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On the Synchronism in the Events within the Core and on the Surface of the Earth: the Changes in the Organic World and in the Polarity of the Geomagnetic Field in the Phanerozoic

D. M. Pechersky, A. A. Lyubushin, and Z. V. Sharonova

Schmidth Institute of Physics of the Earth, Russian Academy of Sciences, ul. Bol'shaya Gruzinskaya 10, Moscow, 123995 Russia

E-mail: diamar1@front.ru

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Abstract—The data on geomagnetic reversals are compared with the changes in the organic world and with the lower-mantle plumes. The times of the formation of plumes and the times of their appearance on the Earth's surface relate to the intervals characterized by the different frequencies of geomagnetic reversals, i.e., there is no interrelation between the formation of plumes and the frequency of the changes in the geomagnetic field polarity. At the same time, a certain synchronism is observed between the frequency of the geomagnetic reversals and the boundaries of the biostratigraphic ages, i.e., the changes in the organic world in the long-period range. A hypothesis is proposed, which explains the change in the sign of the geomagnetic field by the combined effect of the irregular rotation of the internal core relative to the mantle and the changes in the slope angle of the axis of the Earth's rotation, which, in turn, results in synchronous events on the Earth's surface: the rates of changes in the organic world.

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INTRODUCTION

In the present paper we will attempt to compare the processes occurring in the Earth's core (the geomagnetic field, its variations, and the changes in the polarity) with the processes which take place on the Earth's surface but originate at the boundary between the core and the mantle (the plumes), and with the processes going exclusively on the Earth's surface (the changes in the organic world).

According to up-to-date ideas, the regions of active intraplate volcanism are the epicenters on the Earth's surface above the ascending mantle flows of the thermal energy and the heated material—the plumes ascending from the different depths up to the boundary between the mantle and the core (D" layer). The D" layer is laterally nonuniform in temperature, density, and topography. The formation of the plumes may be the result of the incidental instability in the D" layer [Grachev, 2000; Zharkov et al., 1984; Ernst and Buchan, 2003; Loper, 1991; Stacey, 1992; and others].

The studies [Pechersky, 2001; 2007; 2009; Pechersky and Garbuzenko, 2005] revealed an increase in the amplitudes of variations in the direction of the geomagnetic field when approaching the centers of the world's magnetic anomalies and the epicenters of the lower-mantle plumes, which indicates the presence of the close interrelation between these phenomena, which is a result of local excitations at the core–mantle boundary (in the D" layer).

In order to analyze the geomagnetic reversals, we used the magnetochronostratigraphic scale of the Phanerozoic (Table 1), based on the magnetochronostratigraphic scale presented in [Molostovskii et al., 2007], refined and updated by the data presented in [Guzhikov, 2004; Pavlov, 2009; Khramov and Shkatova, 2000; *New Geologic* ..., 2009; Pavlov and Gallet, 2005]. This scale is matched to the geochronological scale–2008 [Gradstein et al., 2008]. The accuracy of the magnetostratigraphic scale and the dating of the geomagnetic reversals are conditional, because the age of the latter is determined in the following way: (a) the mean rate of sedimentation in a given time interval is determined by the division of the stage duration by the thickness of these deposits; (b) the age of the geomagnetic reversal is obtained by the multiplication of the interval of thicknesses from the boundary of the stage to the geomagnetic reversal by the rate of sedimentation. In order to characterize the changes in the organic world, we used the successions of the biostratigraphic stages [Gradstein et al., 2008], which reflect the overall development of the organic life and some other geological and paleo-climatic processes on the Earth's surface. The biostratigraphic stages are the stratigraphic units of shortest duration, which are, undoubtedly, of

