THE IRREGULARITY OF THE EARTH'S ROTATION AS A PLANETARY GEOMORPHOLOGICAL AND GEOTECTONIC FACTOR

by

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TRANSLATOR'S COMMENTS

Though the idea has not been much discussed for the last fifty years, variation in the rotation of the earth must be accompanied by change of the earth's equatorial and polar radii, change of meridian arc length, change of radius of curvature and change of areal relationships on the earth's surface. It has been suggested that the result of such changes, in the polar regions, would be a spider-web pattern of faulting, concentric and radial with respect to the (present or past) pole of rotation. This thesis, however, could not be adequately illustrated from previously available data (cf. Hope [1], pp.421-2).

Gregory, Bower and Morley's chart, here reproduced, does show, in the Canadian Arctic Archipelago, a pattern of deep faulting (wavy lines in the chart) which is concentric and radial with respect to the present pole. (According to paleomagnetic data, the pole of rotation has been more or less stably positioned in the Arctic Ocean area since Mid-Tertiary times.)

It must be emphasized that the said pattern of deep faulting was charted by Gregory et al. purely from the geological and geomagnetic evidence, with no thought that a radial-concentric pattern might be revealed.

One of the postulated faults, concentric with the pole, is shown extending along the remarkable arcuate waterway, 800 miles long, of the Parry Channel (Lancaster Sound, Barrow Strait, Viscount Melville Sound, M'Clure Strait). On this fault, the northern tip of the Boothia Precambrian arch apprears to have been offset westward by perhaps 20 miles, as may be seen by the corresponding lateral displacement of the Boothia magnetic anomaly (Gregory, Bower and Morley [2], Fig. 3 and pp.4,5).

In any map of the Canadian Arctic, the Parry Channel has a fatal attraction for the eye: it so closely follows the parallels of latitude, and shows the northern part of the Archipelago so markedly detached, or separated by a linear subsidence, from the southern part. Compare, for example, the contouring in Savarenski's chart (Hope [1], Fig. 5). Parts of the channel coastline preserve a remarkable straightness; for example, the south coast of Devon Island (Thorsteinsson and Tozer [3], p.358).

The straight eastern boundary of the northern block of the Archipelago is also noteworthy. Along this boundary, it is thought, there has been a relative movement of Greenland, in the direction shown by the heavy arrow that we have added to Gregory, Bower and Morley's chart. Compare Wilson [4], Fig. 5; Harland [5], Fig. 6. Baffin Bay has opened up; Greenland has drifted northwestward into the European Arctic Basin, scraping, as it were, along the straight eastern boundary of the Arctic Archipelago and moving parallel to that part of the Lomonosov Ridge connecting with Ellesmere Island (cf. Hope [1], Fig. 2).

The drift of the Greenland block is ascribed to a convective overturn in the mantle. Of course it is not clear how this drift is to be related to the radial and concentric pattern of faulting --- if this pattern proves to be no illusion. The faulting may have provided lines of weakness along which displacements, subsidiary to the migration of Greenland, may have taken place.

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There are fluctuating changes in the earth's rate of rotation, and also a secular change or long-term drift due to tidal friction (see Munk and MacDonald [6], pp.213, 247). According to the best astronomical estimates (from ancient eclipses), the change in the length of day over the last two millennia has been 1-2 milliseconds per century. These estimates have often been questioned and modified, but recently some interesting new evidence has been brought forward, quite independently indicating that just such a rate of retardation has persisted over geological spaces of time. It is reported that the fine epithecal growth ridges of Middle Devonian fossil corals number about 400 per year, instead of about 360 as in the modern representatives of these corals; they are probably diurnal growth lines (Wells [7]). The Devonian year, then, had about 400 days, or the length of day was about 22 of our present hours. This agrees very well with isotope dates for the Devonian (385-405 million years B.P.) and a lengthening of the day by 1-2 milliseconds per century.

Such a persistant mean deceleration perhaps implies that the retarding friction may be due more to internal tides than to the effect of tides in shallow seas (which must have varied greatly).

Differential acceleration. The tidal deceleration may have been opposed by the effect of shrinkage of the planet. If the shrinkage was from spherical toward tetrahedral shape, there were unequal accelerations from latitude to latitude — a possible source of tectonic action, possibly concentrated toward the equator (Carey [8]). In spite of differences of theory, it is interesting to compare the positions of Spain relatively to the North African coast in Carey [8], Fig 5, and Wilson [4], Fig. 6.

REFERENCES

1) E.R. Hope: Geotectonics of the Arctic Ocean and the Great Arctic Magnetic Anomaly. J. Geophys. Res., 64, no.4, 407-427 (1959).

2) A.F. Gregory, Margaret E. Bower and L.W. Morley: Geological interpretation of aeromagnetic profiles from the Canadian Arctic Archipelago. Geol. Survey of Canada paper no.60-6 (1960); reprinted in: Geology of the Arctic, vol.1, 427-437, Toronto University Press, 1961.

3) R. Thorsteinsson and E.T. Tozer: Structural history of the Canadian Arctic Archipelago since Precambrian time. In: Geology of the Arctic, vol.1, 339-360. Toronto University Press, 1961.

