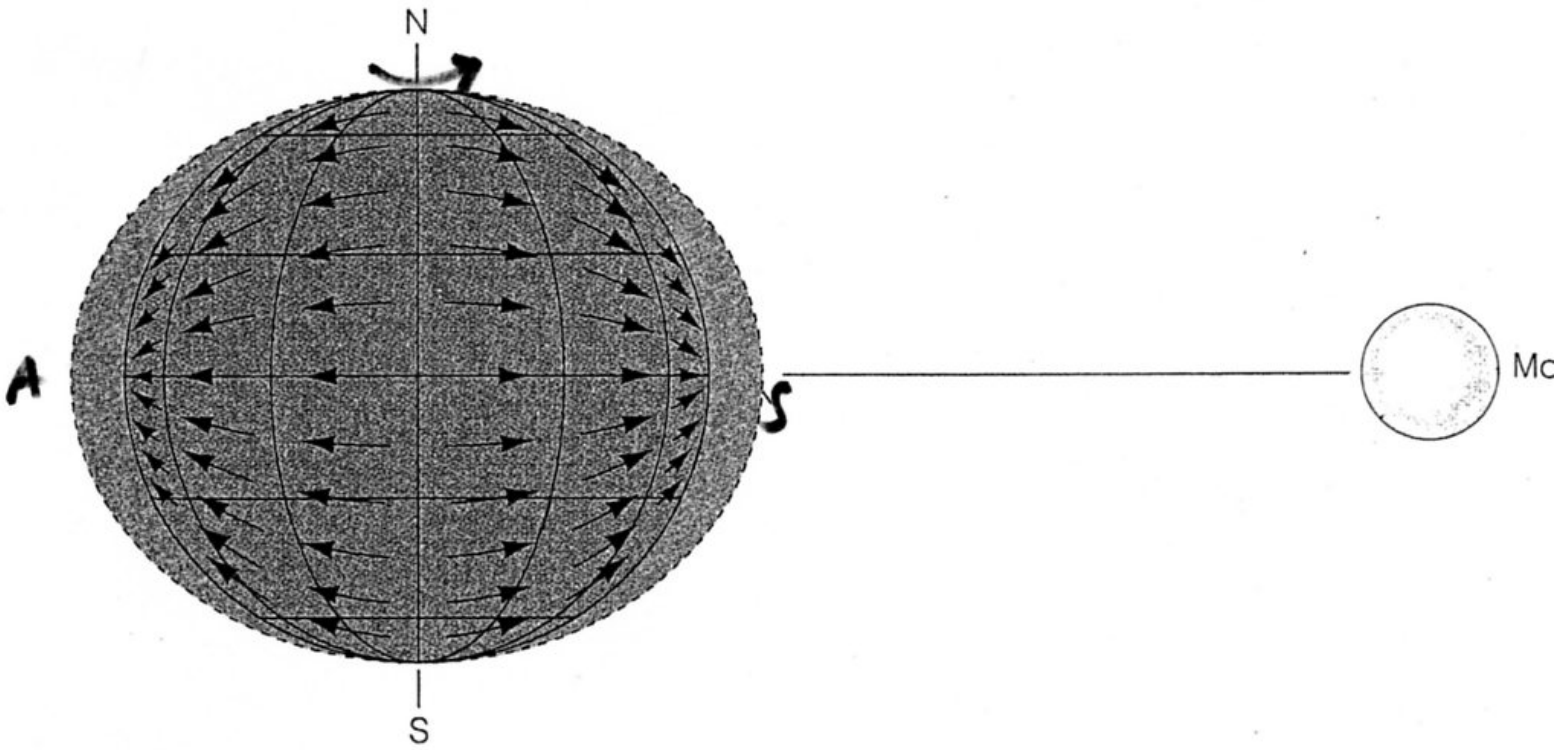
Among all sublunary things it is only in the element of water (as something which is very vast and is not joined and linked with the terrestrial globe as are all its solid parts, but is rather, because of its fluidity, free and separate and a law unto itself) that we may recognize some trace or indication of the earth's behavior in regard to motion and rest. After having many times examined for myself the effects and events, partly seen and partly heard from other people, which are observed in the movements of the water; after, moreover, having read and listened to the great follies which many people have put forth as causes for these events, I have arrived at two conclusions which were not lightly to be drawn and granted. Certain necessary assumptions having been made, these are that if the terrestrial globe were immovable, the ebb and flow of the oceans could not occur naturally; and that when we confer upon the globe the movements just assigned to it, the seas are necessarily subjected to an ebb and flow agreeing in all respects with what is to be observed in them.