Table 1. Scale of the geomagnetic polarity in the Phanerozoic

Chrone, M.y.		Chrone, M.y.		Chrone, M.y.		Chrone, M.y.		Chrone, M.y.		Chrone, M.y.		Chrone, M.y.		Chrone, M.y.	
0.78	N	11.71	R	25.45	N	50.03	R	128.1	N	151.5	R	177.9	N	260.5	R
0.91	R	11.9	N	25.84	R	50.66	N	128.13	R	151.6	N	178.7	R	260.7	N
0.97	N	12.05	R	26.01	N	51.85	R	128.2	N	152.2	R	180.4	N	261	R
1.65	R	12.34	N	26.29	R	52.08	N	128.65	R	152.4	N	182.4	R	261.5	N
1.88	N	12.68	R	26.37	N	52.13	R	128.9	N	152.8	R	185.6	N	262	R
2.06	R	12.71	N	26.44	R	52.83	N	129.1	R	152.9	N	186.3	R	263	N
2.09	N	12.79	R	27.13	N	53.15	R	129.2	N	153.1	R	188.9	N	263.5	R
2.45	R	12.84	N	27.52	R	53.2	N	129.7	R	153.2	N	199.3	R	264	N
2.91	N	13.04	R	28.07	N	53.39	R	129.95	N	153.5	R	202.3	N	264.6	R
2.98	R	13.21	N	28.12	R	53.69	N	130.8	R	153.8	N	203	R	264.8	N
3.07	N	13.4	R	28.51	N	54.05	R	130.95	N	154	R	214.2	N	265	R
3.17	R	13.64	N	29	R	54.65	N	131.1	R	154.3	N	214.9	R	265.4	N
3.4	N	13.87	R	29.29	N	57.19	R	131.3	N	154.7	R	216.5	N	279.5	R
3.87	R	14.24	N	29.35	R	57.8	N	131.8	R	155.08	N	217.9	R	280.5	N
3.99	N	14.35	R	29.58	N	58.78	R	132.3	N	155.1	R	219.1	N	305.1	R
4.12	R	14.79	N	30.42	R	59.33	N	133.4	R	155.2	N	220.4	R	305.6	N
4.26	N	14.98	R	30.77	N	61.65	R	133.95	N	155.4	R	221	N	307.4	R
4.41	R	15.07	N	30.82	R	62.17	N	134.21	R	155.6	N	222.7	R	308.2	N
4.48	N	15.23	R	31.21	N	62.94	R	134.3	N	155.8	R	224.2	N	311.5	R
4.79	R	15.35	N	31.6	R	63.78	N	135.2	R	156.05	N	225.8	R	312.2	N
5.08	N	16.27	R	32.01	N	64.16	R	135.25	N	156.1	R	236	N	315.1	R
5.56	R	16.55	N	34.26	R	64.85	N	135.6	R	156.29	N	241.3	R	315.3	N
5.96	N	16.59	R	34.44	N	65.7	R	135.8	N	156.4	R	242.9	N	315.8	R
6.04	R	16.75	N	34.5	R	68.1	N	136.05	R	156.7	N	243.4	R	316.8	N
6.33	N	16.82	R	34.82	N	68.3	R	136.2	N	156.8	R	244	N	317.3	R
6.66	R	16.99	N	36.12	R	69.6	N	136.7	R	156.96	N	245	R	317.7	N
6.79	N	17.55	R	36.32	N	72.6	R	136.9	N	157.1	R	247	N	318.3	R
7.01	R	17.84	N	36.35	R	73.1	N	137.8	R	157.2	N	247.4	R	320	N
7.1	N	18.07	R	36.54	N	73.2	R	138.3	N	157.3	R	248.9	N	321	R
7.17	R	18.09	N	36.93	R	74.4	N	139.4	R	157.6	N	249.7	R	321.5	N
7.56	N	18.5	R	37.16	N	74.8	R	140.8	N	157.85	R	249.9	N	321.8	R
7.62	R	19	N	37.31	R	74.85	N	141.8	R	158.37	N	250.1	R	321.9	N
7.66	N	19.26	R	37.58	N	75.2	R	142.05	N	160.3	R	250.2	N	322.6	R
8.02	R	20.23	N	37.63	R	79.8	N	143.6	R	160.8	N	250.8	R	323.3	N
8.29	N	20.52	R	38.01	N	81.6	R	143.7	N	161.2	R	251	N	323.9	R
8.4	R	20.74	N	38.28	R	82.2	N	144.4	R	161.4	N	251.2	R	324.6	N
8.54	N	20.97	R	39.13	N	83.2	R	144.5	N	161.6	R	252	N	325.6	R
8.78	R	21.37	N	39.2	R	88.3	N	144.7	R	161.7	N	253.5	R	326.7	N
8.83	N	21.6	R	39.39	N	88.7	R	145.3	N	162.2	R	254	N	330.7	R
8.91	R	21.75	N	39.45	R	107.1	N	145.8	R	162.3	N	254.5	R	331.6	N
9.09	N	21.93	R	39.77	N	108.1	R	146.1	N	162.7	R	254.7	N	332.4	R
9.14	R	22.03	N	39.94	R	109.1	N	146.2	R	164.1	N	254.9	R	333.2	N
9.48	N	22.23	R	40.36	N	110.2	R	146.6	N	164.7	R	255	N	333.6	R
9.49	R	22.6	N	40.43	R	116.1	N	147.4	R	165.3	N	255.2	R	333.9	N
9.8	N	22.9	R	40.83	N	116.3	R	147.8	N	166.6	R	255.5	N	334.2	R
9.83	R	23.05	N	40.9	R	119.7	N	149.2	R	167.7	N	256	R	335	N
10.13	N	23.25	R	41.31	N	120.7	R	149.8	N	168.8	R	256.5	N	335.3	R
10.15	R	23.38	N	42.14	R	123.6	N	149.95	R	169.2	N	257	R	335.9	N
10.43	N	24.62	R	42.57	N	124.2	R	150.05	N	169.7	R	257.5	N	338.9	R
10.57	R	24.77	N	43.13	R	124.8	N	150.7	R	171	N	258	R	344	N
10.63	N	25.01	R	44.57	N	126.8	R	150.8	N	171.7	R	258.5	N	345.9	R
11.11	R	25.11	N	47.01	R	127.5	N	151	R	172.8	N	259.5	R	347	N
11.18	N	25.17	R	48.51	N	128.05	R	151.3	N	176	R	260	N	356	R

Table 1. (Contd.)