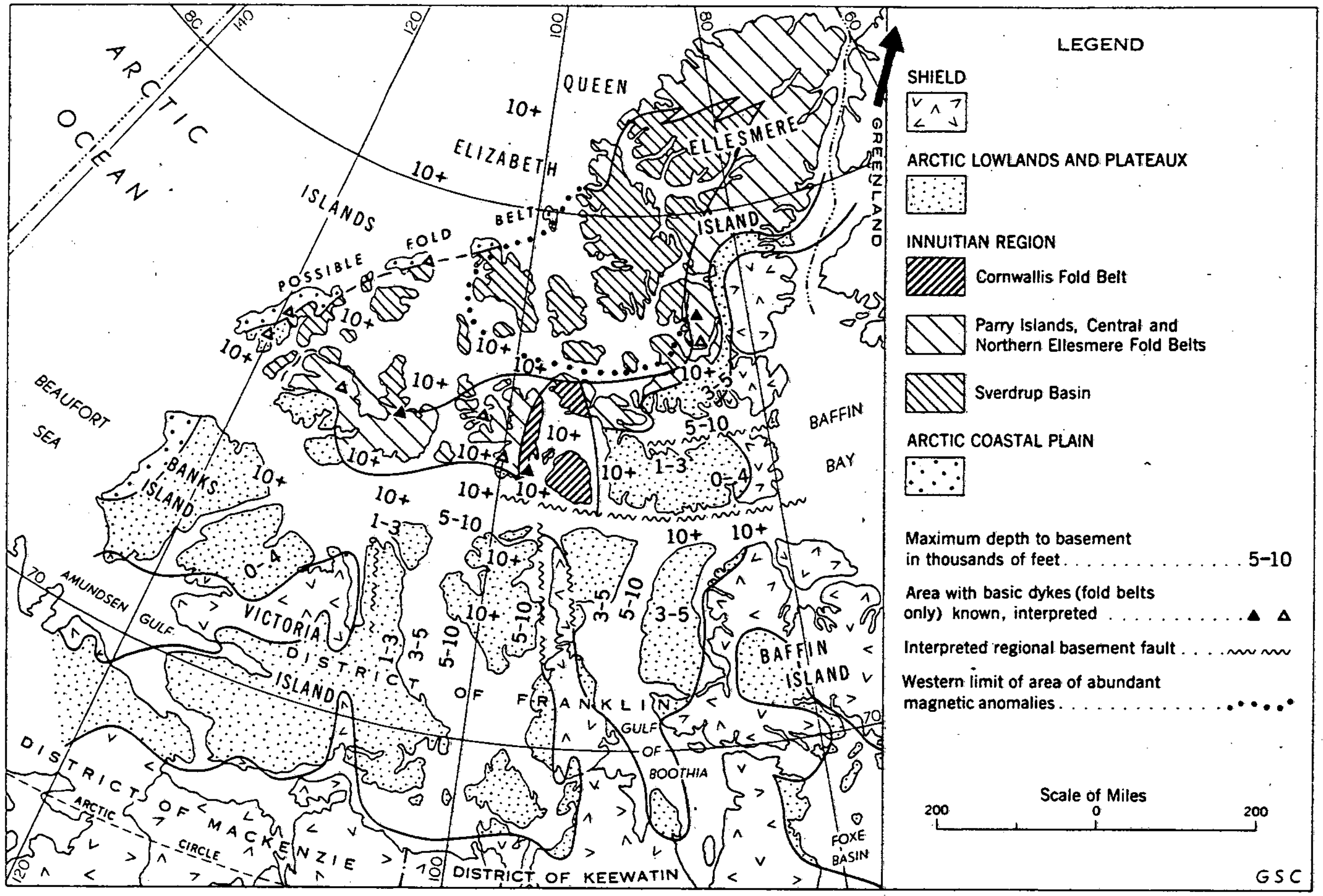
4) J. Tuzo Wilson: Hypothesis of earth's behaviour. Nature, 198, no.4884, pp.925-929.

5) W.B. Harland: An outline structural history of Spitsbergen. In: G.O. Raasch (ed.), Geology of the Arctic, vol.1, 68-132, Toronto University Press, 1961.

6) W.H. Munk and G.J.F. MacDonald: The Rotation of the Earth. Cambridge University Press, 1960.

7) J.W. Wells: Coral growth and geochronometry. Nature, 197, no.4871, pp.948-950 (1963).

8) S.W. Carey: The asymmetry of the earth. Australian Journal of Science, 25, no.9, 369-384 (1963).



Geological regions and maximum depths to basement in the Arctic Archipelago. Reproduced (by permission) from Gregory, Bower and Morley [2].

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THE IRREGULARITY OF THE EARTH'S ROTATION AS A PLANETARY GEOMORPHOLOGICAL AND GEOTECTONIC FACTOR *

M. V. Stovas

Today, the following propositions are regarded as conclusively established:

1. There exists a historically monotonic process of retardations of the angular velocity of the earth's rotation by tidal friction, a retardation which is reflected in an increase in the length of the day. According to data from the study of ancient eclipses, the increase in the length of the day over the last 2500 years has amounted to 0.0024 seconds per century, while over the last century the increase of the day's length is put at 0.0016 seconds.

2. There occur abrupt increases or retardations of the angular velocity of the earth's rotation, due, apparently, to internal and external changes and to the irregular superficial structure of the earth as a figure of equilibrium; effects which in turn produce, both internally and superficially, great stresses and disjunctive disturbances. The abrupt variations of angular velocity differ both in magnitude and in sign, and are as large as 1.6 seconds per year (1910-1913); that is, affecting the length of the day by as much as 0.0044 seconds. The secular retardation of the earth's rotation has considerable fluctuations superimposed on it.

3. Within the year there are variations of the angular velocity of the earth's rotation, probably due to the influence of seasonal changes in the circulation of the atmosphere. The seasonal variation in the length of the day, according to quartz clock and pendulum clock data, may in a year be as large as 0.0025 seconds, with the maximum rotational velocity occurring in August and the minimum in March.

The proven irregularity of the earth's rotation is a fact of fundamental cosmogonic significance, which has given rather encouraging results in the field of celestial mechanics, as regards bringing into agreement with gravitational theory the observational data on the movements of all the bodies of the solar system.

From 1681 to 1954 inclusive, the earth lost 44.28 seconds; thus an annual mean of 0.159 seconds, or a 0.0004442-second change in the length of the day. Over the last 67 years (1887-1954), 38.78 seconds were lost through decrease of the angular velocity of the earth's rotation; thus 0.592 sec/year or 0.001645 sec/day. The relative retardation, then, has increased by a factor of 3.7.

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* An abridged version of this paper was published in the Russian language under the title: The Irregularity of the Earth's Rotation as a Geotectonic Factor (Izv. Vses. Geog. Obshch., 1959, 4, 336-341). The Ukrainian version here translated has been collated against the Russian and slightly edited; new references added to the Russian version have been included. [Translator.]

Such is the irregularity of the earth's rotation in the present historical period. The compression (flattening) of the ellipsoid depends on the angular velocity of the rotation and on the mean density of the earth. A decrease in the density of the planet increases the flattening, while a decrease of the angular velocity will change the potential of the deforming forces and bring about a decrease of the flattening. The degree of flattening essentially depends on the velocity of axial rotation of the planet.

If we consider the earth's figure as a biaxial variable-rotation ellipsoid, the volume of which remains constant in time, we can find the variation ratios of its basic parameters with respect to the variation of the compression α or of the eccentricity e, as follows.

1) For the radius ρ of a parallel of latitude we have:

$$\frac{d\rho}{d\alpha} = \frac{a}{3}\left\{\frac{(1-\alpha)^2 - 2\tan^2\varphi}{[(1-\alpha)^2 + \tan^2\varphi]^{3/2}}\right\}$$

2) For the ordinate y:

$$\frac{dy}{d\alpha} = \frac{a\tan\varphi\,[(1-\alpha)^2 - 2\tan^2\varphi]}{3[(1-\alpha)^2 + \tan^2\varphi]^{3/2}}$$

3) For the radius vector r:

$$\frac{dr}{d\alpha} = \frac{a}{3}\left\{\frac{[2 + (1-\alpha)^2\cos^2\varphi - 2]}{[1 - (2\alpha - \alpha^2)\cos^2\varphi]^{3/2}}\right\}$$

4) For the mean radius of curvature, R:

$$\frac{dR}{d\alpha} = \frac{2a}{3}\cdot\frac{\{2\tan^4\varphi + [5(1-\alpha)^2 + 4(1-\alpha)^4]\tan^2\varphi - (1-\alpha)^6\}}{[(1-\alpha)^3 + (1-\alpha)\tan^2\varphi]^2}$$