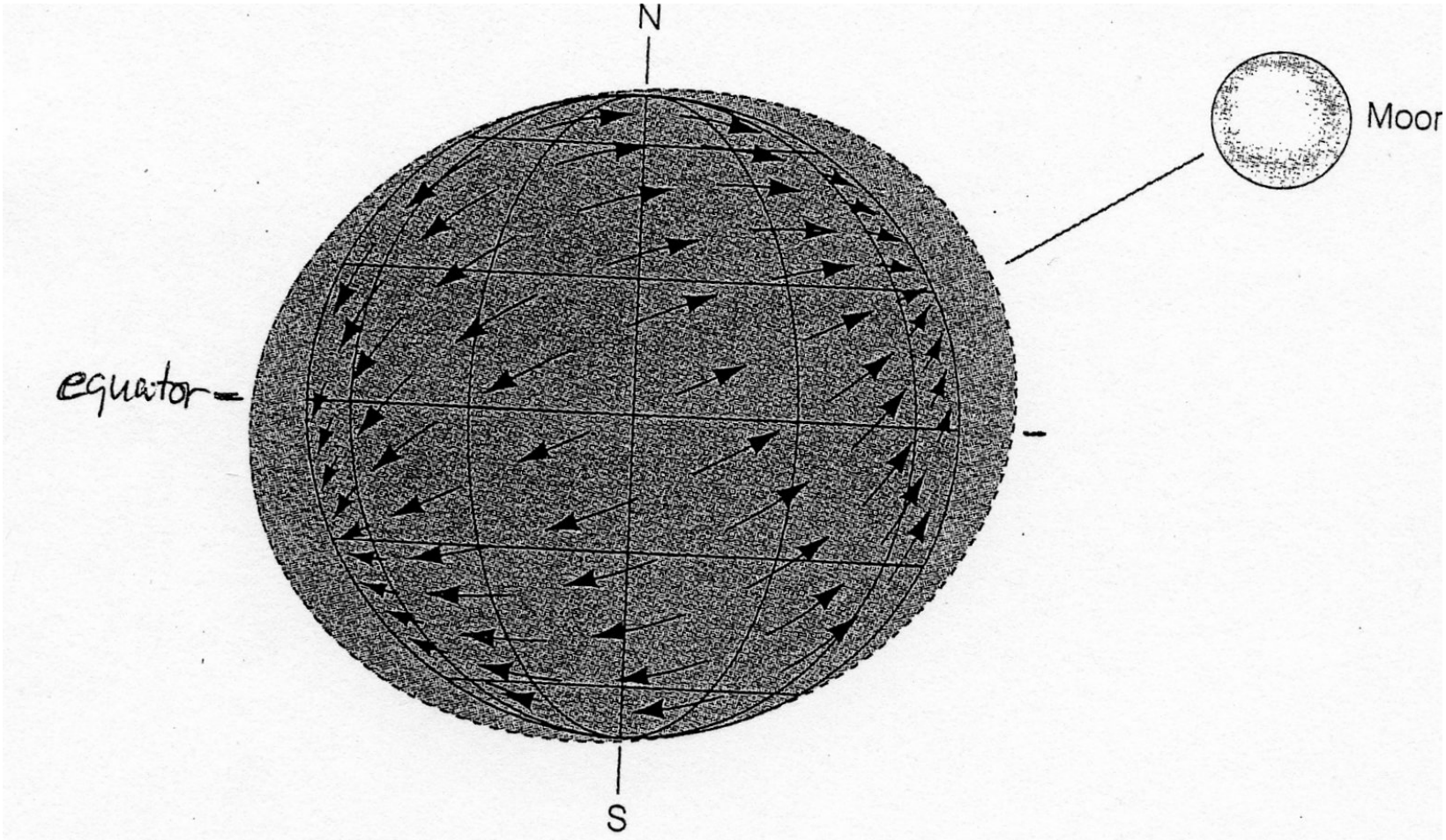


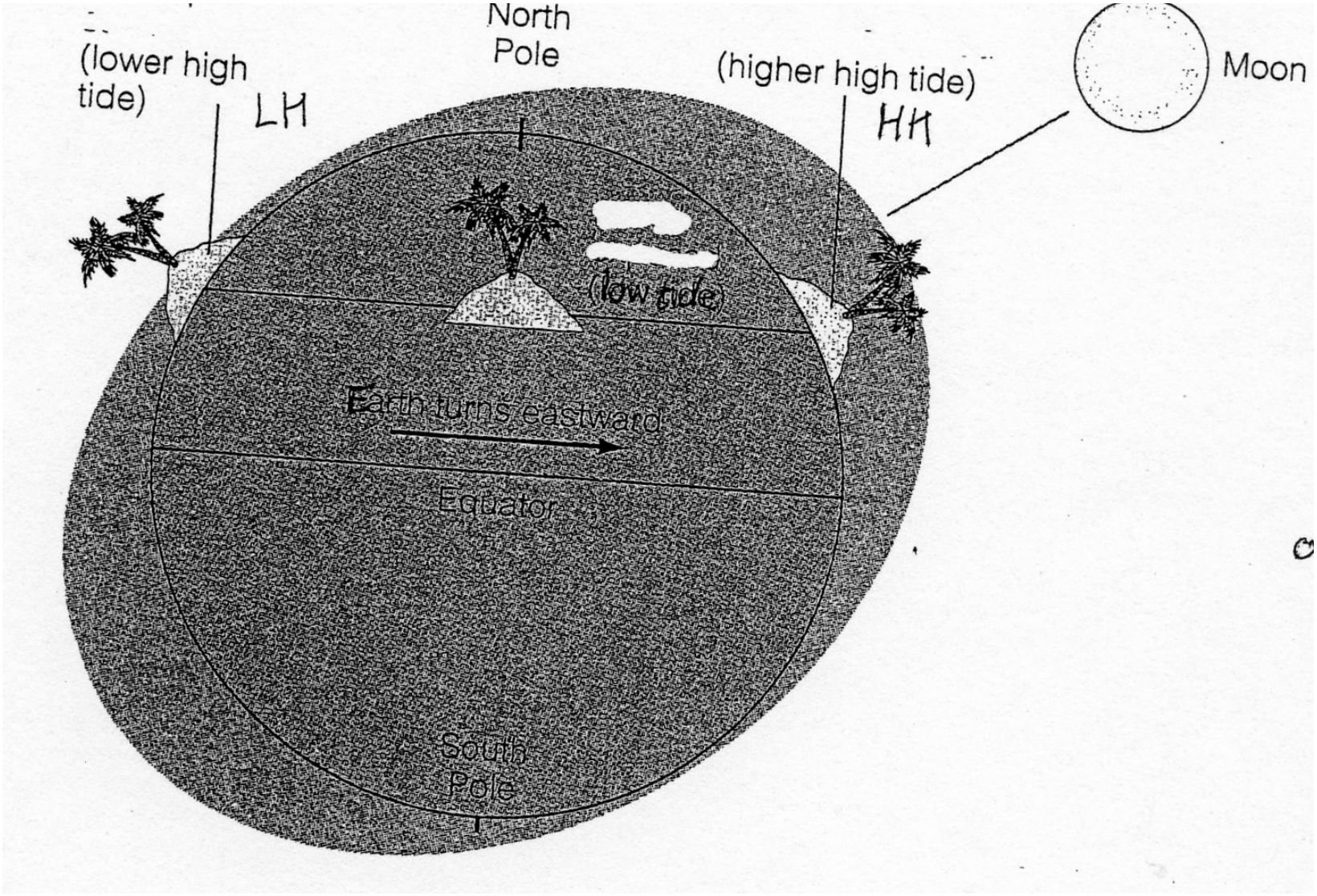
The two forces that can move the ocean are balanced only at the center of Earth (point CE). Elsewhere the net imbalance is a small force that causes ocean water to converge into two equal "bulges," as shown.
(inertialess)