Chrone, M.y.		Chrone, M.y.		Chrone, M.y.		Chrone, M.y.		Chrone, M.y.	
359.5	N	413.7	R	488.6	N	508.25	R	530.6	N
360.8	R	413.9	N	488.8	R	508.3	N	530.7	R
361.2	N	414.1	R	489	N	508.83	R	530.72	N
363.5	R	414.2	N	489.2	R	509.25	N	530.75	R
363.8	N	416	R	489.3	N	509.45	R	530.9	N
365.6	R	417.2	N	489.8	R	509.6	N		
366.9	N	419.1	R	490.25	N	510	R		
369.2	R	420.4	N	490.8	R	510.2	N		
371.5	N	420.9	R	491.3	N	510.3	R		
374.8	R	422	N	491.8	R	510.45	N		
376.3	N	424.2	R	491.9	N	510.6	R		
377.7	R	425.8	N	492	R	510.8	N		
378.4	N	428.3	R	492.1	N	511.2	R		
379.2	R	428.8	N	494.6	R	511.3	N		
380	N	429.3	R	494.8	N	512	R		
380.8	R	429.5	N	496	R	512.05	N		
384.1	N	429.7	R	496.2	N	512.1	R		
384.9	R	430.1	N	496.25	R	512.35	N		
385.9	N	430.8	R	496.3	N	512.4	R		
386.6	R	433.2	N	496.4	R	512.48	N		
386.9	N	434.4	R	497.4	N	512.6	R		
387.8	R	436.8	N	498.1	R	512.9	N		
388.7	N	437.7	R	498.5	N	513	R		
390.8	R	439.3	N	499.5	R	513.2	N		
392	N	439.7	R	501	N	513.5	R		
392.6	R	440.8	N	501.56	R	514	N		
393.1	N	442.7	R	501.7	N	516.5	R		
393.9	R	443.5	N	501.72	R	517.3	N		
394.2	N	445.5	R	501.8	N	517.4	R		
396.6	R	448.6	N	502.93	R	517.7	N		
399	N	453.8	R	503.19	N	524.4	R		
402.5	R	454.9	N	503.29	R	524.43	N		
404	N	455.6	R	503.54	N	524.45	R		
405.3	R	456.5	N	503.6	R	524.5	N		
405.7	N	457.2	R	503.7	N	524.55	R		
406.8	R	457.6	N	504.08	R	524.6	N		
409.1	N	458.1	R	504.1	N	524.7	R		
409.7	R	458.7	N	504.2	R	524.8	N		
410	N	459.2	R	504.3	N	524.9	R		
410.1	R	459.5	N	504.35	R	525	N		
410.2	N	460.9	R	504.4	N	525.3	R		
410.4	R	461.1	N	504.6	R	526	N		
410.6	N	461.12	R	504.65	N	526.05	R		
410.7	R	461.2	N	504.7	R	527.2	N		
410.9	N	461.22	R	504.85	N	527.3	R		
411.1	R	461.25	N	504.9	R	528	N		
411.3	N	462	R	505.05	N	528.6	R		
412.7	R	462.07	N	505.28	R	528.65	N		
412.9	N	483.6	R	505.95	N	528.8	R		
413.1	R	484.4	N	506	R	529	N		
413.2	N	484.65	R	506.36	N	529.6	R		
413.4	R	487.8	N	506.7	R	529.65	N		
413.5	N	488.28	R	508.14	N	530.3	R		

global significance and widespread occurrence; their boundaries are synchronous, although examples are known of significant lateral changes in the age of the boundary between the stages [Guzhikov et al., 2003; Pechersky and Garbuzenko, 2005; and others]. Smaller biostratigraphic units, the biozones, are predominantly of regional significance. Thus far, there is no unified scale of biozonal division for the Phanerozoic Eon. There are many controversial intervals in both the magnetostratigraphic and the biostratigraphic scales. Therefore, setting apart the examination of these scales, for the purposes of comparison between the magnetostratigraphic and the stratigraphic data, it was important to refer them to ***the same*** geochronological scale; and we decided to use the scale–2008 [Gradstein et al., 2008].

THE RESULTS OF THE DATA ANALYSIS

A typical feature during the Phanerozoic is an obvious predominance of the reversed polarity (Table 1) [Molostovskii et al., 2007], which is in agreement with the modern counterclockwise rotation of the Earth. According to the fractal analysis of the magnetochronostratigraphic scale [Pechersky et al., 1997] there were two modes of the magnetic field generation in the Phanerozoic: the first one was the chaotic regime of frequent geomagnetic reversals (the fractal dimension $d < 0.6$), and the second one was the regime of a stable field with rare geomagnetic reversals (up to the absence of reversals) which exhibits a distinct ***self-similarity*** (d is close to 1). The results of the fractal analysis are confirmed by wavelet analysis [Galyagin et al., 2000; Pechersky, 1998]: the periods in the frequency of the geomagnetic reversals and in the polarity of the field, identified in the Phanerozoic, which are shorter than 60 M.y., represent short bursts chaotically distributed in time. The relatively prolonged fluctuations appear only with periods of 100–130 M.y. and longer, which corresponds to the second fractal regime.

In accordance with the two regimes of the geomagnetic reversal, there should be also two regimes of generation of the geomagnetic field. We propose the following ***unified*** mechanism for generation of the geomagnetic field with different polarity, which is connected with the rotation of the inner solid core relative to the mantle. We assume, as it has been mentioned above, that the predominant reversed polarity of the geomagnetic field is due to the counterclockwise rotation of the Earth. This polarity will be preserved, if the rotation of the inner core, the outer core, and the mantle coincide or if the inner core pass ahead of them. This is quite possible because of the following reasons: (a) from the set of observations it follows that the inner core is mobile and its axial rotation differs from the rotation of the Earth as a whole [Avsyuk et al., 2001]; (b) the deceleration of the diurnal rotation

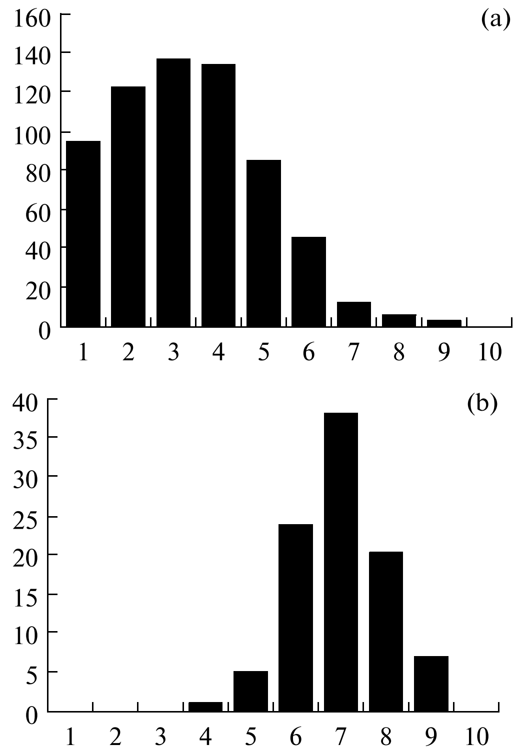

Fig. 1. Histograms of distribution (a) of the magnetochrones (Table 1) and (b) of the stages (Table 2). The time intervals (in M.y.) are plotted along the *X*-axis: (1) 0–0.1, (2) 0.1–0.2, (3) 0.2–0.4, (4) 0.4–0.8, (5) 0.8–1.6, (6) 1.6–3.2, (7) 3.2–6.4, (8) 6.4–12.8, (9) 12.8–25.6 .

