Paleointensity behavior in Barremian–Cenomanian (Cretaceous)

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[1] Fragmentary knowledge on geomagnetic field intensity in Barremian–Cenomanian stage obtained from sediment rocks is summarized. Three types of periodical variations are revealed in the paleointensity behavior. The types differ by the amplitude and duration (tens of millennia, hundreds of millennia and more than million years). It is found that in all the magnetopolar intervals an alternating of quiet and burst-like regimes of magnetic field generation is observed, the regimes differing by the oscillation amplitude and mean values of the paleointensity. It is demonstrated that the mean values of the paleointensity of quiet regimes of geomagnetic field generation were (0.5–0.8) H_0, where H_0 is the intensity of the contemporary magnetic field of the Earth. During burst-like regimes of the geomagnetic field generation the mean values of the paleointensity were 1.2 H_0, whereas the maximal values exceeded H_0 by a factor of 3 and more. An attempt is made to compare variations of the paleointensity with epochs of riftogenesis and orogenesis. A comparison is performed of the results of geomagnetic field intensity determination from sediments and thermomagnetized rocks. *INDEX TERMS:* 1503 Geomagnetism and Paleomagnetism: Archeomagnetism; 1522 Geomagnetism and Paleomagnetism: Paleomagnetic secular variation; 1527 Geomagnetism and Paleomagnetism: Paleomagnetism applied to geologic processes; *KEYWORDS:* Geomagnetic field paleointensity; Magnetopolar intervals; Geomagnetic field generation.

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1. Introduction

[2] Revealing of the periodicity in the dynamics of the geomagnetic field intensity makes it possible to compare it with geodynamical processes. Such comparison is an important acelement in studying mechanisms governing the evolution of our planet. According to recent estimates, in the Quaternary the intensity of some geotectonic processes and paleointensity have similar by duration recurrence changes. For example, according to *Kozhemyaka* [2001] and *Chernyshev et al.* [2002] the volcanogenic activity in Quaternary was not permanent but was manifested in the form of bursts with duration usually not exceeding 100 millennia. *Guyodo and Valet* [1999] and *Petrova et al.* [2002] (curves Sint 800, Vadm 21) showed that the duration of the cycles of paleointensity variation also was from a few tens to a few hundreds millennia. Apparently, the dynamics of these events is determined by a series of common causes: processes within the Earth and cosmogenic factors. The results of *Herrero-Bervera and Valet* [2002] indicated a close periodicity of the volcano activity and paleointensity dynamics. It follows from their paper that in the current magnetopolar epoch most part of the Hawaii volcano lava flows has been formed at relatively high values of the geomagnetic field intensity. According to *Herrero-Bervera and Valet* [2002] the averaging of the results of paleointensity determination from volcanogenesis provides an overestimated evaluation of its mean value as compared to the paleointensity value derived from sediments. Therefore a complete picture of the paleointensity behavior cannot be obtained without attracting data obtained from sediment rocks.

[3] At the same time, permanent data on the dynamics

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of the magnetic field intensity obtained from sediments are few. The behavior of the paleointensity is studied in detail only during the recent 4 Myr [*Valet and Meynadier*, 1993]. They determined the behavior of the paleointensity during three recent magnetopolar intervals. It follows from their results that the geomagnetic field intensity is varying cyclically. However, the paleointensity behavior is strongly complicated by frequent events of changes of its polarity, so it seems impossible to reveal a periodicity exceeding 100–200 millennia at this time interval.

[4] The paleointensity of some fragments of the Cretaceous period obtained from marine sediments of the Russian platform was determined in a series of our publications [*Guzhikov et al.,* 2002; *Kurazhkovskii et al.*, 2002, 2003]. A compilation of these results into a joint picture would make it possible to obtain at least relatively complete representation of the dynamics of the magnetic field intensity in Barremian–Cenomanian (a time interval 20–30 Myr long) and to find new features in its behavior.

[5] This paper is dedicated to a compilation of fragmentary information on the paleointensity of the Cretaceous period (Barremian–Cenomanian), to searches for the recurrence in its dynamics, and to an attempt to compare it with geotectonic processes.