5) For the radius of curvature of a meridional cross-section, M:

$$\frac{dM}{d\alpha} = \frac{a[(1-\alpha)^4 + \tan^2\varphi]^{1/2}}{3(1-\alpha)^2}\times$$

$$\times\frac{4\tan^4\varphi + [13(1-\alpha)^2 - 14(1-\alpha)^4\tan^2\varphi - 5(1-\alpha)^6}{[(1-\alpha)^2 + \tan^2\varphi]^{5/2}}$$

6) For an element of meridian arc ΔS:

$$\frac{d\Delta S}{de} = \frac{e\Delta S}{3(1-e^2)}\cdot\frac{[1 - (3 - 8e^2)\sin^2 L - 6e^2\sin^4 L]}{(1 - e^2\sin^2 L)}$$

7) For a meridian arc from the equator to a point at latitude **L**:

$$\frac{dS_0^L}{de} = ae\left[\left(-\frac{1}{6} + \frac{1}{16}e^2 + \frac{15}{128}e^4 + \dots\right)\frac{L''}{g''} + \left(\frac{1}{4} + \frac{1}{4}e^2 + \frac{145}{512}e^4 + \dots\right)\sin 2L -\right.$$

$$\left. - \left(\frac{33}{64}e^2 + \frac{335}{512}e^4 + \dots\right)\sin 4L + \left(\frac{15}{64}e^4 + \dots\right)\sin 2L\cos 4L + \dots\right]$$

8) For an element of area, ΔZ, in the zone of latitude L:

$$\frac{d\Delta Z}{de} = \frac{2e\Delta Z[1 - (3 - 5e^2)\sin^2 L - 3e^2\sin^4 L]}{3(1-e^2)(1-e^2\sin^2 L)}$$

From the set of equations (1)-(8) we have:-

Parameters of the ellipsoid	Parallels on which the parameters of the ellipsoid are independent of change of the compression	Parallels on which the parameters of the ellipsoid have their extreme conjugate values
ρ	±35°15'52" (±35°)	1) ±61°52'28" (±62°) 2) equator
y	±35°15'52" (±35°)	1) poles 2) ±19°28'16" (±20°)
r	±35°15'52" (±35°)	1) poles 2) equator
μ	±48°11'22" (±48°)	1) poles 2) equator
R	±35°15'52" (±35°)	1) poles 2) equator
ΔZ	±35°15'52" (±35°)	1) ±61°52'28" (±62°)
S_o^L	±65°17'07" (±65°)	1) ±35°15'52" 2) poles.

Thus with change of compression the maximum conjugate change of area will occur on parallels ±62° and the equator; the change of area will be minimum at the poles and on parallels ±35°. The parallels of ±62° and the equator are conjugates; a lengthening on one hand corresponds to a shortening on the other. But lengths along the parallels ±35° remain constant under changing compression of the ellipsoid. The conjugate variations of arc-length along the parallels, variations which have their extremes on parallels ±62° and the equator respectively, must cause, in the deformed ellipsoid, latitudinal tangential stresses. Such stress is maximum at the equator and decreases toward parallels ±35°, where it is zero; then it changes sign and increases toward the high latitudes, reaching its extreme value on parallels ±62°; then it decreases toward the poles, where it again becomes zero [17-20].

Change in the radius vector and radius of curvature of the meridional cross-section of the ellipsoid, due to variation of the compression under the influence of deforming forces, causes a meridional warping of the surface of the terrestrial ellipsoid, which is important for study of the changes in the height of ancient marine terraces and the temporal change in the north-south slopes of the surfaces of large lakes. Change in the compression of the ellipsoid means a general deformation of the entire figure of the earth, with the result that in each hemisphere there is set up a flow of the subcrustal substrate in one direction or the other across the critical parallels ±35°.

As a result of the conjugate variations in the length of meridional arcs, of one sign from the equator to ±35° and of the other sign to the poles, together with the similar conjugate deformation of areas, the substrate flow and also precessional nutation, there is a development of tangential stresses in the meridional direction, with maxima at the poles and on parallels ±35° (the sign-change parallels). The tangential meridional stresses control latitudinal deformation.

The substrate flow, just like the conjugate deformations of the crustal layer, is a necessary consequence, following directly from the law of constancy of the moment of inertia; that is, from the dependence of the earth's shape on its angular velocity of rotation at any given moment. This in turn causes great stresses both in the body of the earth and in its surface, the release and repercussions of which show up for us in the deep tectonics and in the surface tectonics.

To the question of whether the energy of the earth's rotational retardation and of nutation is sufficient for the conjugate deformation of the ellipsoid, for the accumulation of stresses leading to a tectonic pulse, and for the formation of folding, an answer is provided by two special researches, one of which is due to L.S. Leibenzon [9] and the other to the well-known French mathematician A. Véronnet [36].

Leibenzon's study of the potential of the deforming forces (the potential that directly determines the compression or flattening of the earth's figure) and Veronnet's study of the precession both demonstrate that great stresses are developed, which with passage of time deform the figure of the earth --- a process that undoubtedly has tectonic effect.

"I come to the conclusion", writes Leibenzon, "that the tidal deceleration of the earth's rotation gives rise to such great stresses in the thin outer crust that this crust would necessarily be disrupted. I see in this a confirmation of my conclusion in the preceding chapter, that a thin stony envelope is impossible". ([9], p.191.) And further: The effect of tidal friction, as we know, is to retard the earth's rotation. G. Darwin's studies show that in past eras the earth rotated much faster. Hence it is clear that if the outer envelope of the earth solidified in a state of equilibrium between gravitational and centrifugal forces, then with the slowing down of the earth's rotation this equilibrium must be destroyed; the crust will be deformed, and come into a new state of elastic equilibrium." ([9], pp.256-257.)

As a result of his researches Leibenzon concludes that "after a long time the deforming forces due to the slowing down of the earth's rotation will cause a new disruption of the earth's crust, accompanied by reintensified earthquakes and volcanic activity; this process will continue as long as the tides retard the earth's rotation." ([9], p.261.)

In 1912 A. Véronnet's doctoral dissertation [36] was published, in which he showed that precession sets up, in the crustal layer, tangential stresses in the meridional direction --- compression and tension toward ±35°. "Thus," writes Véronnet, "the parallels of ±35° becomes zones of crustal fractures and dislocations. (More precisely, the latitudes are ±35°15'52".) These are the circles on which a sphere of the same volume intersects the ellipsoid, and furthermore they are lines of no movement, where the ellipsoid ruptures if it is deformed. It is sufficient to mention that the 35th parallel passes through San Francisco, High Mexico, Lisbon, Sicily, Calabria, Iran and Japan; it is one of the earth's lines of prevailing earthquakes. In the southern hemisphere this parallel is out over the ocean, except for the tips of the continents: the Cape, Melbourne, Buenos Ayres." ([36], pp.430-431.)