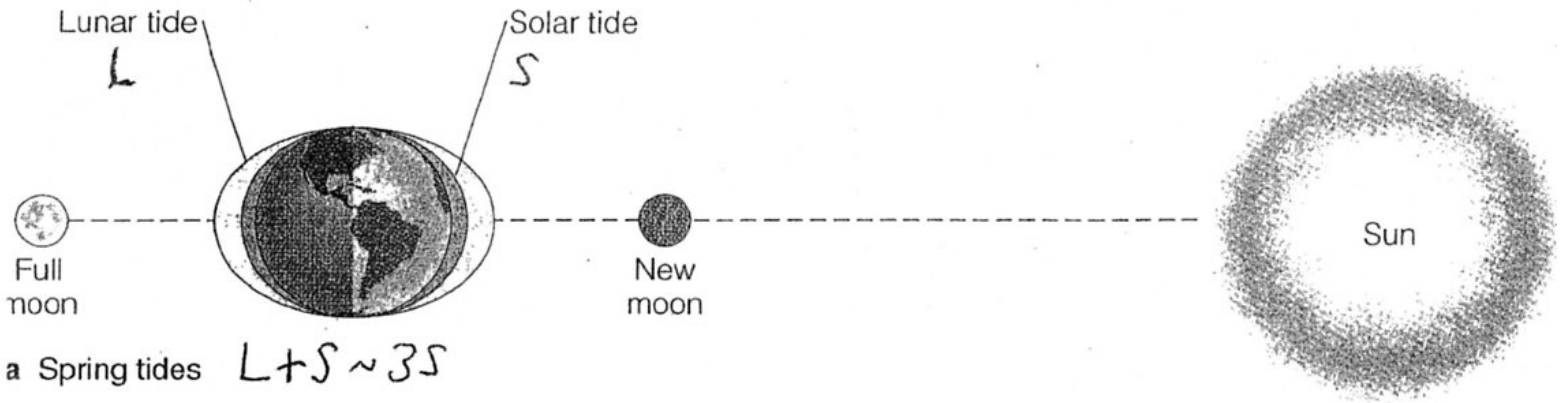



N
S
Mc

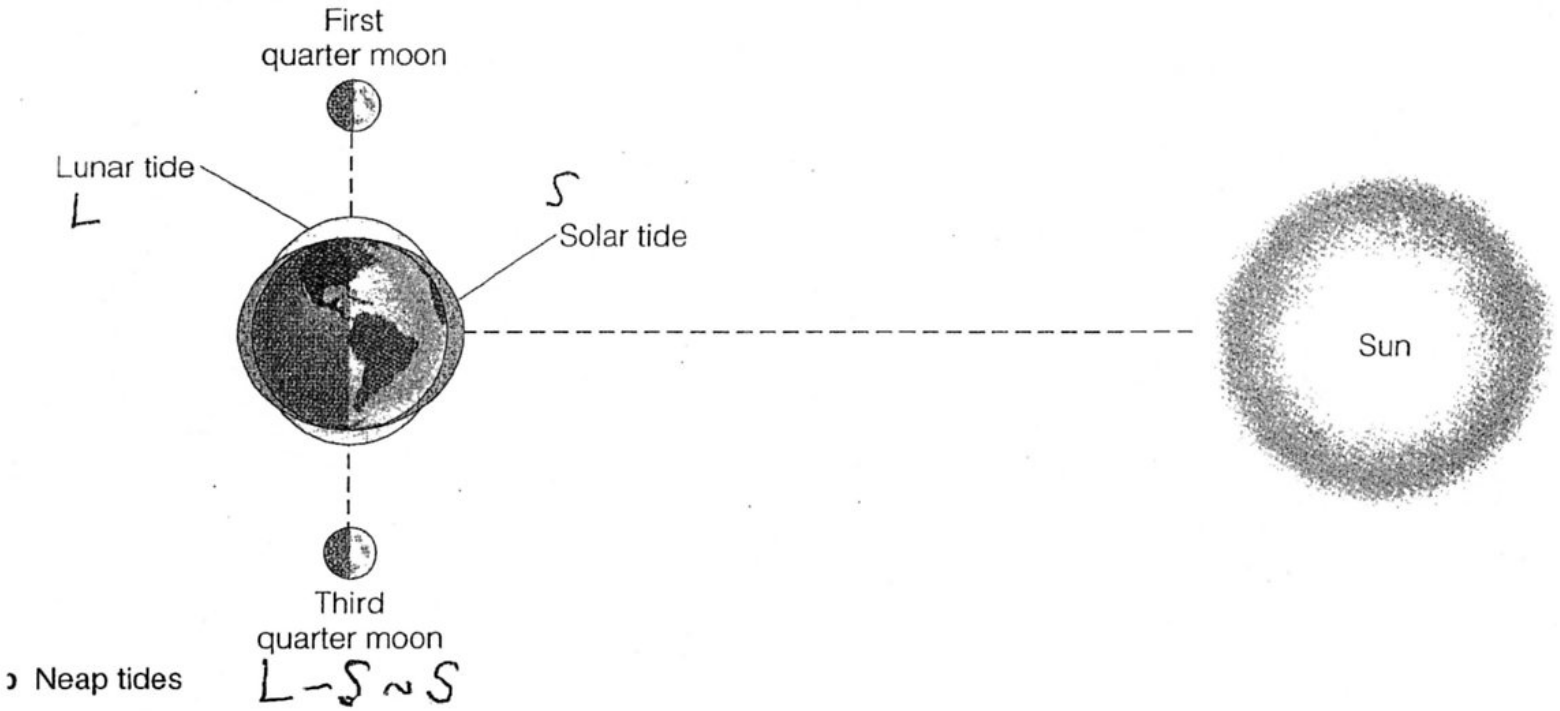

0
12
24
t


N
Moon
equator
S


North Pole
(lower high tide)
LH
(higher high tide)
HH
Moon
(low tide)
Earth turns eastward
Equator
South Pole



a Spring tides $L+S \sim 3S$



b Neap tides $L-S \sim S$

Sidereal month	=	month for moon to return to same position relative to stars	=	27.321681 d
Sidereal year	=	year for sun to return to same position relative to stars	=	365.256363 d
Anomalistic month	=	month of perigee	=	27.554550 d
Anomalistic year	=	year of perihelion	=	365.259635 d
Tropical month	=	~month of rising equatorial crossing	=	27.321582 d
Tropical year	=	year of spring equinoxes (~calendar year 365.2564 with leap days)	=	365.242189 d
Synodic month	=	month of new/full moon	=	29.530589 d

TGBody	Orbit	Frequency	Period	Name	Mnmic	Amp
Moon	Circular in Erth Eq Plane	2 / Lunar day	12.42	Lunar SD	M2	.2423
Moon	Elliptical in Erth Eq Plane	2 / Lunar Day – 1/ Anom Month	12.65	Lunar Elliptic SD	N2	.0464
Moon	Circular, not in Erth Eq plane	1 / Lunar Day +/–	25.84	Lunar D	O1	.1005
		1 / Tropical Month	23.92	Lunisolar D	K1	.1416
Sun	Circular in Erth Eq Plane	2 / Solar day	12.00	Solar SD	S2	.1128
Sun	Elliptical in Erth Eq Plane	2 / Solar Day – 1/ Anom yr	12.01	Solar SD Elliptic SD	T2	.0066
Sun	Circular, not in Erth Eq plane	1 / Solar Day +/–	25.84	Solar D	P1	.1005
		1 / Tropical Yr	23.92	Lunisolar D	K1	.0468
Moon	Circular not in Erth Eq Plane	2/tropical Month	327.86	Fortnightly	Mf	.0417
Moon	Elliptical in Erth Eq Plane	1/Anom Month	661.31	Lunar mthly	Mm	.0220

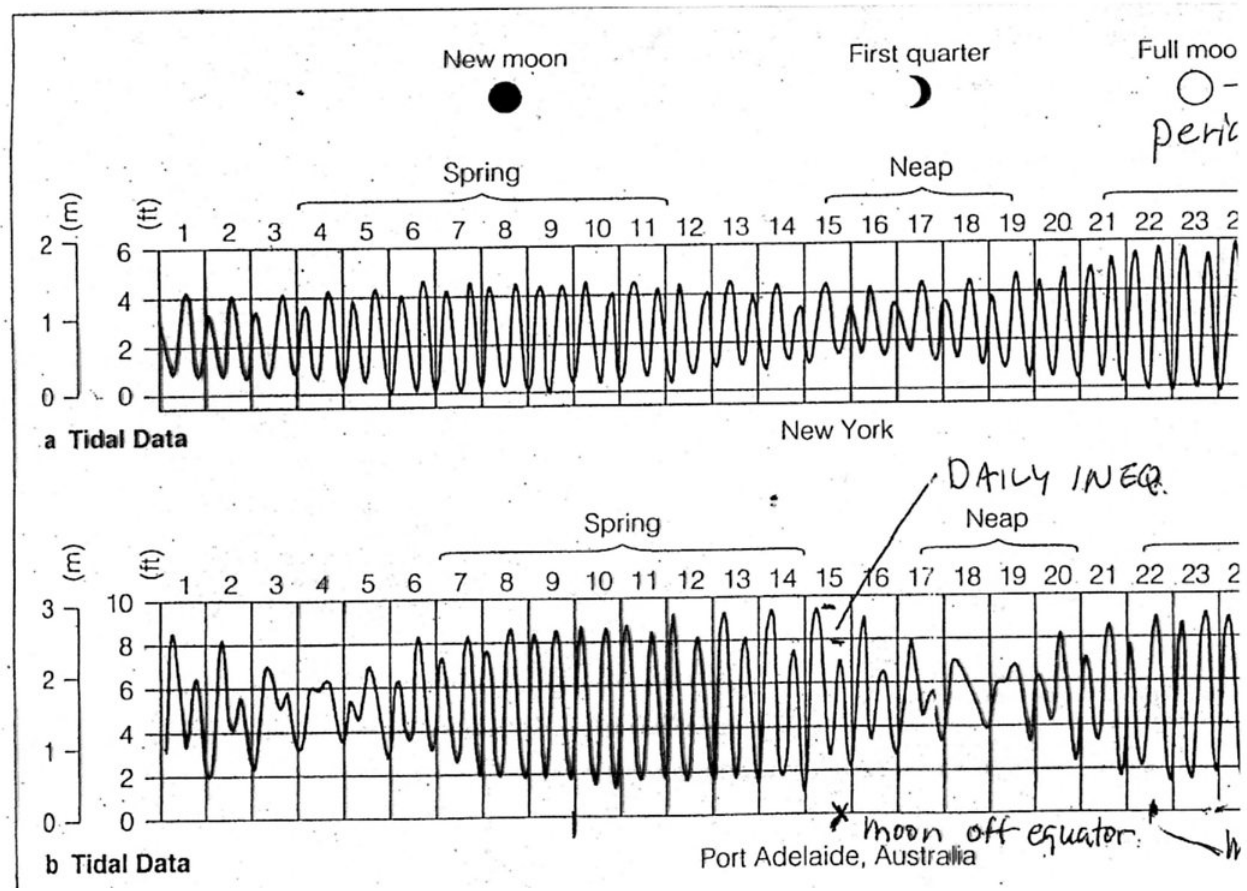
Components	Effect	
M2+S2	spring–neap cycle in semidiurnal tide	(2/synodic month)
M2+N2	perigean high tides	(1/anomalistic month)
S2+T2	perihelion high tides	(1/anomalistic year)
K1+O1	declinational cycle in L semidiurnal tide	(2/tropical month)
K1+P1	declinational cycle in S semidiurnal tide	(2/tropical year)