2. Analyzed Material

[6] The time interval (Barremian–Cenomanian) has been chosen because of the following reasons.

[7] 1. According to the classical ideas [*Khain and Lomidze*, 1995], in the Barremian and Aptian ages the stretching processes (of the riftogenesis epoch) prevailed on the planetary scale. In Albian–Cenomanian, there occurred an activation of orogenesis processes (the Austrian epoch of the Alpine geotectonic cycle). We think that studying of this temporal interval makes it possible to compare the behavior of the paleointensity during the epochs of predominant stretching and predominant compression of the Earth crust.

[8] 2. A temporal prevailing of long magnetopolar intervals of direct polarity over intervals of inverse polarity was noted in Barremian–Cenomanian [*All-Russian Scientific Research Geological Institute (VSEGEI),* 2000]. Excluding from consideration intervals of inverse polarity, one can obtain a relatively simple (not complicated by the polarity changes) and fairly complete picture of the paleointensity behavior.

[9] 3. Until recent time, there has been carried out almost no determination of the paleointensity in the studied part of the Cretaceous. The information on the paleointensity of the lower Cretaceous available in publications is based on the results of studies of Valangine and Goterive [*Solodovnikov*, 1995; *Tanaka and Kono,* 2002]. A correctness of interpolation of these results to Barremian, Aptian, and Albian is not substantiated. We plan to fill in this gap in the data of the magnetic field intensity partially by the results of this paper.

[10] The sediments used in this paper have been formed approximately in similar conditions of Cretaceous epicontinental seas of the Russian platform and adjacent territories. All the sediments had similar aleurite-clay structure. The main bearer of magnetization in all cases was detrital magnetite, whereas the natural magnetization was of an orientation nature. Orientation nature of the magnetization is manifested in low values of the Keniksberger factor, low compactness of the initial magnetization directions, and visual studies of the separated sediment grains containing the bearer of the residual magnetization. The sediments of the same sediment strata (polar interval), except one case, had slightly changing by power petromagnetic parameters. For example, in the Albian–Cenomanian sediments the magnetic receptivity K varied within $(5-10)\times10^{-5}$ SI units, and the residual saturation magnetization was Irs $\sim$(0.1–0.3) A m^{-1}. In the Aptian sediments, K was $(13-20)\times10^{-5}$ SI units, and Irs was (1.0–3.0) A m^{-1}; however, several lower samples had Irs more than 100 A m^{-1}. In the Barremian sediments, K and Irs were $(15-25)\times10^{-5}$ SI units and (0.5–1.0) A m^{-1}, respectively.

[11] The data on the paleointensity of Cenomanian and Albian and upper Barremian were taken from *Kurazhkovskii et al.* [2002] and *Kurazhkovskii et al.* [2003], respectively. These results have been obtained in studies of marine gray magnetite-containing aleurite-clay sediments in the eastern part of the Russian platform. The paleointensity of the lower Barremian was determined from the magnetite-containing gray sediments of north Caucasus [*Guzhikov et al.,* 2002]. The data on the paleointensity of Aptian are being published for the first time. The data have been obtained in studies of marine aleurite-clay magnetite- and hematite-containing gray sediments sampled in the Crimea (Simferopol, Mar'ino village). In the same way as in the previous publications [*Kurazhkovskii et al.*, 2002, 2003] the values of the geomagnetic field intensity H/H_0 were calculated in the following manner: $H/H_0 = \mathrm{Rns}_{350}/\mathrm{Acp}_{350}$, where H is the field intensity of the ancient magnetic field, the Rns_{350} parameter is equal to the ratio $\mathrm{In}_{350}/\mathrm{Irs}_{350}$ (In is the natural remanent magnetization, Irs is the remanent saturation magnetization, the 350 index is the temperature of magnetic cleansing), A_{350} is the coefficient equal to $\mathrm{Ird}_{350}/\mathrm{Irs}_{350}$ (Ird is the mean laboratory orientation magnetization of one sample obtained as a result of several redepositions). The average value of this coefficient was calculated separately for each sedimentational strata. To determine it, the results of redeposition of samples from all layers of one studied cut of sedimentations were used. This method of H/H_0 evaluation with performing of a grading suggested by *Kurazhkovskii and Kurazhkovskaya* [2001] (the values of the A_{350} coefficients should not be less than 2×10^{-3}, their difference in the thickness of the sedimentation strata should not exceed 20%) the random error does not exceed 13%. To determine the paleointensity, such sediments were used that their initial magnetization was revealed at temperatures not higher than 350°.