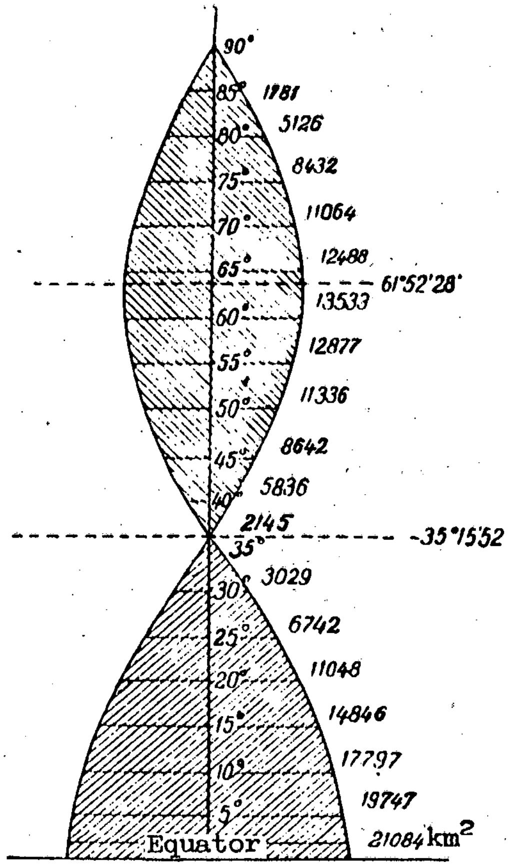

Fig. 1. Difference of latitude-zone areas on the (terrestrial) ellipsoid with compression $a_1 = 1:299$ and with compression $a_2 = 1:210$, for each five degrees from the equator to the pole.

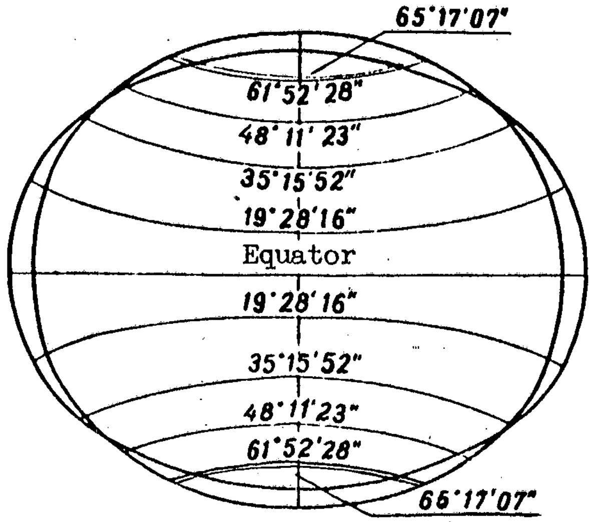

Fig. 2. Diagram of critical parallels on the earth's surface.

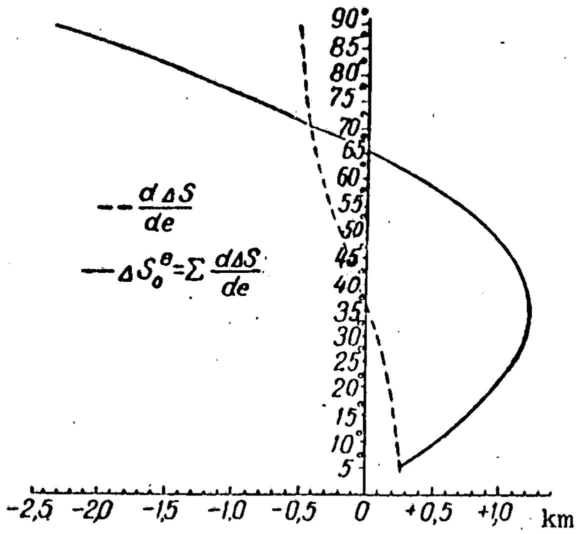

Fig. 3. Change of meridian arc lengths for change of compression from 1:210 to 1:299.

These studies justify the assertion that in the figure of the earth there are critical zones (equator, 35th parallels and poles) where the greatest effect is exerted by variation of the potential of deforming forces and by precessional nutation; this is a consequence of the conjugate deformations of the parameters of a variable-rotation ellipsoid, with its variation of compression or flattening.

Equations (1)-(8) indeed establish seven critical parallels on the variable-rotation ellipsoid of the earth, seven zones where change of flattening, precessional forces and density change will influence the temporal development of the earth's surface, namely: the poles (±90°), ±65°, ±62°, ±48°, ±35°, ±20°, and the equator (0°). Reversals of the acceleration of the rotational velocity, in conjunction with precessional influences, probably account for the thrust that is seen by geologists in folded systems of north-south strike.

Accepting the tidal theory we may, for the Silurian Period, take the compression of the terrestrial ellipsoid as 1:210. Comparison with the present ellipsoid then yields the following picture.

The total surface area of the terrestrial ellipsoid, with a compression of 1:210, is 510,083,800 km^2.

The zonally conjugate changes of area for one hemisphere may be exhibited by the following data:-

Compression	90° - 0°	35° - 0°	90° - 35°
1 : 210	255,041,900	147,133,063	107,908,837
1 : 298.3 *	255,041,530	147,040,956	108,000,574
Differences	+370	+92,107	-91,737

As is seen from this table, the tidal retardation of the earth's rotational velocity [since Silurian times] has decreased the earth's superficial area in the equatorial bulge zone (35°S to 35°N) by 184,214 km^2 and has increased the area between the two critical parallels ±35° and the poles by 183,474 km^2, with an insignificant decrease of 740 km^2 in the total surface area of the ellipsoid.

If we take into consideration that the process of folding is irreversible and that considerable fluctuations and precessional oscillations are superimposed on the tidal deceleration of the earth's rotation, then the above-cited figures for the conjugate change of areas since the Silurian Period will be several times greater, and this is probably one of the causes of folding. The change in the equatorial radius of the earth [since the Silurian] amounts to 3009 m, and the increase of the polar semi-axis, 5997 m. The decrease in the length of the equator during this time is approximately 19 km, while the length of the critical parallels of ±62° is increased by 11.7 km. The length of the critical parallels of ±35° remains constant. The length of the meridian quarter-circle over the same period of time was increased by 2.35 km. There is simultaneously a decrease of 1.24 km in the meridian arc from the equator to ±35° and an increase of 1.24 km from ±35° to ±65°; the meridian arc from the equator to ±65° is unaltered by variation of the compression; the change in the total length of the meridian arc is contributed by the latitudes from ±65° to the poles.

* Translator's note: See Véronnet [36], pp. 396, 418.

Such is the general description of the conjugate deformation of the ellipsoid over the geologically historical period. The global deformation must cause deformation of the crustal layer, epeirogenic movements, tangential stresses, and flow of sub-crustal matter from the equatorial region to the high latitudes. The conjugate variations of areas and arc-lengths of parallels and meridians must play an important part in the formation of folding, in faulting of 'planetary' scale, in the development of geosynclines, and in the accumulation of stresses prior to a tectonic pulse. In this regard, N.S. Shatski's geological hypothesis is highly important: namely, that "the planetary distribution of these tectonic sutures is determined by the rotation of the earth and by possible changes therein." ([22], p.23.)

Under change of compression or flattening, the conjugate changes of arc-length on the parallels and meridians set up, in the crustal layer, a characteristic ellipse of tangential stresses, while the conjugate variations in the radii of the parallels and in the radius vector cause epeirogenetic movements.