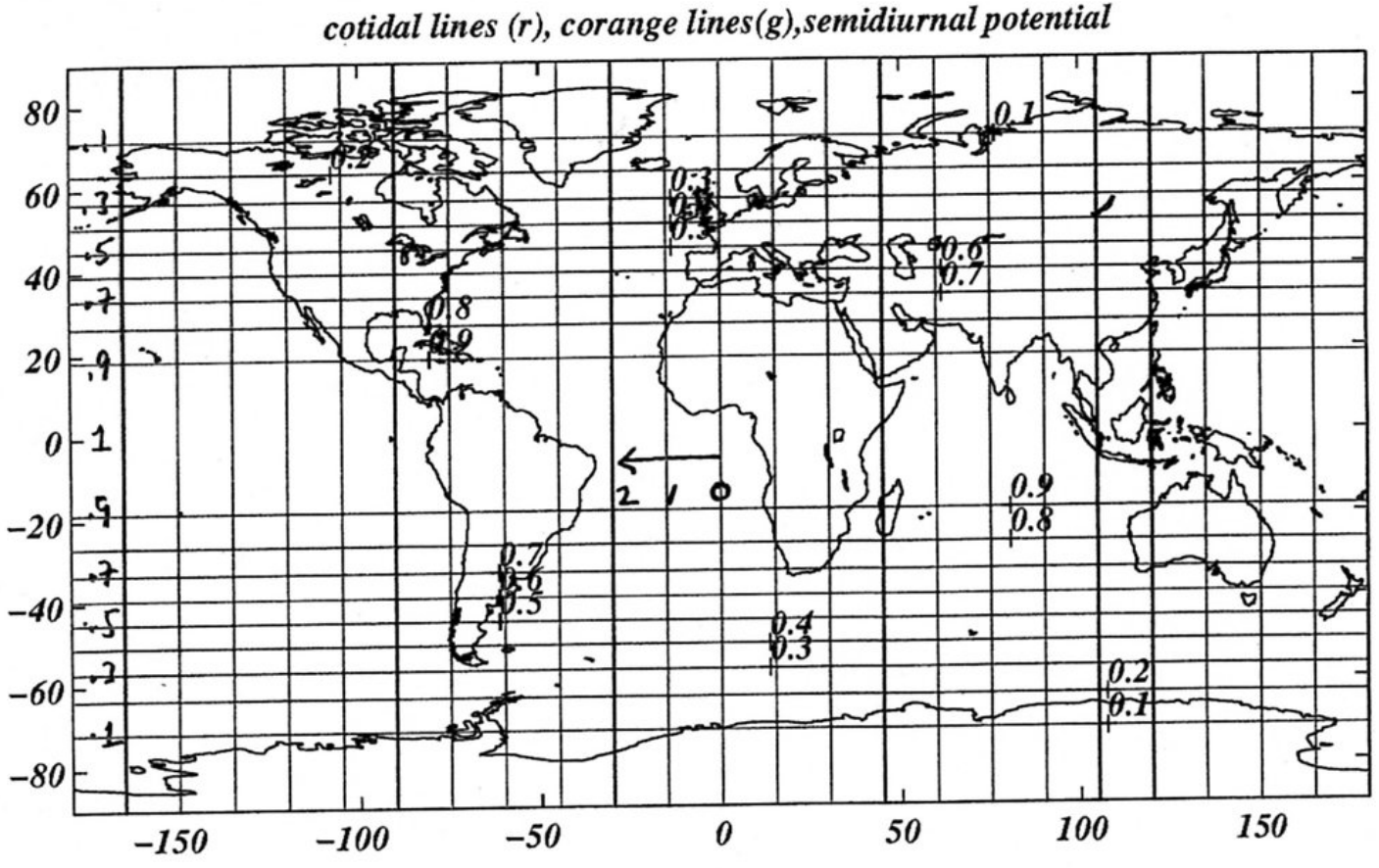
Good references:
http://en.wikipedia.org/wiki/Tide
http://en.wikipedia.org/wiki/Month
http://en.wikipedia.org/wiki/Year
http://en.wikipedia.org/wiki/Arthur—Thomas—Doodson (for true afficionados)

Sylodic 29.531 (lunar)

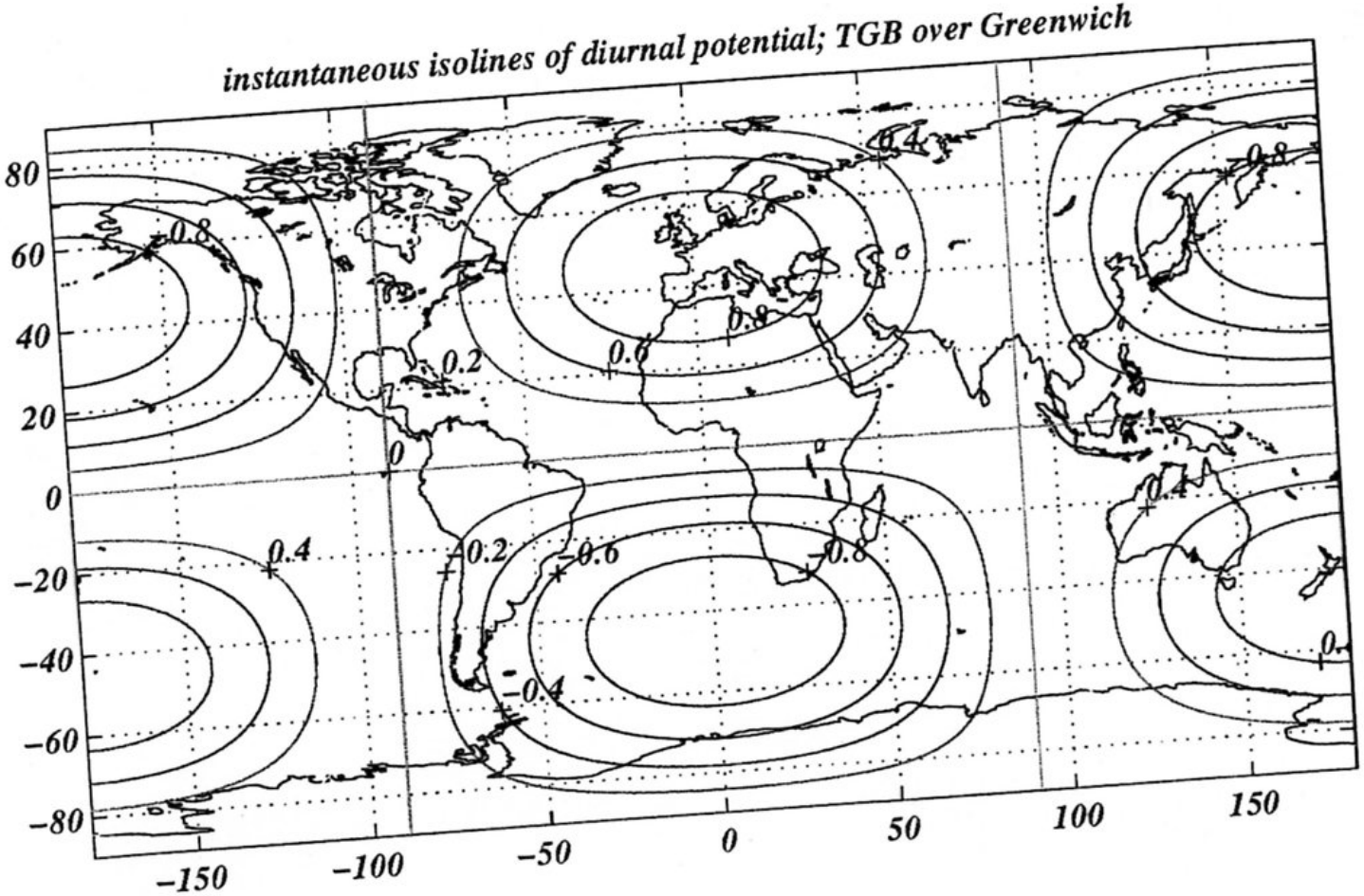
anomalistic 27.554551 (perigee)