of the Earth during the Phanerozoic by approximately three hours is known [Munk and MacDonald, 1964] and it was shown theoretically that in this case the inner core keeps ahead of the mantle [Groten and Molodensky, 1999]; (c) periods of the acceleration in the rotation of the Earth are known, for example, during the past few decades [Sidorenkov, 2004]; then, the delay of the rotation of the inner core relative to the mantle rotation is quite probable. Certainly, this is too short a time interval in the context of our task, but it demonstrates the principal possibility of the acceleration in the rotation of the mantle and, correspondingly, of the delay in the rotation of the inner core, relative to the mantle's rotation during the longer time intervals. In this case, the relative reverse motion appears on the boundary between the solid and the liquid core, and, hence, its related field must have the opposite sign, i.e., the sign observed at the present time.

A change in the speed of the Earth's rotation should be manifested in the synchronism of the processes on the Earth's surface and in its core. In order to check this, let us compare the series of the magnetochrones (Table 1) and the stratigraphic stages [Gradstein et al., 2008]. First, each of the series forms a ***unified*** single-modal set with a logarithmically normal distribution (Fig. 1), which indicates that each series is a unified set. In this case, an extremely wide spread is typical in the duration of the magnetochrones (from hundredths to tens of millions of years) and in the duration of the stratigraphic stages (from the tenths to tens of millions of years). Second, the histograms are essentially different in the modes (the mode in the case of magnetochrones is 0.2–0.4 M.y., and in the case of stages, it is 3–6 M.y.) and in their left-hand sides. In the case of the scale of the geomagnetic polarity, the histogram is clearly incomplete due to the insufficient resolution, and noticeable contribution to it should be provided by the micromagnetochrones with a duration noticeably shorter than 0.05 M.y., including the excursions. In the case of the chronostratigraphic scale, we consider only the stages; correspondingly, the histogram begins only from 0.4 M.y. (excluding the Holocene).

The direct comparison of the boundaries of the two series is rather meaningless because of the enormous difference of the number of the geomagnetic reversals (640) and the stages (99) [Gordstain et al., 2008] and because of the conditional character of the dating of the boundaries of magnetochrones. It makes sense to compare the boundaries of the stratigraphic units and magnetostratigraphic units of a higher rank, specifically, on the one hand, on the level of geological periods of the chronostratigraphic scale, and, on the other hand, on the level of hyperchrones of the magnetochronostratigraphic scale (Table 2). The chronostratigraphic and the magnetochronostratigraphic scales are compiled according to absolutely different principles; therefore, their convergence (or the absence of it) is an objective fact independent of the researchers. If during the construction of the chronostratigraphic scale the subjective opinion of a researcher might be of a certain importance, then the new version of the magnetochronostratigraphic scale constructed in [Molostovskii et al., 2007] is maximally objective. For constructing the magnetochronostratigraphic scale, we used the asymmetry of the geomagnetic polarity in the form of the cumulative distribution function of the total duration of the N- and R-polarity intervals with their signs, i.e., the algebraic sum of the intervals of N- and R-polarity. The proposed version of the cumulative curve of the field asymmetry is quite stable, since the appearance of new large-scale magnetostratigraphic units is hardly probable; the addition or elimination of short magnetochrones is only possible, which only slightly changes the values of the asymmetry, and, consequently, should not essentially change the structure of the scale. Abrupt changes in the shape of the cumulative curve indicate the boundaries of the magnetostratigraphic unit, in our case the boundaries of the hyperchron. For each hyperchron, the total duration of the intervals of N- and R-polarity, referred to the duration of a given hyperchron, is determined from the cumulative curve. The letters R or N in Table 2 indicate the predominant polarity, and the numeral designates the percentage of asymmetry ranging from zero (the duration of N- and R-polarities are equal) to one hundred (a single polarity exists). As evident from Table 2, only one boundary of the geological period coincides with the magnetohyperchron (to an accuracy of 0.5 M.y.): these are the lower boundaries of the Paleogene and the Khorezm. There are no other coincidences. Consequently, at the level of changes of the large-scale epochs, the interrelation between the evolution in the organic world and the geomagnetic field is not observed.

If our hypothesis is true, the interrelation between the processes in the core and on the Earth's surface must exist. This interrelation should be searched for in the ***rates*** of change of the events in the core and on the Earth's surface rather than in the coincidence of the events themselves. Therefore, we compare the frequency of changes in the polarity of the geomagnetic field with the frequency of changes of the biostratigraphic stages (the number of changes within a certain time interval) and/or their duration.

The median (as the most typical value) distance between the boundaries of the stages is 4.5 M.y. [Gradstein et al., 2008]. Therefore, for both time series, we chose a uniform time step equal to the rounded value of four. When choosing the time step, we used the time series of the boundaries between the stages, since it contains much fewer points than the time series of the magnetochrones (101 values against 640), whereas in the joint analysis it is necessary to use the typical time step for the rarest observations. Further, using the smoothing with a Gaussian kernel of radius two, we passed to this uniform time step for the both time series, and, hence, obtained 133 counts in each time series (Fig. 2). Similar types of procedures for passing from the time series with nonuniform time steps to uniform time steps are described in detail in [Pechersky et al., 2005; Lyubushin, 2007]