The continual character of movement in the critical zone of 35° latitude (north or south) is clearly marked out by arching upfolds and waviness of the topographic relief in Central Asia, in the Caucasus, in the Alps, in the Cape Mountains and Atlas Mountains of Africa; by down-vaultings and waviness of the floor of the Mediterranean depression, by the breaking-off of Tasmania from Australia; it is manifested in the continual tectonic and seismic phenomena, increasing as the critical parallels of ±35° are approached. Thus it is no accident that I.S. Shchukin notes: "Mountains attain their greatest heights, in both hemispheres, at subtropical latitudes (30-35°), a fact that likely has some connection with the general structural plan of the earth." ([23], p.240.)

V.H. Bondarchuk, investigating undular movement of the lithosphere, comes to the conclusion that since the end of the Carboniferous, upliftings of sialic masses have been "most intensive in the subtropical zones, between 30° and 40° latitude in the northern hemisphere and around 40° of southerly latitude". ([3], p.238.)

This phenomena constitutes a regular law in the life of our planet, and its association with the zones of the critical parallels ±35° is a consequence of conjugate deformations of the terrestrial ellipsoid due to the temporal irregularity of the earth's axial rotation and to precessional nutation. Along therewith, of course, phenomena arising from the internal structure of the earth (density change) are not to be ignored.

Present-day complex vertical fluctuations of the earth's crust indicate latitudinally zonal uplifting in the high latitudes and ubiquitous subsidence of the equatorial bulge of the earth.

In the high latitudes we recognize the uplifting of Greenland and Iceland, of the Scandinavian and Canadian Shields, of the northern shores of Scotland, Novaya Zemlia, Spitsbergen, of the whole northern coast of Siberia, of the northern coasts of the [Soviet] Far North, of eastern Alaska, and in general, of all Antarctica.

That an ubiquitous subsidence is characteristic of the equatorial zone of the earth is indicated by: the equatorial depression on the ancient African platform (the so-called Congo syncline), the Amazonian equatorial depression between the Guiana and Brazilian highlands, the depression of the Amazonian plain (as a result of which the river Tocantins, a right-hand tributary of the Amazon, has now been converted into an independent river), and finally the post-Tertiary subsidence of the geosynclinal region of the Malay Archipelago.

In recent geological and geographic literature there is quite a lot of factual material indicating the existence of tangential stresses, meridional in direction, on the 35th parallel.

a) Kraus [29], examining the Tellobetian structures and recent orogenic processes in that region, concludes that during the geosynclinal development of the Mediterranean depression there were, and are still today, meridionally directed tangential forces, southward from Europe and northward from Africa.

b) F.N. Krasovski [7] believes that "most favorable for tangential displacements of the crust are the regions adjacent to the 35th parallel (in the northern and southern hemispheres). It is just here on the earth's surface, between the parallels 20° and 50°, that we find a great deal and indeed a maximum of folding and overlapping to occur, and in general, much tectonic disturbance." And further: "We finally have an intricate complex of causes, making possible the meridional displacement of areas of the terrestrial crust. Important for geologists is the following conclusion: The terrestrial crust, in the zones between latitudes 20° and 50° must have, as compared with the rest of the surface of the globe, a greater adaptability to changes in the figure of the earth resulting from changes in the rotational velocity" (p.235).

c) V.V. Belousov [2] presents factual data on visible vertical and horizontal displacements of the earth's surface during the last seventy years (Table 21, p.473). The vertical and horizontal displacements here adduced coincide in latitude, in both hemispheres, with the zones of the critical parallels ±35°, a fact which indicates their genetic connection with the conjugate deformations of the earth's figure.

Amplitude of visible displacements during the most intense earthquakes (outside the USSR)

Location of epicenter	Year	Length of reactivated geosuture (in km)	Maximum displacements (in m)	
			Horizontal	Vertical
Wellington, N.Z.	1885	150	-	3
Sonora (Mexico)	1881	60	-	9
Mino-Owari (Japan)	1891	65-120	4	7
Baluchistan	1892	< 20	0.7	-
Assam	1897	20	-	12
California	1906	450	7	-
Taiwan	1906	50	3	-
Nevada	1915	30	-	5
Murchison, N.Z.	1929	> 4	-	5
California	1940	65	5	-

d) An absolute majority of the catastrophic and destructive earthquakes over the last 300 years took place in the immediate vicinity of the thirty-fifth parallel.

The distribution table and graph of catastrophic earthquakes (Fig. 4) c show the continual presence of horizontal movements in the zones of the critical parallels ±35°, movements presumably arising from conjugate deformation of the variable-rotation ellipsoid of the earth, and from precession.

On the other hand, a connection has been observed between fluctuations in the rotational velocity of the earth and the most intense volcanic eruptions occurring between 1870 and 1907 [31a], a fact which supports our views on the causation of the phenomenon.

The hydrosphere, being more mobile than the lithosphere, should react <u>instantaneously</u>, with a change of its mean level, to the fluctuating process of retardation of the angular velocity of the earth's rotation; that is, there will be a change in the [oceanic] surface of the geoid; the very character of the [tidal] retardation of rotational velocity must produce annual and secular oscillations of sea level. Study of the mean variation of sea level over many years at a number of stations on the Atlantic seaboard shows that such a [seasonal] variation actually exists, with a minimum level between January and March and a maximum between August and September. For the Pacific Ocean seaboard we have a similar picture of variation in the mean annual sea level, with a minimum in April and a maximum in September. One is impressed by the clear genetic connection of the extremes in the seasonal fluctuation curve of the angular velocity of the earth's rotation with the annual oscillation of sea level [18].

In 1930 Lallemand and Prévôt [30] noted a relationship between the fluctuation of the mean longitude of the moon and the fluctuation of mean sea level --- which in the last analysis is an effect exerted by the irregularity of the earth's rotation upon the position of the surface level of the geoid.

Besides the annual oscillation of mean sea level on the Pacific and Atlantic seaboards, periodic secular fluctuations of the mean sea level have been demonstrated, with the character of the fluctuation almost identical at all stations, that is to say, subject to one and the same periodic law [31]. These oscillations cannot be explained by the influence of long-period terms in the climatic and tidal variations. We explain them by the fluctuations in the angular velocity of the earth's rotation.

The position (in time) of mean sea level in the countries of Western Europe relative to the Amsterdam tidal gauge NN, gives a picture of ubiquitous rise of the mean zero level with increasing latitude of the location [24]:

Kronstadt	B = 59°59'N	+0.11 m;
Amsterdam	B = 52°22'N	+0.00 m;
Genoa	B = 44°24'N	-0.31 m;
Trieste	B = 43°35'N	-0.37 m;
Marseilles	B = 43°19'N	-0.26 m;
Alicante	B = 38°21'N	-0.52 m.