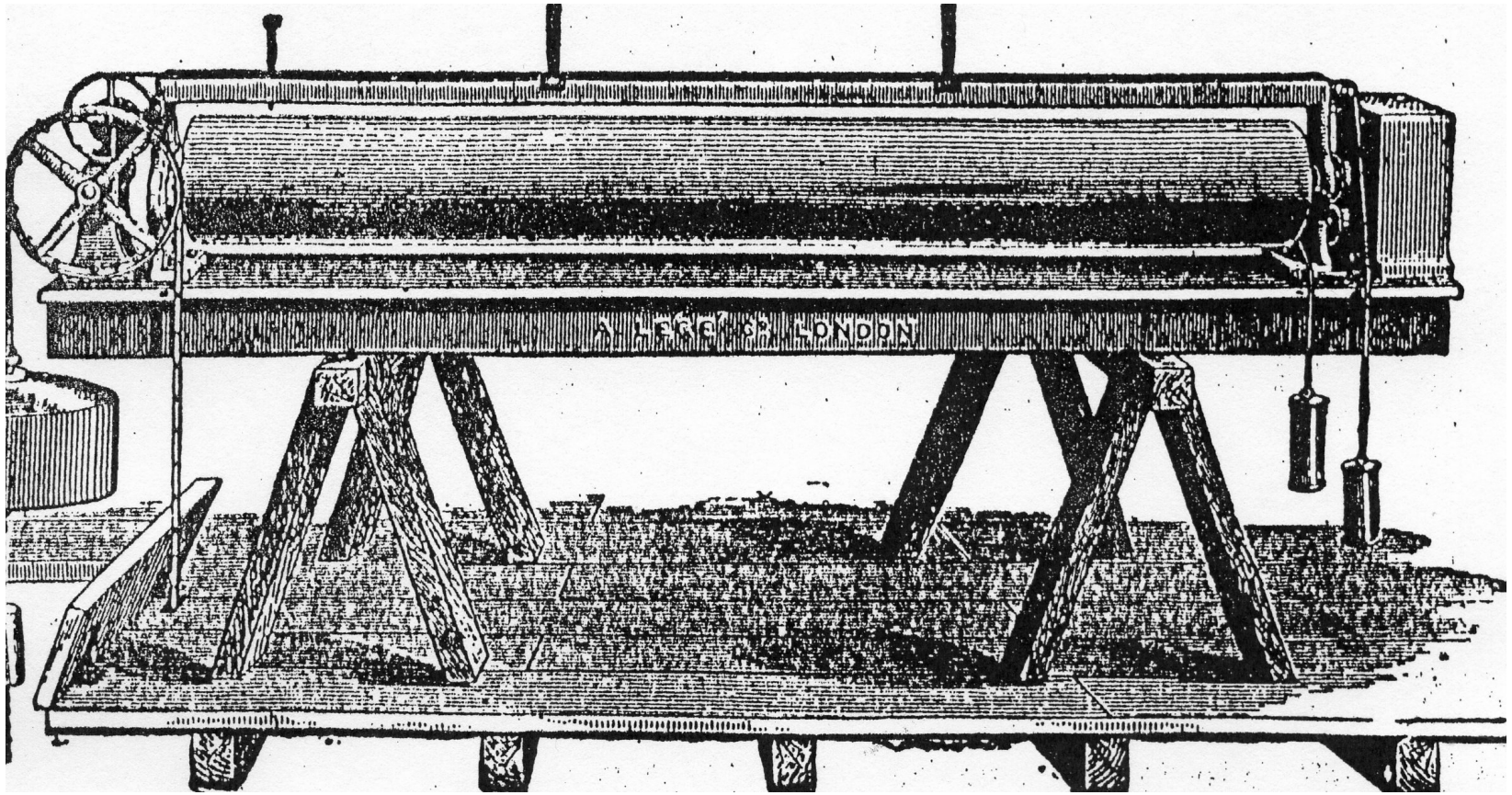
tropical 27.321582 (node)





(or solid earth tide)


instantaneous isolines of diurnal potential; TGB over Greenwich
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
0.8
0.4
0.2
0.6
-0.4
-0.6
-0.8


A. HERBERT. LONDON.

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		1 / Tropical Month	23.92	Lunisolar D	K1	.1416
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		1 / Tropical Yr	23.92	Lunisolar D	K1	.0468
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K1+O1	declinational cycle in L semidiurnal tide	(2/tropical month)
K1+P1	declinational cycle in S semidiurnal tide	(2/tropical year)

Good references:
http://en.wikipedia.org/wiki/Tide
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http://en.wikipedia.org/wiki/Year
http://en.wikipedia.org/wiki/Arthur—Thomas—Doodson (for true afficionados)