As can be seen from Fig. 2, the durations of the magnetochrones and the stages are noticeably different. Both curves have 18 maxima each, and only 10–11 of them are synchronous; in this case, the amplitudes of the maxima noticeably differ. This is reflected in the power spectra (Fig. 3) and on the Morlet wavelet diagram (Fig. 4), where only the periods of 60 M.y. and, partly, ~100 M.y. coincide, which can be seen during the larger part of the Phanerozoic; the period of 100 M.y. is much less distinct. The fluctuations with a period less than 60 M.y. form only short "bursts" (Fig. 4). For describing the extent of the frequency-dependent synchronism (with a possible phase shift and, consequently, with a time delay) in the fluctuations in both time series, we evaluated the symmetrical squared modulus of the spectrum of coherence (Fig. 5). The squared modulus of the spectrum of coherence (it can be named roughly the squared coefficient of correlation, which depends on the frequency or on the period) is equal to that fraction of the power of fluctuations in a particular frequency band, which is due to the linear relation with the time series compared. For this estimation, we applied the classical method of averaging of the periodograms and the cross-periodograms [Brillinger, 1975; Lyubushin, 2007]. These periodograms and cross-periodograms, with the length of the time series of 133 counts, after the zero extension up to the nearest length equal to the power of two (which is necessary for

Table 2. The bottom boundaries of the geological periods and the magnetohyperchrone

Time, M.y.	Period	Hyperchrone
23.8	the Neogene	
30		Sogdiana (R12)
65.5	the Paleogene	
66		Khoresm (R25)
83		Tuarkyr (N29)
122		Dzhalal (N88)
145.5	the Cretaceous	
160		Hissar (N9)
197		Omolon-2 (N3)
199.6	the Jurassic	
242		Omolon-1 (N23)
251	the Triassic	
258		Illawara (R38)
299	the Permian	
315		Kiama (R81)
347		Donetsk (R19)
359.2	the Carboniferous	
416	the Devonian	
429		Sayan (R17)
443.7	the Silurian	
449		Napskii (N20)
462		North Baikal (N5)
483.6		Khadar (R98)
488.3	the Ordovician	
525?		Arginskii (R32)
531?(542?)	the Cambrian	

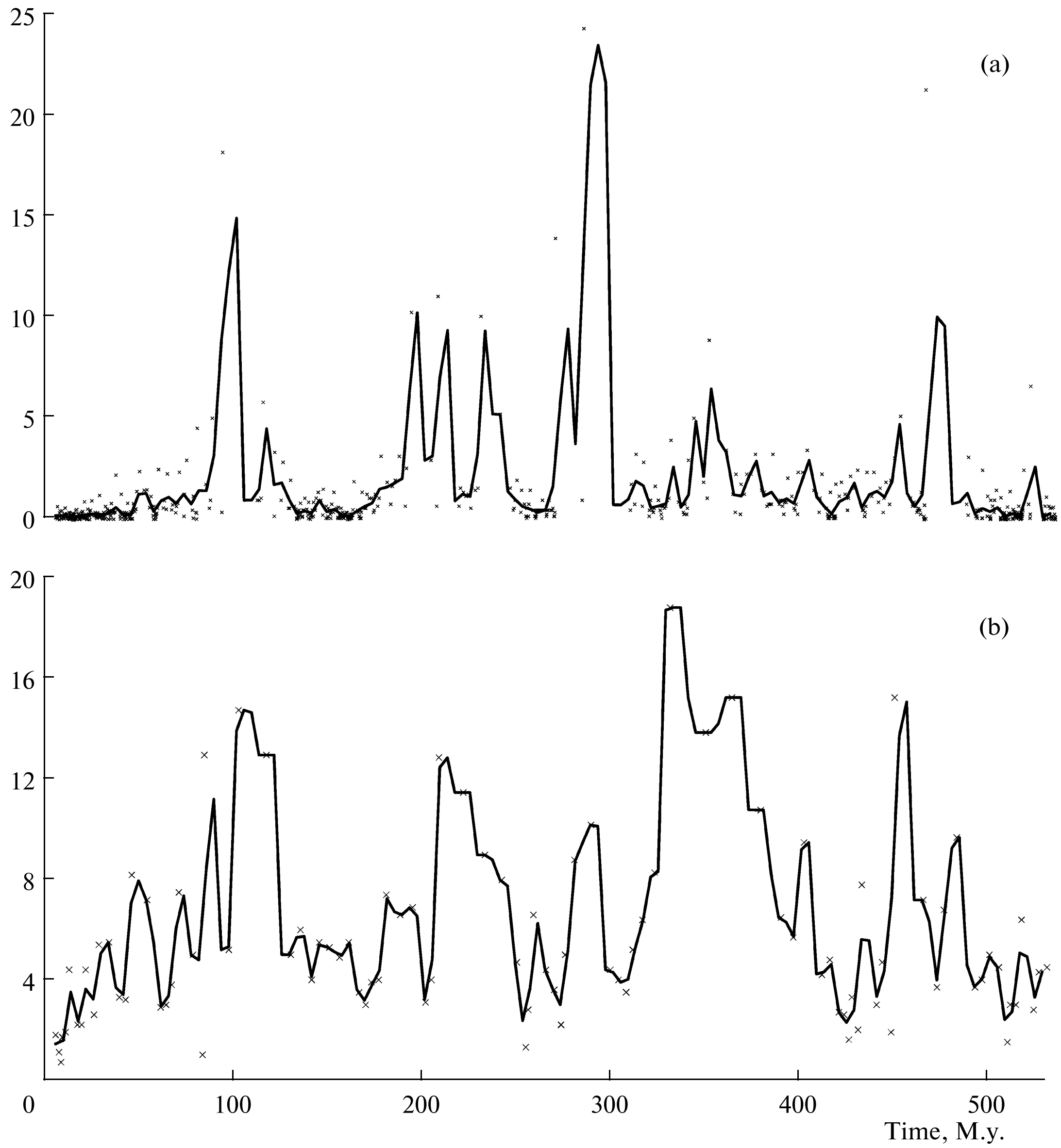

Fig. 2. Initial data (points) and the result of passing to the uniform time step (lines) equal to four M.y. with smoothing using the Gaussian kernel of radius two: (a) a series of duration of the magnetochrones (Table 1), (b) a series of duration of the stages (Table 2).

the application of the fast Fourier transform) contain 256 values of the orthogonal frequencies. Before the zero extension and the Fourier transform, we passed to the incremental series in order to mitigate the influence of low frequencies and, hence, to lower the influence of the cyclic effect of the finite numerical Fourier transform at the edges of the finite sample. Since passing to increments is a nondegenerate linear filtering applied in the same manner to the both series, this operation does not formally affect the value of the spectrum of coherence. Further, the periodograms and cross-periodograms were averaged within the frequency moving window with a radius of five frequency values. It is evident from Fig. 5 that for the periods of 60 M.y., the quadratic coherence is 0.51 (i.e., the coefficient of linear correlation is 0.71), whereas for the other periods the quadratic coherence is smaller.