[12] *Kurazhkovskii and Kurazhkovskaya* [2001] showed that the usage of the Rns parameter to create the paleointensity dynamics reduces the probability of random errors. Conducting of a reprecipitation makes it possible to exclude errors due to the variations in magnetomineralogical and granulometric composition and also to evaluate the absolute values of the paleointensity.

[13] In all cases the sediment strata had a thickness of a few tens of meters and nearly similar aleurite-clay structure. Thus one may suggest that the studied paleointensity fragments had approximately the same duration. The intervals between the levels of Cenomanian–upper Barremian depositions where samples had been collected were about 1 m. The lower Barremian samples of the northern Caucasus were collected from the strata separated by 2–3 m. This magnetopolar interval is studied in less detail.

3. Results

[14] The behavior of the Barremian–Cenomanian paleointensity is shown in Figure 1. In each magnetopolar interval studied there are burst-like and relatively quiet regimes of the geomagnetic field generation. Depending on the character of paleointensity variations, one can reveal several types of periodicity in its behavior.

[15] 1. Under quiet regimes of the magnetic field generation, short-time (with the duration from a few tens to a few hundreds millennia) variations of the field intensity are observed. The amplitude of paleointensity variations usually did not exceed 0.5 H_0. This type of variations is most distinctly pronounced in the lower and middle Cenomanian.

[16] 2. The change of geomagnetic field generation regimes took place in all fragments of the Cretaceous paleointensity. In the majority of cases the burst-like regime of the geomagnetic field generation was observed in the middle parts of polar intervals. The existence duration of these regimes was from a half to a quarter of the magnetopolar epoch duration (from a few hundreds to a million years).

[17] 3. It is worth noting a periodicity of paleointensity bursts repetition. The paleointensity values during the bursts were reaching 3 H_0. Since not more than one burst of the terrestrial magnetic field intensity was observed in each polar interval, their recurrence frequency should be of the order of millions years.

[18] The mean values of the geomagnetic field intensity under quiet regimes of its generation differ depending on the magnetopolar interval studied or even parts of the same interval. The maximum mean values of the paleointensity of 0.8 H_0 were detected in the lower Albian and upper Aptian. The minimum values of the mean paleointensity of 0.5 H_0 were obtained for the lower Cenomanian, lower Aptian and the upper part of the upper Barremian. The mean value of the paleointensity over the entire time interval studied was 0.8 H_0.

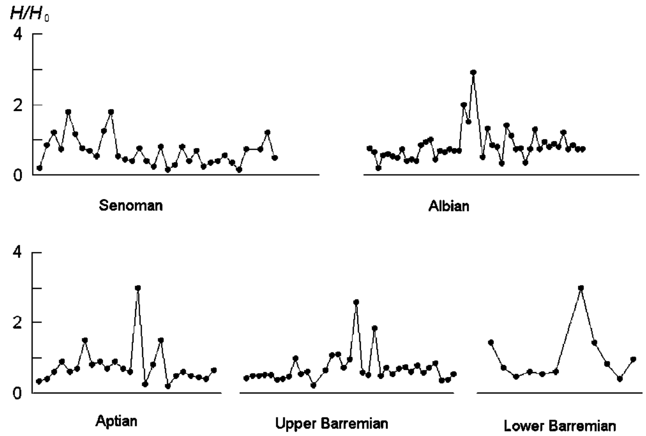

Figure 1. Paleointensity fragments of Cenomanian-Barremian. According to the definition of *Guzhikov and Eremin* [1999] the lower and upper Barremian correspond to the M2 and M1 zones of the magnetochronological scale, respectively.