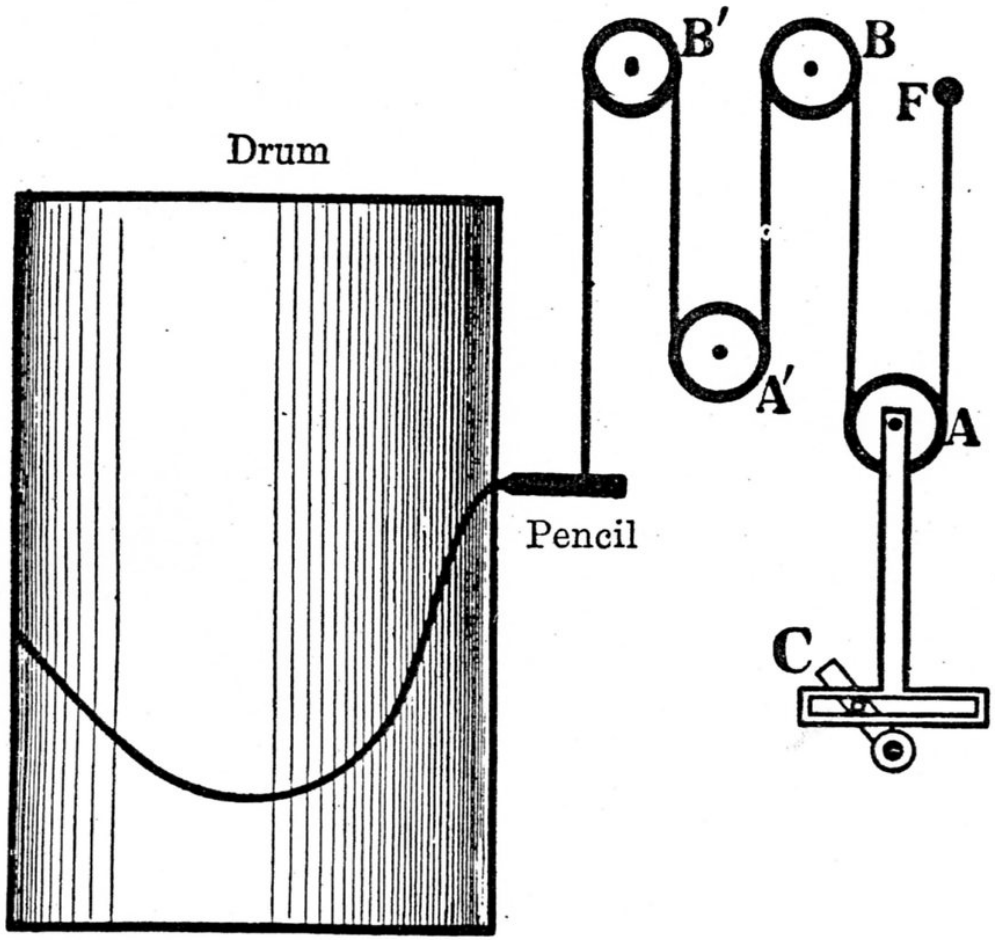


DIAGRAM OF TIDE-PREDICTING INSTRUMENT

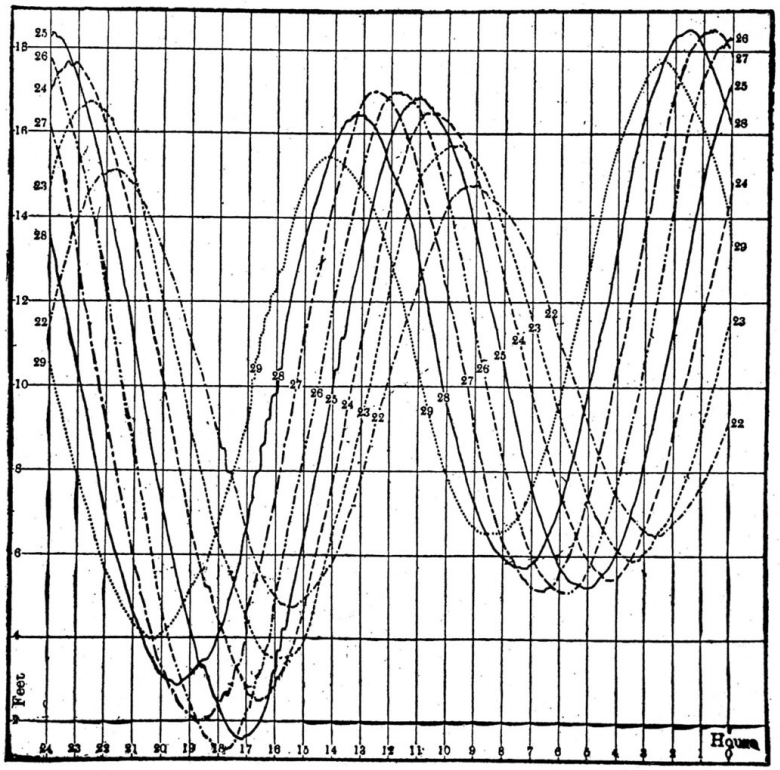


FIG. 5.—BOMBAY TIDE-CURVE FROM NOON, APRIL 22, TO NOON, APRIL 30, 1884

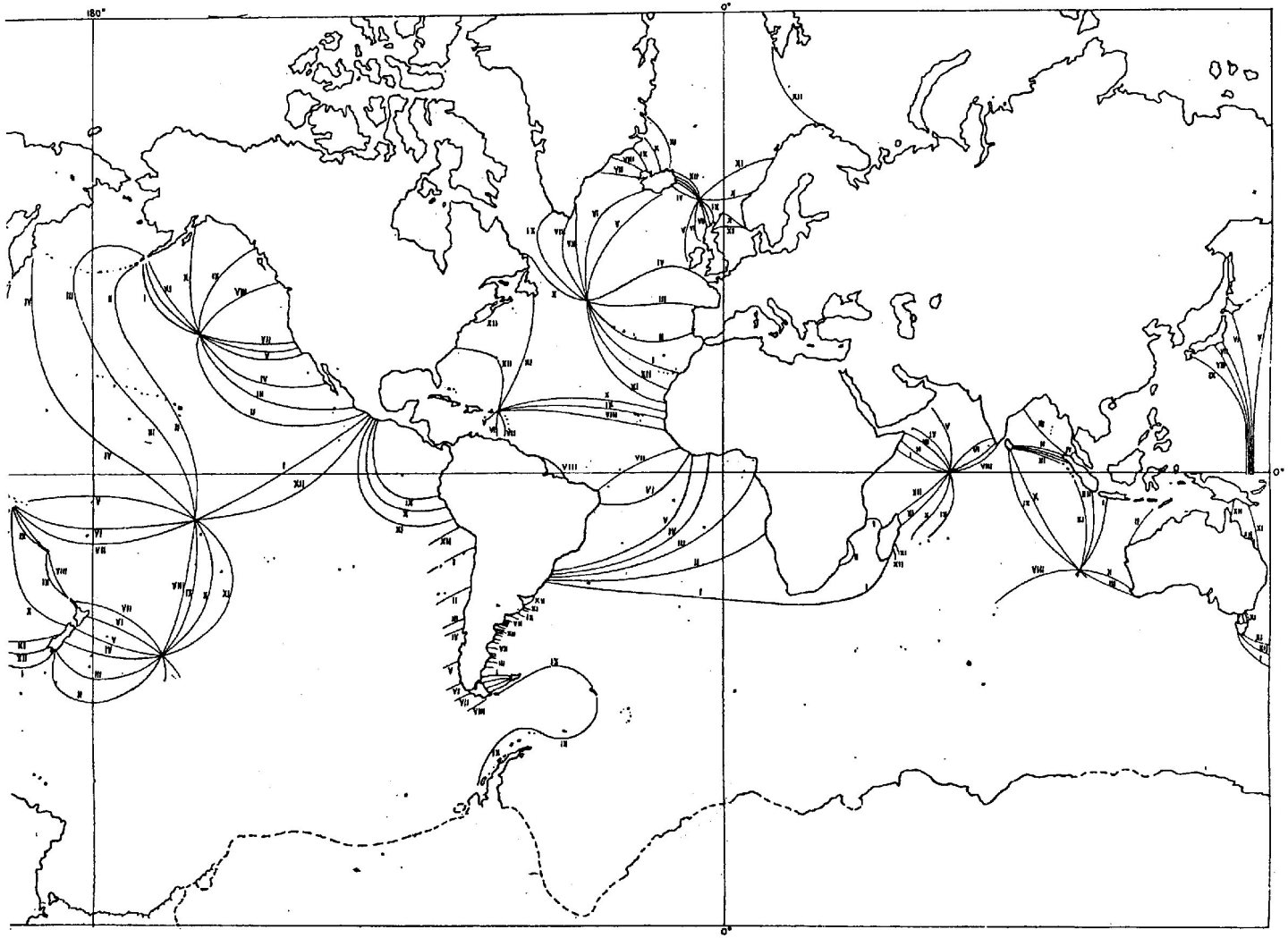
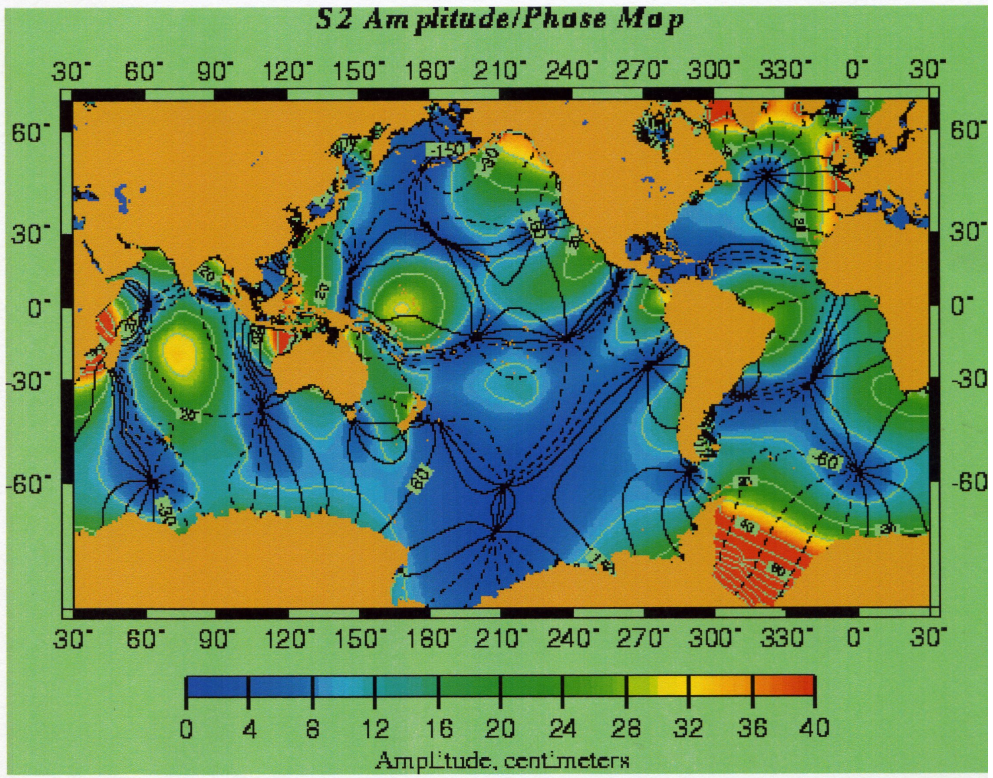
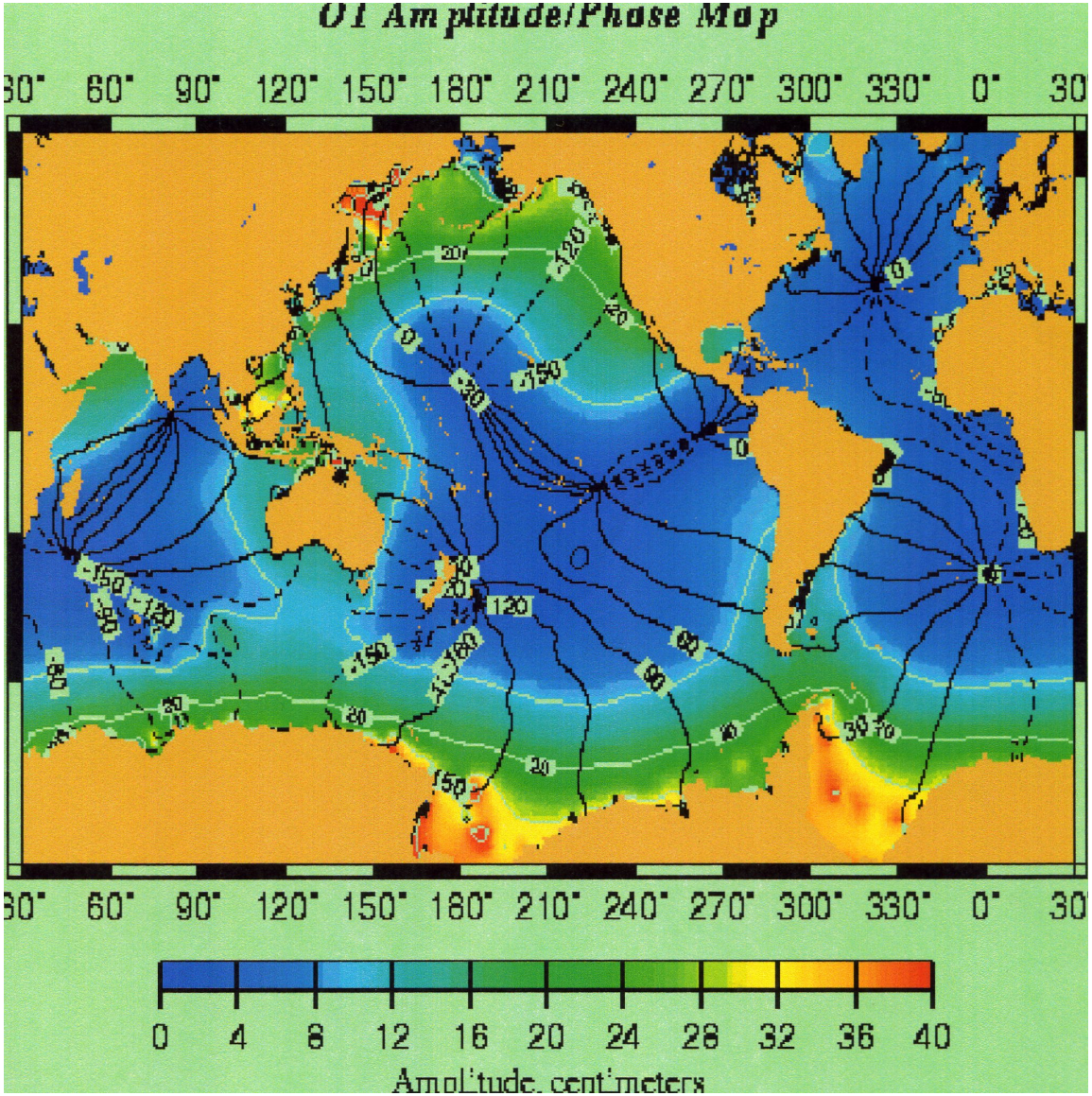


Figure 10.22 Cotidal lines for M_2 (in lunar hours relative to moon's transit over Greenwich). (Villain, 1952.)


S2 Amplitude/Phase Map
30° 60° 90° 120° 150° 180° 210° 240° 270° 300° 330° 0° 30°
60°
30°
0°
-30°
-60°
0 4 8 12 16 20 24 28 32 36 40
Amplitude, centimeters


O1 Amplitude/Phase Map
30° 60° 90° 120° 150° 180° 210° 240° 270° 300° 330° 0° 30
0 4 8 12 16 20 24 28 32 36 40
Amplitude, centimeters

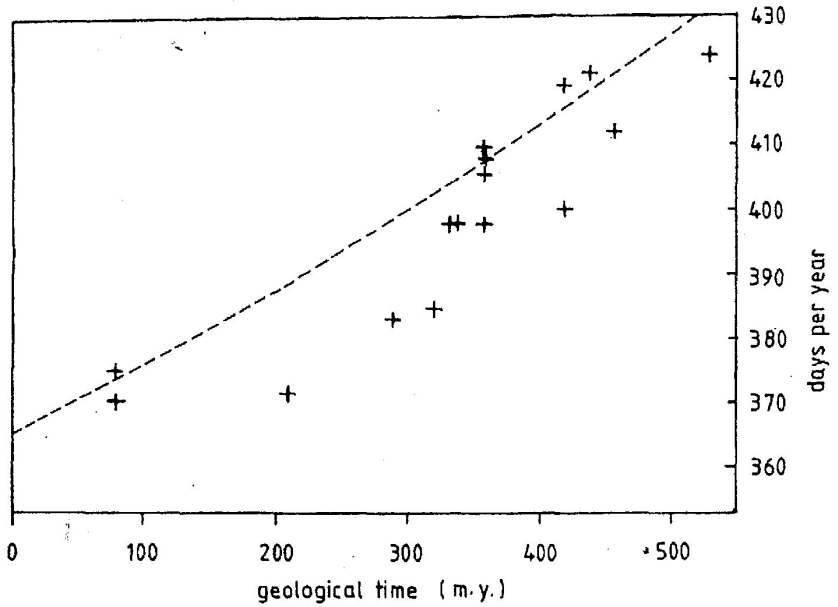


Fig. 1. Summary of paleontological data showing days per year. (After Scrutton 1978). The broken line extrapolates the present rate of deceleration

Figure 1 is taken from a review of Scrutton (1978) presented at the first Bielefeld meeting on tidal friction. It summarizes all paleontological data available and indicates that the length of the day (l.o.d.) has changed remarkably during the last 500 m.y. But the assumption of a constant lengthening of the day of 2 ms/century (about the present rate) can only roughly fit the data as shown by the dashed line. Instead, there is an indication of a relatively low dissipation rate during the last 300 m.y. (up to the Permian), whereas before that time a rate even somewhat higher seems reasonable.