In order to further exclude the discrepancies in the estimates of the ages of various events, as well as other disputable moments and inaccuracies, let us consider the number of changes of the geomagnetic polarity and the biostratigraphic stages that fall on each 10 M.y. of the Phanerozoic (Fig. 6a). From Fig. 6, one can see that both curves are similar and, correspondingly, the minima and maxima of both curves are located close to each other, which indicate close to synchronous rates of changes in the organic world and the frequency of changes of the geomagnetic field's polarity in the Phanerozoe. The

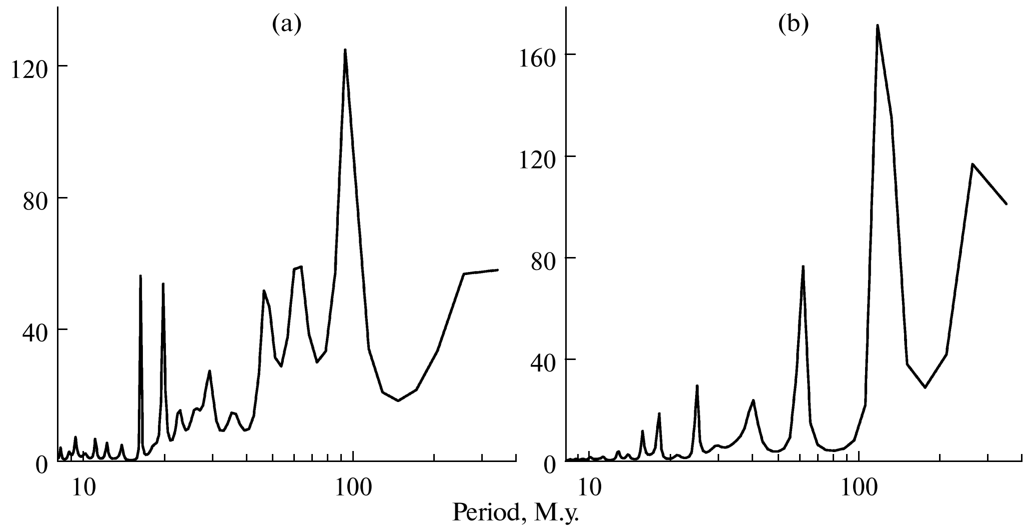

Fig. 3. Estimates of the power spectra: (a) a series of durations of the magnetochrones, (b) a series of durations of the stages.

number of maxima on each curve is nine, and seven of them coincide. Some discrepancies can be attributed to the incompleteness of the paleomagnetic information. The smoothing within the interval of 30 M.y. enhances the similarity of the curves: the number of maxima is five, and four of them coincide (Fig. 6b).

Thus, the synchronism in the long-period part of the spectrum of fluctuations in the changes of the geomagnetic polarity and the boundaries of the stages is revealed only starting from the interval of averaging of 10 M.y., which is likely due to the short duration and the chaotic distribution of the bursts in the duration of the magnetochrones and the stages, as distinctly demonstrated by the wavelet diagram (Fig. 4). This resembles the situation with the paleomagnetic record in sediments. If the sediments are deposited, say, within a few days randomly distributed in a year, then, the layer of sediments accumulated during a year will contain absolutely random information on the value and the direction of the geomagnetic field. Obviously, the same is also true for the averaging during tens and even hundreds years, and only beginning from thousands of years and more can we see the regular patterns in the total effect of the geomagnetic field's behavior.

Let us recall the missing correlation between the number of diversities or extinctions of the families of marine organisms and the frequency of the geomagnetic reversals in the Phanerozoic [Pechersky, 1998]; in addition, the Vendian/Cambrian boundary is characterized by a sharp increase in the diversity of biota, whereas the other two boundaries between the stages are associated with the mass extinction of biota on the Earth. Thus, the synchronism in the processes is not indicative of their causal relationship [Pechersky, 1998].

The global changes in the organic world and the other geological processes which define the boundaries between the stratigraphic units of the scale (in our case, these are the stages), may well be connected with the prolonged changes in the speed of the Earth's rotation and, to an even greater extent, with the changes in the slope's angle of the axis of its rotation, which leads to essential climatic changes.

The prolonged changes in the speed of the Earth's rotation and in the slope of the axis of its rotation, which lead to the synchronous rates of changes in the duration of the magnetochrones and stages, are most likely associated with such processes as the tidal evolution of the Moon–Earth system, the evolution of the Earth as a part of the Solar system, and in the general evolution of the Galaxy.

If we are right, i.e., if the changes in the polarity of the geomagnetic field are related with the changes in the rotation of the inner core relative to the mantle and the liquid core, whereas the formation of plumes occurs near the boundary between the liquid core and the mantle, we may expect no (or, more cautiously speaking, no noticeable) interrelation between such phenomena as the changes in the polarity of the geomagnetic field, on the one hand, and the formation of plumes, on the other hand. For checking this hypothesis we plotted the ages of the active plume magmatism on the Earth's surface on the graph showing the frequency of the geomagnetic reversals (Fig. 7). As evident from the figure, the ages of the epicenters of plumes, as well as the times of the plume formation (if we add 20–50 M.y., which is the duration of the plume lifting, to the age of the epicenters of plumes) fall within the intervals of absolutely different frequencies of the geomagnetic reversals up to their complete vanishing, which is indicative of the absence of any relation between the processes, which cause geomagnetic reversals and the formation of plumes.