4. Discussion

[19] Reconstructing the paleointensity from the sediment rocks, the arguments are usually presented showing that the obtained data manifest, namely, the geomagnetic field dynamics. In the practice of paleomagnetic studies such arguments used to be considered: (1) petromagnetic homogeneity of the sediment strata used to recover the paleointensity dynamics; (2) independence of the dynamics of the obtained paleointensity on the behavior of petromagnetic parameters; and (3) identity of the behavior of the paleointensity obtained from sediments of the same age. In application to our study the corresponding arguments are presented below.

[20] 1. While building the paleointensity, we used the sediments having an orientation nature of the natural residual magnetization. The Ird/Irs parameter is the parameter characterizing the ability of particles to be oriented in the magnetic field [*Kurazhkovskii and Kurazhkovskaya*, 2001]. In the sediment strata used by us it almost did not varied along their thickness. In this sense the sediments may be considered homogeneous. The petromagnetic homogeneity of the sediment strata is also manifested in small changes in Irs and K.

[21] 2. The most variable petromagnetic parameter in the Albian–Cenomanian and upper Barremian (M1) sediments was found the increase of the magnetic receptivity of the samples (TK) after heating up to a temperature above 500°. The variations in this parameter are due to the physical and chemical situation in the process of sediment accumulation; that is, they demonstrate the changes in the sediment accumulation conditions. The comparison of the behavior of TK and paleointensity presented in Figure 2 shows that the dynamics of the geomagnetic field intensity does not coincide with variations in the sediment accumulation conditions.

[22] Significant changes in Irs were observed in the Aptian sediments. The comparison of Irs with the behavior of the paleointensity (Figure 3) shows that even very significant changes in the amount of the bearer of the residual magnetization most probably do not influence the obtained picture of the paleointensity. Thus it is evident that the results of the performed paleoreconstruction are not a consequence of the changes in the sediment accumulation.

[23] 3. We studied the paleointensity of some polar intervals over different sediment strata. For example, the M2 zone of the lower Barremian was studied on the basis of the

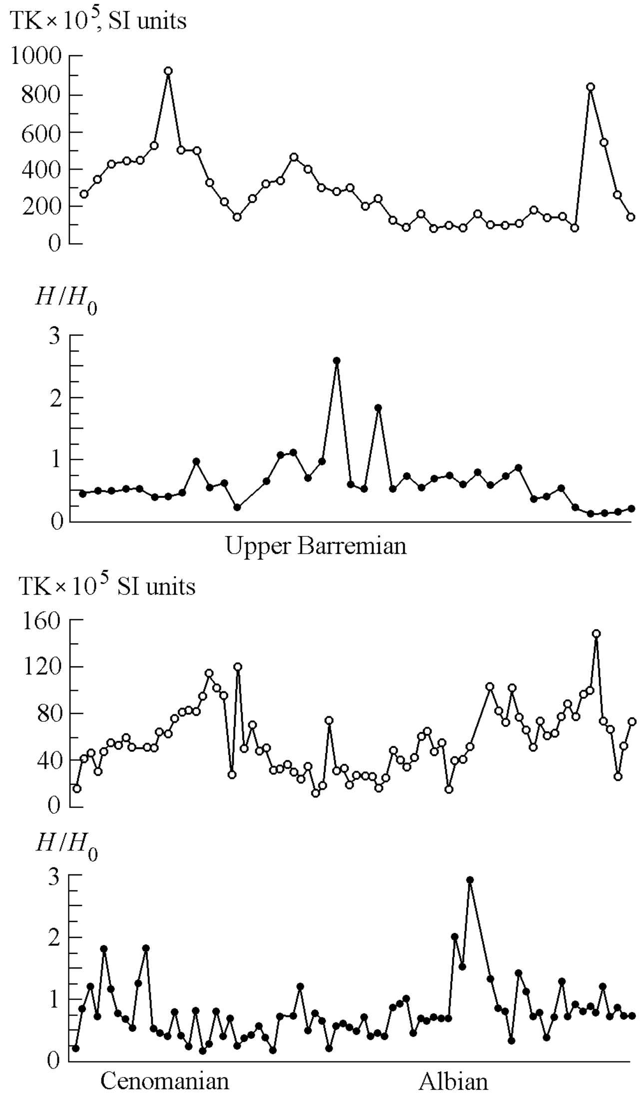

Figure 2. Comparison of the paleointensity dynamics (H/H_0) of Barremian, Albian, and Cenomanian to the variations in the physical and chemical situation (TK).