Garrett Nature 1972

$T_{M2} = 12.42h$

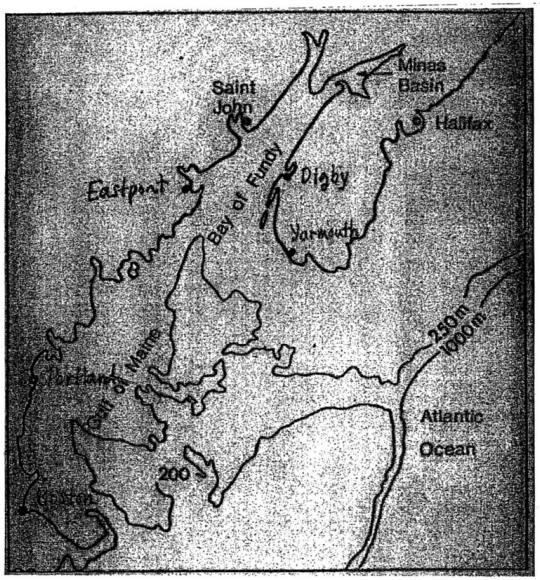
$T_{RES} = 13.3h$

My calculations suggest that the Bay of Fundy and Gulf of Maine have a resonant period of 13.3 ± 0.4 h and that the present M_2 tide has a Q of 5.25 ± 1.5. Smaller constituents have the same resonant period but a slightly smaller Q.

There can be little doubt that the resonant period is greater than the M_2 period of 12.42 h. Construction of barriers in the upper part of the Bay of Fundy for the generation of electrical power would change the tidal amplitude at any point in the Bay of Fundy chiefly by increasing ω_0. Unless the change of geometry is drastic enough to put ω_0 further above ω_M than it is at present below it, a slight amplification of the tides appears likely.

By decreasing T_{RES} towards M_2

Previous work on this problem[6,15,17,18], which predicted a decrease in tidal amplitude, considered too small a region and was based on the false assumption that the tidal amplitude at the outer boundary of the system would be unchanged by barrier construction, an assumption contrary to results from studies of analogous problems[11,12].



6. Dissipation of tidal energy

The observed discrepancies in the motion of Moon and Sun have fascinated philosophers and scientists alike. The role of tidal friction was proposed in 1754 by Kant in an essay 'Untersuchung der Frage, ob die Erde in ihrer Umdrehung um die Achse, wodurch sie die Abwechselung des Tages und der Nacht hervorbringt, eine Veränderung seit den ersten Zeiten ihres Ursprunges erlitten habe, und woraus man sich ihrer versichern könne.' Laplace rejected this suggestion because it implied a secular acceleration in the motion of the Sun and planets, as well as of the Moon, and this had not yet been observed. In 1865 Delaunay revived the hypothesis to account for the secular acceleration of the Moon, but not until 1905 did Cowell discover the prerequisite acceleration of the Sun. The first discussion of the role of oceanic tides appears in the *Treatise on Natural Philosophy* (Thomson and Tait, 1879, p. 191). In 1881 Frederick Engels* criticized Thomson and Tait, claiming that only bodily tides can account for the lunar discrepancy. Engels's critique is based on a misconception concerning the energetics of the situation.

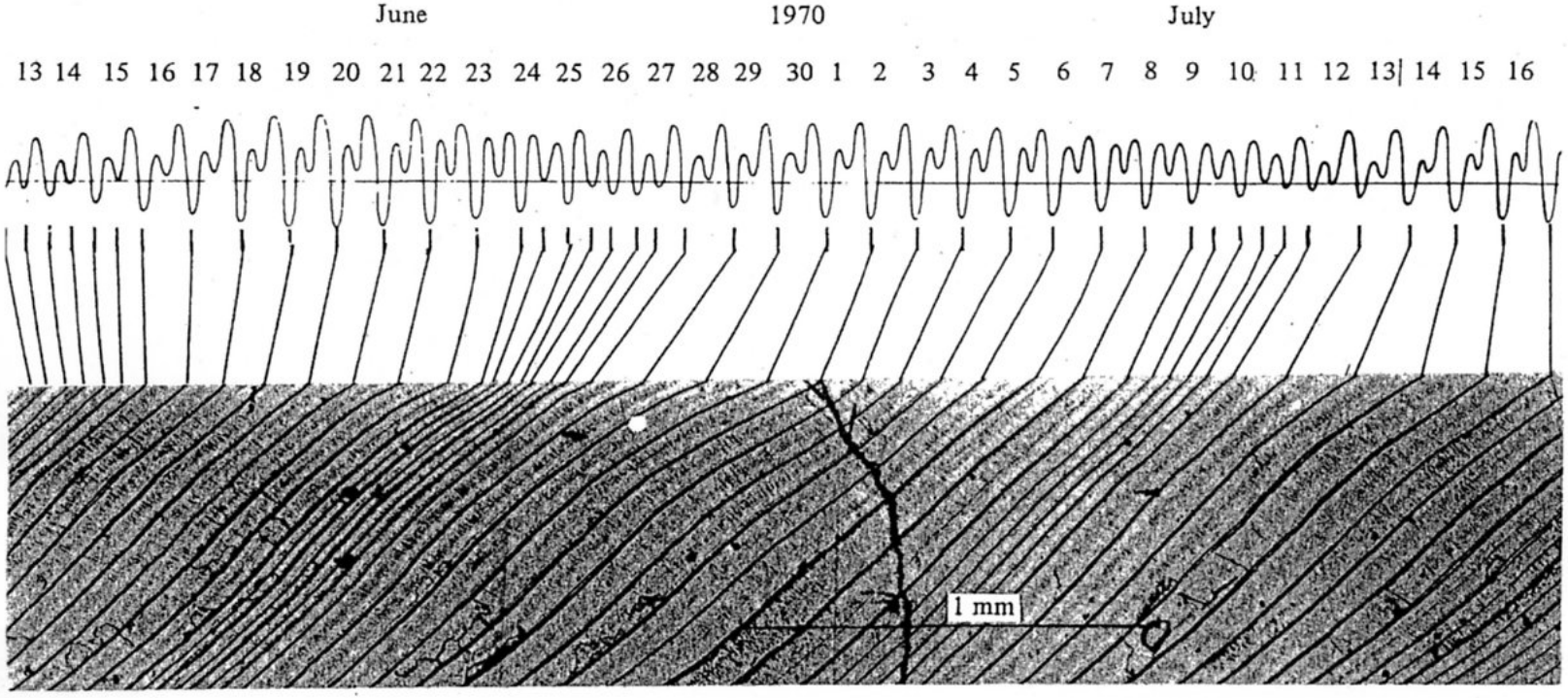


Figure 11.8. Internal growth lines in *Clinocardium nuttalli* compared with tidal predictions for the same period. The horizontal line drawn through the tide curve marks the intertidal position at which the specimen was found. Lines form when the tide drops below this position (from Evans 1972).