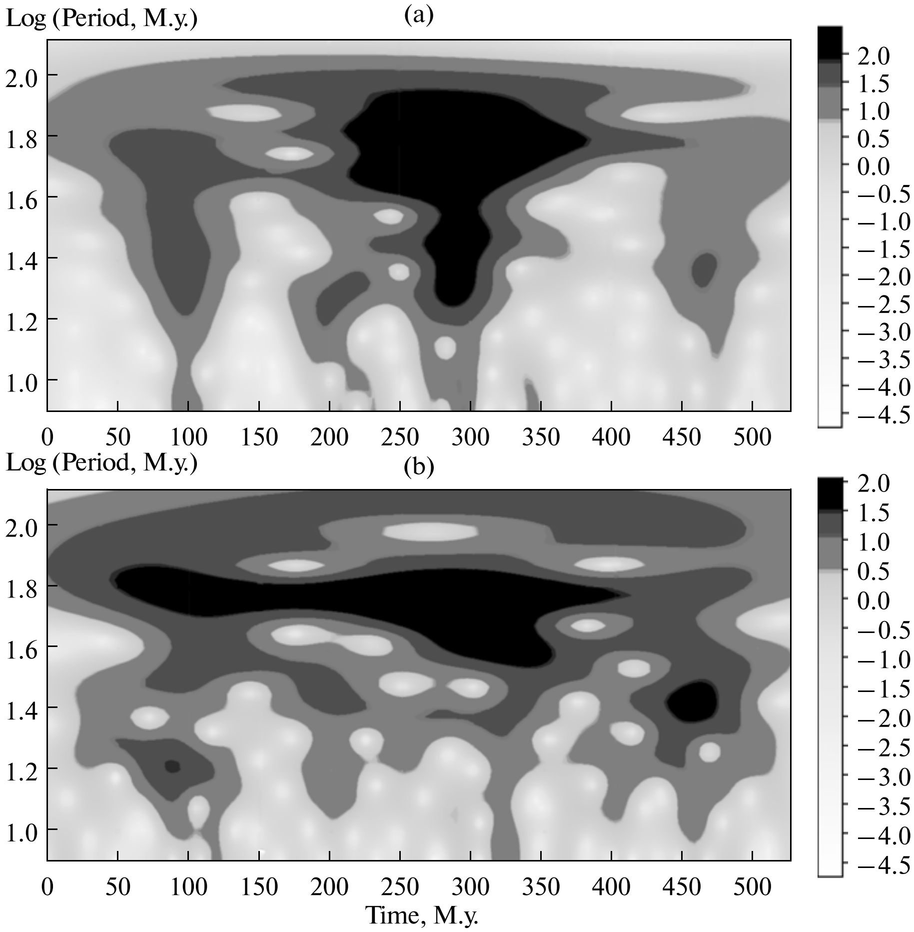

Fig. 4. Morlet wavelet-diagram of durations of the magnetochrones and the stages, the decimal logarithmic squared modulus of the wavelet coefficients of a continuous Morlet wavelet transform, depending on time and common logarithm of the period. Before the calculation of the continuous wavelet transforms, the trend in each signal was eliminated by fitting the local polynomial of the third order in a moving time window with a radius of 15 counts: (a) a series of magnetochrones, (b) a series of stages.

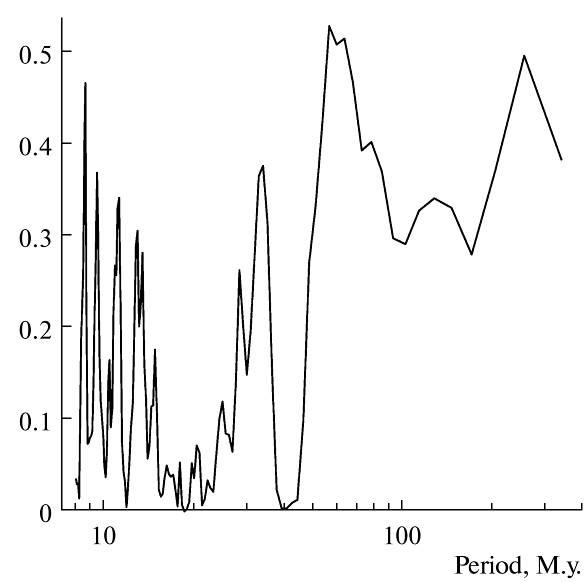

Fig. 5. Estimate of the squared modulus of the spectrum of coherence (*Y*-axis) between the series of durations of the magnetochrones and the stages.