Catastrophic Earthquakes

Region of earthquake	Year	Approximate latitude
Lisbon	1755	+38°
Concepción	1835, 1939	-36°
California	1872, 1906	+38°
Alaska	1912, 1938	+62°
Sicily and Calabria	1633, 1659, 1783, 1905, 1907, 1908	+38-39°
Shansi-Kansu	1556, 1920, 1927	+35-37°
Tokio	1923	+35°
Mino-Owari (Japan)	1891	+36°
Assam	1897, 1950	+27°
Ashkhabad	1948	+37-38°

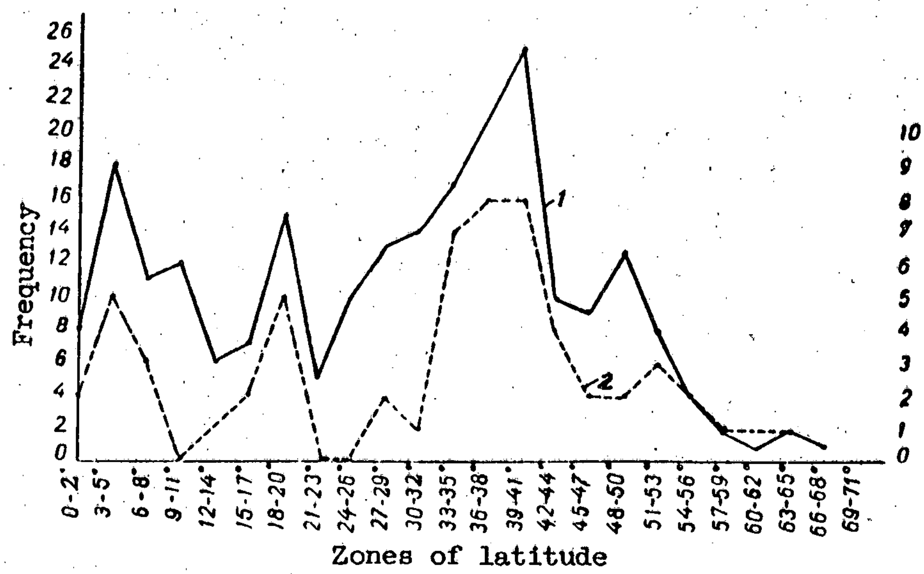

Fig. 4. Frequency of catastrophic and destructive earthquakes. (Great Soviet Atlas of the World, vol.1, chart 25.)

Baenisch [24] points out that in recent decades there has been, in the northern hemisphere, a demonstrable general rise of the mean sea level from the equator to the pole.

All the most important tectonic movements and major marine transgressions during geological time are, according to Li Si-Guan [14], distributed in the northern hemisphere along certain critical parallels (62°, between 30-40° and 35°, and the equator); this also points to their genetic connection with the conjugate deformations of the earth's figure; that is to say, with the earth's rotation.

"To put it briefly", writes Li Si-Guan [14], "it follows from this that marine transgressions in the low latitudes are accompanied by a general regression of the sea in the high latitudes (the underlining is ours [M.S.]). Before the beginning of an orogenetic phase, or during such a phase, or shortly after it, a general marine transgression occurs in the high latitudes and in general regression in the low" (p.289). And further (p.291): "When we examine the principal marine transgressions and tectonic movements as events sequentially connected one with another and regulated by changes in the earth's rotational velocity, we cannot but accept the thesis elaborated in so much detail by Stille". (See diagram, Fig.5.)

A reflection of zonal-latitudinal uplifting in the high latitudes is found in the variation of the north-south slopes of the surfaces of large lakes. This is discussed by G. Yu. Vereshchagin [4,5], P.F. Domrachev [6], B.A. Fedorovich [21], K.K. Markov [15], N.I. Nikolayev [16] and by a number of Finnish and American geomorphologists. The Finnish authors find an uplift of all the northern shores of lakes in Finland and a corresponding depression and flooding of the southern shores. Vereshchagin's papers [4,5] testify to a change of slope on our large lakes (Segozero, Onega, Ladoga): for instance, on the north shore of Lake Onega several lacustrine terraces have been identified, as high as 54 m above the level of the present lake.

The meridional change in the slope of lake surfaces in the northern hemisphere is indicated by their morphological structure. The southern shores of such lakes are straight, low-lying, rimmed with beaches and strips of sand dunes, while the northern shores are marked by a terraced structure, by a high degree of indentation, and by the existence of numerous islands near the shore. In consequence of the change of slope, the water passes from the northern shores to the southern, inundates new areas, and may establish a new outlet pattern, transferred to the south shores. This has happened with Lake Ladoga, the outlet of which has been shifted southward, that is, from the River Vuoksi into the River Neva. A change of lake drainage from the White Sea to the Baltic Sea has been noted for almost all the lakes in Karelia and Finland, that is to say, in the higher latitudes.

In the Arctic, the picture of an increasing relative uplift of the lithosphere with increasing latitude has been established by many authors. N.I. Nikolayev [16] writes: "Tracing these movements from north to south, we note a decrease in the amplitude of the uplift" (p.220). S.S. Kuzneçov [8] points out that: "It is important to note that the phenomenon of uplifting is particularly wide-spread in the high northern latitudes. Uplifting is observed in Scotland, in Iceland, in Spitsbergen, in Novaya Zemlia, and in Greenland. In Greenland, remains of now-living marine mollusks are found at a greater altitude, the more northerly the location."

On the western coasts of Greenland, recent shorelines are found at a height of 25-40 m, and on the northeastern coast of Baffin Land (69°30'-70°40'N) at 45-60 m [25]. Characteristic of the north coast of Scotland is the existence of several levels of Quaternary marine terraces, for instance at 30-40, 15-20 and 7-8 m; on the southern shores of England such terraces are lacking. The northern part of the British Shield is rising in dome fashion with a speed of 5.5 mm/year. The speed of uplift is gradually damped out southward. The southern part of the island is undergoing subsidence in the region of the English Channel [35]. *

The study of marine terraces on the shores of both the Atlantic and Pacific Oceans indicates a decrease of their heights toward the equator [8].

The data of repeated levelings in the Great Lakes are of North America and geomorphological work on the Canadian Shield --- Taylor, Freeman, Gutenberg [26-28] and Sherman Moore [34] --- lead to quite important conclusions as regards the change of slope of the Canadian Shield.

1. The existence of an east-west zero-line of equilibrium (±48°) in the earth's crust is established, north of which uplift is everywhere taking place, and south of which there is everywhere subsidence.

2. The zero line of crustal equilibrium passes, on the Pacific coast, through Seattle (47°40'N); then along the north shores of the Great Lakes (48°20'-44°20'N), and on the Atlantic coast through the northern part of Newfoundland (48°N) (Daly).

3. For the northern shores of the Great Lakes a general uplift is characteristic --- the ancient shorelines are as high as 150 m above the present level of the lakes, ** while everywhere on the southern shores a subsidence is noted, as a result of which a drowning of coastal forests is taking place, and an increase in the area of the lakes. On the southern shores one finds tree trunks and stumps, submerged and silted up with lacustrine sediments, at depths of over 5 m. [34]

4. The rate at which the southern shores of the Great Lakes are being submerged averages as much as 15 cm per century [32].