North Caucasus sediment objects located at a distance of 400 km from each other. Therein the reconstructed dynamics of the paleointensity was found the same [*Guzhikov et al.,* 2002]. The comparison of the paleointensity dynamics of the upper Barremian (M1) obtained on the basis of the sediments in the Penza region and Crimea (which are distanced by about 2000 km) showed that they coincide (Figure 4). The magnetization bearers of the Crimea sediments had mainly authigenic (chemical) origin [*Pimenov et al.,* 2003]. These sediments are usable for creation of the paleointensity dynamics but do not allow obtaining the absolute values of the magnetic field intensity using reprecipitation. The nature of the residual magnetization of the Crimea and Saratov sediments is different; however, the paleointensity dynamics derived from them coincide. The only known factor capable to provide such a coincidence is the geomagnetic field.

[24] The obtained material demonstrate that in the main features the studied magnetopolar intervals had similar structure of the paleointensity dynamics. Each magnetopolar epoch started with a quiet regime which was changed to a burst-like regime and then was transformed into a quiet regime of the geomagnetic field generation. This picture of the paleointensity structure of the epoch of direct geomagnetic polarity in Cenomanian–Barremian should be considered as a preliminary one, because it seems impossible to determine how completely geomagnetic events have been fixed in magnetic properties of sediment thickness. Nevertheless, the very existence of different regimes of geomagnetic field generation and their changes during a magnetopolar interval seems to us fairly convincing.

[25] The comparison of the mean value of the paleointensity determined by us to the mean paleointensity value of the current magnetopolar epoch (0.75 H_0) performed by *Guyodo and Valet* [1999] and *Petrova et al.* [2002] showed that they coincide. Thus the paleointensity of the current magnetopolar epoch and the Cretaceous magnetopolar epochs of direct polarity differ not by its mean value, but by the character of its variations. According to *Valet and Meynadier* [1993] no such high (3 H_0) values of the paleointensity has been observed during the current magnetopolar epoch. The bursts of the paleointensity detected by us in Barremian–Cenomanian are not unique events in the history of the terrestrial magnetic field. According to the results of paleointensity determinations compiled in the *Tanaka and Kono* [1994] database, the geomagnetic field intensity values in

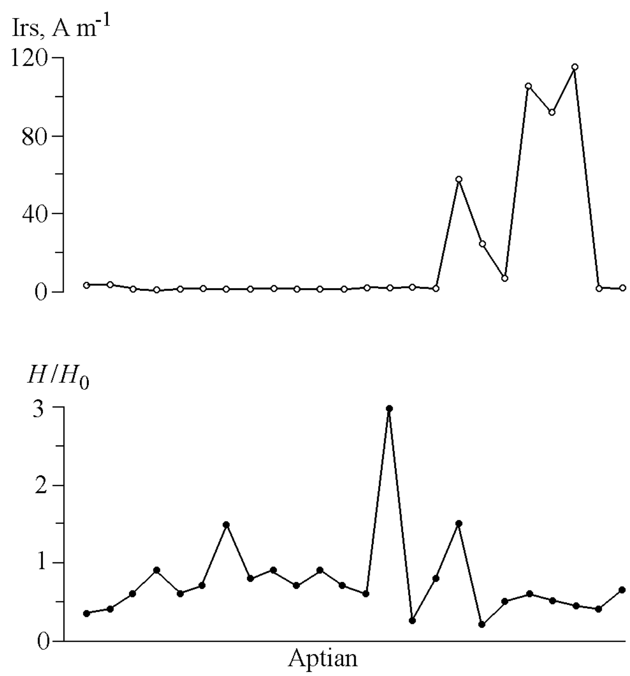

Figure 3. Comparison of the paleointensity dynamics (H/H_0) of Aptian with the amount of the residual magnetization bearer (Irs).