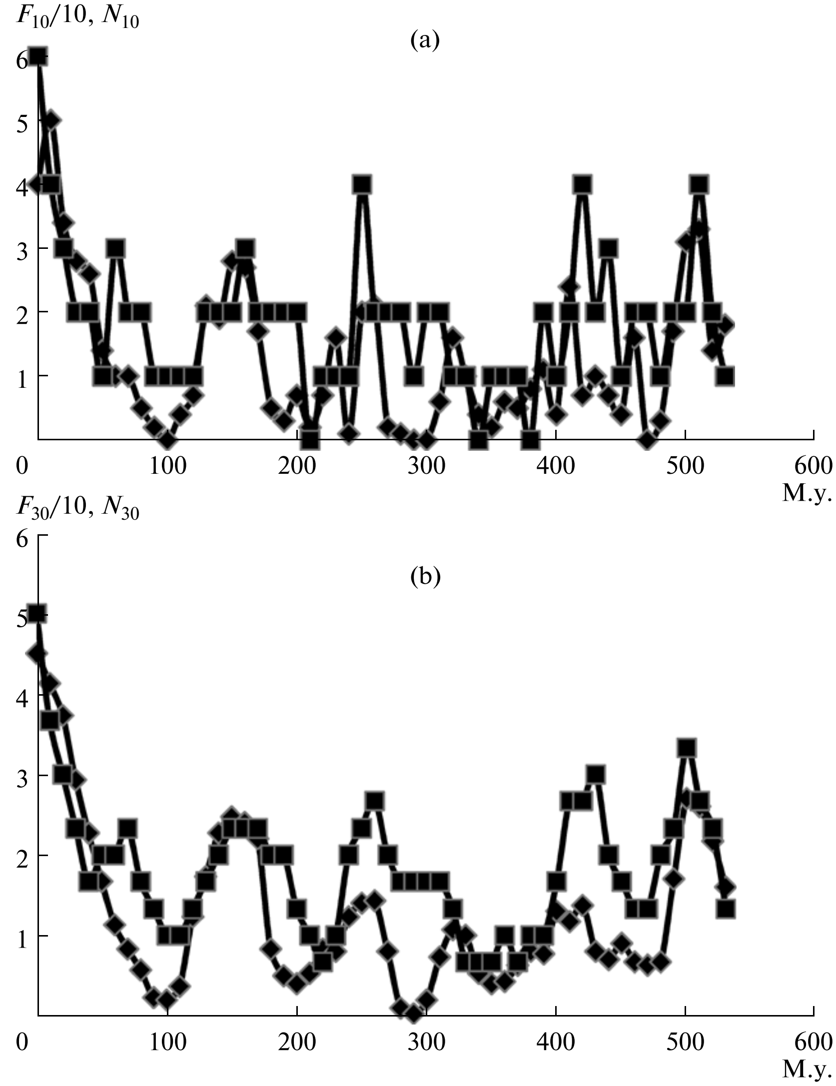

Fig. 6. The frequency of changes in the geomagnetic polarity (small squares) and of the biostratigraphic stages (diamonds) in the Phanerozoic: (a) the number of geomagnetic reversals and the lower boundaries of the stages during 10 M.y., (b) the smoothed curves, the interval of smoothing is 30 M.y., the time step is 10 M.y., N is the number of stages, $F/10$ is the number of the geomagnetic reversals F divided by 10 (for clarity). The data on the frequency of the geomagnetic reversals are taken from Table 1; the data on the frequency of the stages are taken from Table 2.

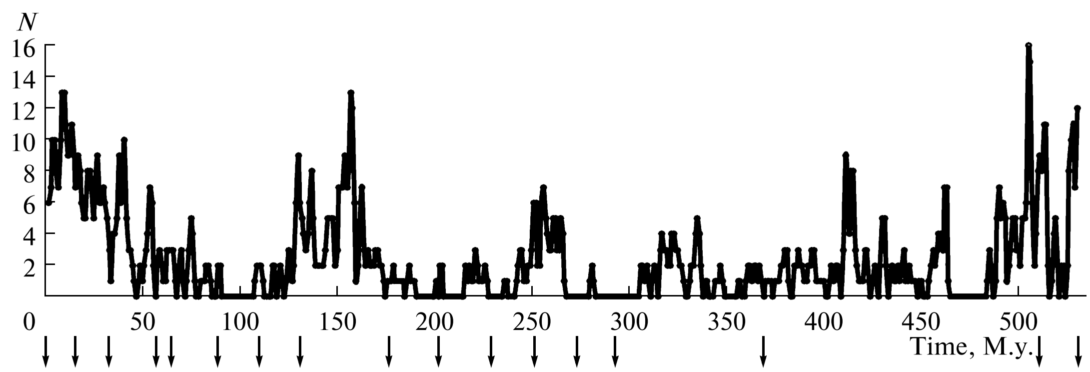

Fig. 7. Comparison of the frequency of the geomagnetic reversals (the number of geomagnetic reversals during three M.y., the time step is one M.y.) with the times of the magmatic activity of plumes on the Earth's surface [Ernst and Buchan, 2003]. The times of the magmatic activity of plumes are indicated by the vertical arrows below the X-axis.

CONCLUSIONS

From the data presented the following conclusions can be drawn:

(a) the boundaries between the geological eras, periods, and stages, as a rule, are not fixed by the change in the polarity of the geomagnetic field; at the same time, synchronism is observed in the **rates** of the biostratigraphic changes and the frequency of changes of the geomagnetic polarity;

(b) the plume formation occurred at very different frequencies of the geomagnetic reversals. This indicates that the sources of plumes, on the one hand, and, the geomagnetic reversals, on the other hand, are different. If the appearance and the formation of plumes are confined to the core–mantle boundary, then one may suppose that the changes in the sign of the geomagnetic field is associated with the boundary between the liquid and the solid core. The predominant reversed polarity of the geomagnetic field is due to the counterclockwise rotation of the Earth. This polarity will be preserved if the rotation of the inner and outer core and the mantle are synchronous, or if the inner core pass them. If there is a delay between the rotation of the solid core and the mantle, then the normal polarity of the geomagnetic field is observed, as is the case at present;

(c) beginning from the interval of averaging of 10 M.y., regular synchronism appears in the changes of the geomagnetic polarity and of the boundaries between the stages. We relate this synchronism to the prolonged changes in the speed of rotation of the Earth and in the slope of the axis of its rotation. The changes in the speed of rotation of the Earth and in the slope of the axis of its rotation can be related to processes such as the tidal evolution of the Moon–Earth system, the Earth's evolution as a part of the Solar system, and the general evolution of the Galaxy;

(d) the periods of 60 M.y. and partly ~100 M.y. are identified both in the duration of magnetochrones (the distance between the geomagnetic reversals) and in the stages; these periods are seen during the larger part of the time interval considered. In this case, the synchronism of the period of 60 M.y. is quantitatively demonstrated for the changes of the geomagnetic polarity and the boundaries of stages, which emphasizes the synchronism of the rates of prolonged changes in the core and on the Earth's surface.

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