5. The movements are not limited to regions formerly glaciated, and on the other hand, a number of regions that were once beneath the ice do not exhibit any vertical movements.

6. Gravity studies in the Great Lakes region yield anomalies which in the mean are near to zero; therefore the theory of isostatic recovery from the ice load is now found inadequate. Sherman Moore writes: "This theory turns out to be insufficient to explain many observed facts" ([34], p.708). Its inadequacy was also indicated by Taylor in 1915.

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* But see D.F.W. Baden-Powell: Isostatic recovery in Scotland, Nature, 199, no.4893, p.546-7 (1963). [Translator.]

** Thus S.S. Kuzneçov [8] writes: "The ancient shorelines are clearly traceable on the shores of the lakes, for instance, Lakes Bonneville, Huron, Michigan and others, while on the northern shores the terraces lie higher than on the southern."

In 1951 the Dominion Observatory made 2100 gravimetric determinations at points on the Canadian Shield. The isostatic anomalies of gravity thus determined indicate a practically complete isostatic compensation, thus controverting the hypothesis of a presently proceeding isostatic adjustment of the Canadian Shield due to liberation from the ice load [33].

We should mention that as early as 1933 the Soviet geologist A.D. Arkhangel'ski [1], discussing the uprise of the Scandinavian and Canadian Shields, pointed out that the process of isostatic leveling developed long before the glacial period, and accordingly believed that there were no grounds whatever for ascribing the uplifting of the shields to the disappearance of glacial loading. Thus all recent researches contradict the hypothesis of glacially induced isostatic leveling of the lithosphere in the high latitudes, so that if we were to ignore the conjugate deformations of the ellipsoid under the influence of variation of the deforming forces, then geology would be left with no way of explaining the causes responsible for the ubiquitous (zonal) uplifting in the high latitudes --- not to speak of the lack of causes to explain subsidence of the whole equatorial bulge of the earth. All that would remain to us would be to talk about the "inheritance" of movements from the Tertiary.

As is seen from the foregoing, the process of historical variation in the ellipticity of the earth's figure must find its expression in the present-day dissymmetry of topographic relief and in the latitudinal zonality of epeirogenetic movements.

In 1946 Bondarchuk [3], from consideration of submeridional and latitudinal dissymmetry of topographic relief, came to the conclusion that in the body of the earth there exist tangential stresses, caused, in his opinion, by the earth's rotation. He writes: "The tangential stresses are indeed a consequence of the rotational motion of the earth", and further: "Thus the dissymmetry on the earth's surface is a component part of the earth's shape, and like the earth's shape, is caused by the rotational motion" (p.174). It is probable that processes connected with change of internal density veil the general background and character of the conjugate deformation of the variable-rotation ellipsoid. Here we may cite the analogy of the effect of the Coriolis accelerational forces (Baer's law *) on the formation of river valleys, an effect that can only reveal itself over large intervals of time, and is sometimes veiled by the influence of other factors, as for instance the slope and structure of the valleys.

The pulsatory character of the retardation of the earth's rotation manifests itself in a variation of the potential of the deforming forces and a continual modification of the ellipticity of the earth; the general rising in the high latitudes of each hemisphere and the ubiquitous subsidence of the equatorial bulge of the earth are due to a single isostatic process of leveling of the earth's figure, determined by the conjugate deformations of the ellipsoid.

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* In rivers flowing in the meridional direction across plains, the right bank is usually elevated and the left bank low. The Russian scientist Baer explained this as an effect of the earth's rotation, as also the tendency of rivers in the northern hemisphere, whether flowing north or south, to deviate to the right. [Translator.]

In a series of papers since 1924 B.L. Lichkov [10-13], on the basis of much regional geological and geomorphological data, has put forward the idea of the conjugate latitudinal zonality of epeirogenetic movements --- movements that quite continuously reflect the conjugate deformation of the earth's figure which we ascribe to temporal variation of tangential and radial deforming forces.

REFERENCES

1) ARKHANGEL'SKI, A.D. Geology and gravimetry. Tr. N.-I. Inst. Geol. i Miner. [Tr. Inst. Geological and Mineralogical Research], vol.1, 1933.

2) BELOUSOV, V.V. Osnovnyye voprosy geotektoniki [Fundamental Problems of Geotectonics]. Moscow, 1954.

3) BONDARCHUK, V.H. Tektoorogeniya [Tectonic Orogenesis], Kiev, 1946.

4) VEREŞHCHAGIN, G. Yu. Positive and negative movement of the shore-line on Lake Segozero. Tr. Oloneçkoi nauchn. eksped. [Tr. Oloneç Scientific Expedition], part III, no.2, 1931.

5) VERESHCHAGIN, G. Yu. On the question of the non-uniformity of uplifts of the shores of Lake Onega. Tr. Oloneçkoi nauchn. eksped., part III, no.2, 1931.

6) DOMRACHEV, P.F. Balkhash i Pribalkhash'ye [Lake Balkhash and the Balkhash Country]. Alma-Ata, 1947.

7) KRASOVSKI, F.N. Present problems in and the development of degree-length measurements. Izv. Akad. Nauk SSSR, Geogr. and Geophys. Series, vol.3, 1941.

8) KUZNEÇOV, S.S. Osnovy geologiyi [Principles of Geology]. Moscow, 1933.

9) LEIBENZON, L.S. Deformation of an elastic sphere as related to the question of the earth's structure. Collected Works, vol.IV, Academy of Sciences Press, 1955.

10) LICHKOV, B.L. Change of the relief of the terrestrial globe in connection with its movement and energy-relationships (contribution toward a characterization of geological space). Dok. Akad. Nauk SSSR, vol.14, no.8, 1944.

11) LICHKOV, B.L. Concerning V.V. Dokuchayev's law of horizontal zonality as applied to soil water, and concerning the degree of dependence of other subterranean waters on the horizontal zonality law. Geogr. Sbornik [Geogr. Repository], vol.VI, 1954.

12) LICHKOV, B.L. Isostasy and the present-day concept of movement of the earth's crust. Priroda, 1928, nos.7-8.

13) LICHKOV, B.L. Fundamental regularity of secular uplifts and subsidences of the terrestrial crust. Priroda, 1927, no.11.

14) Li Si-guan. Geologiya Kitaya [Geology of China]. Moscow, Foreign Literature Press, 1952.

15) MARKOV, K.K. Osnovnyye problemy geomorfologiyi [Basic Problems of Geomorphology], Moscow, 1948.

16) NIKOLAYEV, N.I. Noveishaya tektonika SSSR [Recent Tectonics of the USSR]. Acad. Sc. Press, Moscow-Leningrad, 1949.

17) STOVAS, M.V. On the question of the critical parallels of the terrestrial ellipsoid. Leningrad National University, 1951.

18) STOVAS, M.V. The question of the latitudinal zonality of the earth's seismicity. Nauchn. Vysshei shkoly geol.-geogr. nauki [Scientific Papers, Higher School of Geol. and Geogr. Science], no.3, 1958.