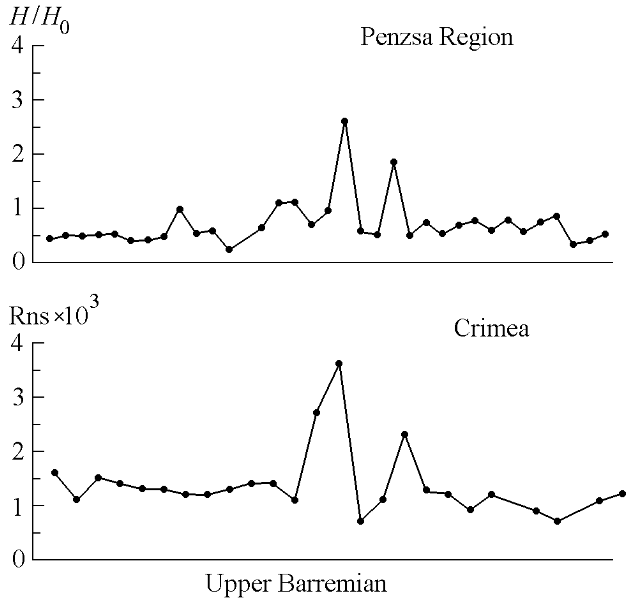

Figure 4. Comparison of the paleointensity dynamics of the upper Barremian (the M1 zone) obtained from the sediment strata of Crimea and Penza region.

the Tertiary reached 4 H_0. Evidently in those times the geomagnetic field generation also was of a burst-like character. The detailed picture of the paleointensity behavior obtained in this paper made it possible to formulate problems which arise while interpreting results of its determination. The paleointensity fragments of Cenomanian and Albian can be referred to the same magnetopolar interval separated be a series of short events of geomagnetic polarity changes. Such an approach shows that within one magnetopolar interval there is observed more than one burst of the paleointensity. That does not change the evaluation of the duration of paleointensity variation cycles related to its bursts, but is important for formation of the picture of the geomagnetic field structure of magnetopolar intervals.

[26] The differences in the behavior of the mean paleointensity of separate parts of magnetopolar intervals may be due to two causes: the paleointensity behavior and the completeness of cuts studied and detailedness of the studies. Moreover, it should be noted that the geomagnetic field intensity has a complicated and still weakly studied structure. Therefore the problem (absolutely unsolved in the paleomagnetism practice) on how much data are enough for grounded interpretation of the paleointensity behavior gets a special actuality.

[27] The rate of sedimentation accumulation similar to that used in this paper usually is evaluated as tenths of millimeter per year. This estimate means that in one sample there is averaged information on the geomagnetic field for at least 200 years. Probably postsedimentation processes and thickening of the sediments in the process of their burial increase considerably the duration of this estimate. Therefore the above obtained picture of the paleointensity behavior should have a smoothed (averaged) character, and its true amplitude values should exceed the values obtained in this paper.

[28] The problem of the lower Cretaceous paleointensity is rather complicated and evidently can not be solved in the scope of the currently available paleomagnetic materials. It has been noted above that the mean paleointensity of the analyzed time interval is 0.8 H_0. This value exceeds the paleointensity value of the lower Cretaceous (0.5 H_0) obtained by *Solodovnikov* [1995]. At the same time, a fragmentary character of our knowledge on the lower Cretaceous paleointensity does not provide great hops that the above estimates are final.

5. Conclusion

[29] The analyzed materials make it possible to note that in the paleointensity behavior one can reveal three types of periodical variations different by the amplitude and duration.

[30] 1. Paleointensity variations during quiet regimes of geomagnetic field generation occur with an amplitude of up to 0.5 H_0 and periodicity of the order of tens of millennia. This periodicity coincides to the periodicity in changes of paleointensity and volcano activity during the current magnetopolar epoch.

[31] 2. The change of the geomagnetic field generation regimes occurs with a periodicity of a few hundreds millennia.

[32] 3. The periodicity of paleointensity bursts occurrence is a few millions years. During the bursts the paleointensity can increase up to 3 H_0 and higher. The mean paleointensity values of the lower Cretaceous intervals of direct geomagnetic polarity coincide with the mean paleointensity of the current magnetopolar epoch. In the time interval studied, no differences in paleointensity behavior is found for the epochs of predominant stretching and predominant compression of the Earth crust.

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