19) STOVAS, M.V. Variability of the earth's rotation, and geotectonics. Geol. J. Lwów National University, no.5, 1958.

20) STOVAS, M.V. The potential of deforming forces and its variation with change in the rotational regime of an ellipsoid. Vestnik of Leningrad National University, 1959, no.1.

21) FEDOROVICH, B.A. New data on the Aralian type of bayed shores. Problemy Fiz. Geogr., vol.XI, 1942.

22) SHATSKI, N.S. Origin of the Pachelmian downwarp. Comparative tectonics of ancient platforms. Biull. MOIP [Bull. Moscow Soc. of Naturalists], Geological Section, vol.30 (5), 1955.

23) SHCHUKIN, I.S. Mountains. (Article in the Great Soviet Encyclopedia, second edition, vol.12.)

24) Baenisch, K. Über Hydrologie und Nivellements. Vermessungstechnik, vol.2, no.5, 1954 [Supplement to Bauplan und Bautechnik].

25) Goldthwait, R. Centres of glaciation and recent uplift around Baffin Bay. Bull. Geod., no.31, 1954.

26) Gutenberg, B. Tilting due to glacial melting. J. Geolog., vol.41, 1933.

27) Gutenberg, B. Changes in sea level postglacial uplift and mobility of the earth's interior. Bull. Geolog. Society of America, vol.52, 1941.

28) Gutenberg, B. Postglacial uplift in the Great Lakes region. Arch. Meteorol. Geophys. und Bioklimatol., A. 7, 1954.

29) Kraus, E.C. Zur Erklärung der Westmediterraneen Überschwere-Anomalie durch die Unterströmungstheorie. Z. Dtsch. Geolog. Ges., vol.104, part 2, 1953.

30) Lallemand, Ch. et E. Prévôt. Les lentes variations du niveau moyen de la mer sur le littoral français. Bull. Geol., no.25, 1930.

31) Marmer, H.A. Is the Atlantic Coast sinking? The Evidence from the Tide. Geographical Review. The American Geographical Society of New York, vol.37, no.4, 1948.

31a) Nagaoka, H. Fluctuations in secular variation of the rotation of the Earth, and volcanic eruptions. Proceedings of the Imperial Academy, Tokyo, vol.9, no.2, 1933.

32) Pincus, Howard, J. Geology of the Lake Erie basin, with emphasis on contemporary processes. Bull. Geod., no.31, 1954.

33) Report of the Special Committee on the Geophysical and Geological Study of Continents, 1951-1952. Transactions of American Geophysical Union, vol.34, no.2, 1953.

34) Sherman Moore. Crustal movement in the Great Lakes area. Bull. Geolog. Society Amer., vol.59, no.7, 1948.

35) Valentin, H. Gegenwärtige Niveauveränderugen im Nordseeraum. Petermann's Geogr. Mitt., vol.98, no.2, 1954.

36) Véronnet, A. Rotation de l'ellipsoïde hétérogène et figure exacte de la Terre. Journal de Mathématiques pures et appliquées, series 6, vol.8, 1912.

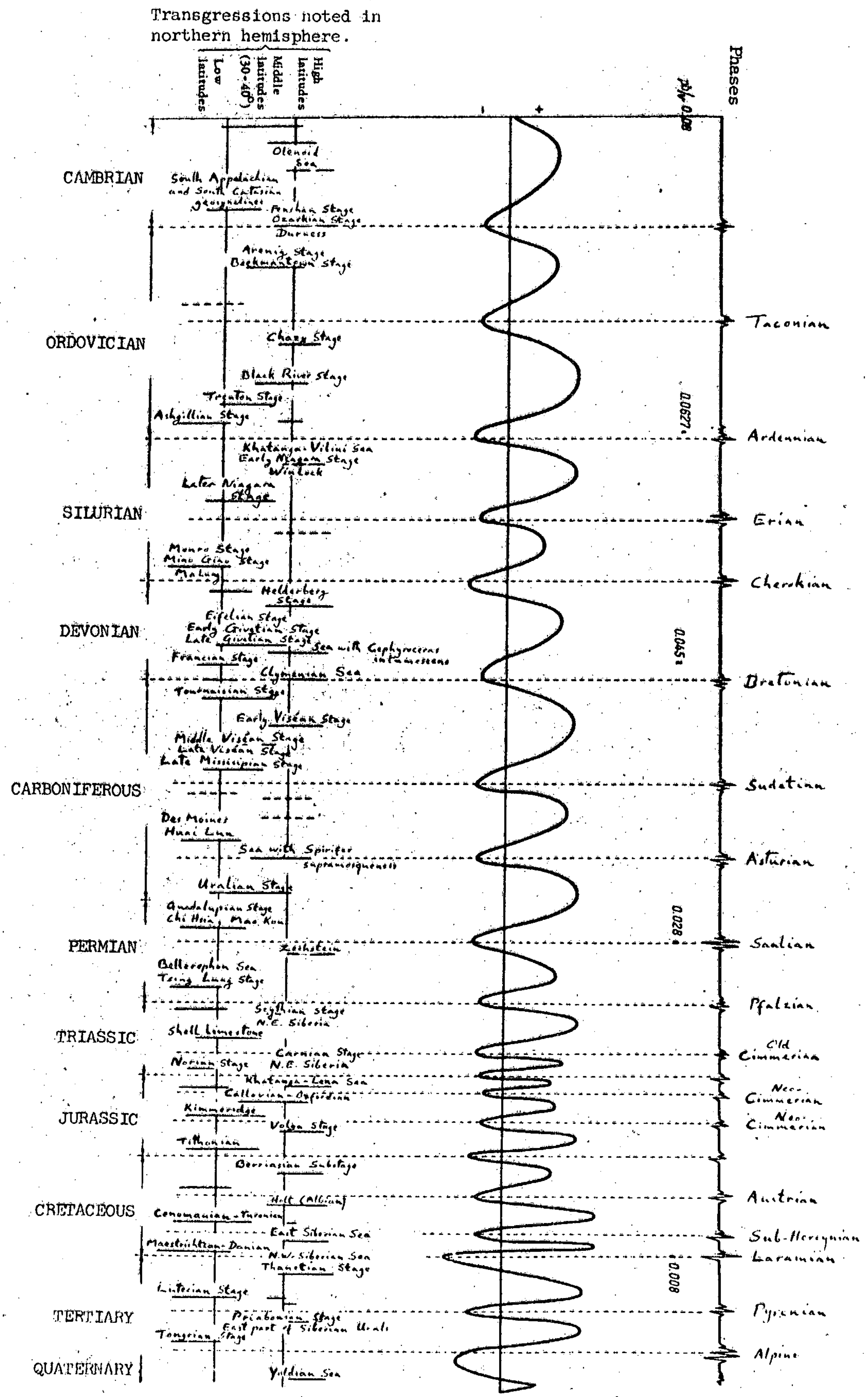

Fig. 5. Graph showing most important tectonic movements and major marine transgressions in the geological past. Geological durations, according to Holmes (radium-uranium ratio).