LUPINE PUBLISHERS

Open Access Journal of Environmental and Soil Sciences

DOI: 10.32474/OAJESS.2023.06.000250

ISSN: 2641-6794

Research Article

How Meteorite Impact Affects Paleomagnetism: A Case Study of the Chicxulub Event

Li Changcheng[1]*, Zhang Yunwei[1,2] and Liu Lei[1,2]

[1]*Department of Earth and Space Sciences, Southern University of Science and Technology, China*

[2]*School of Earth and Space Sciences, University of Science and Technology of China, China*

***Corresponding author:** Li Changcheng, Department of Earth and Space Sciences, Southern University of Science and Technology, Shenzhen, China

Received: September 05, 2023 **Published:** September 13, 2023

Abstract

The formation and evolution of the geomagnetic field has always been one of the frontier topics in the field of earth science, because it provides us with a livable environment and is also an important link between the various layers of the earth. Based on the mechanical effects of meteorite impacts, this study quantitatively explores the possibility of meteorite impacts causing changes in the strength of the Earth's magnetic poles and even reversal of the magnetic poles. Quantitative calculations show that the impact of meteorites 66 million years ago resulted in a rotation speed difference of 0.022cm/s-0.025cm/s in the rotation speed of the Earth's core and mantle. This result is comparable in magnitude to the drift rate of the Earth's magnetic poles, which can cause variations in the strength of the Earth's magnetic field at the poles. Compared with the actual observation results, it is found that the meteorite impact event may have strengthened the Earth's magnetic field. This study is of great significance for improving our understanding of the impact of meteorite impacts and changes in the Earth's magnetic strength on the Earth and the human living environment.

Keywords: Meteorite impact; paleomagnetism; quantitative calculations

Introduction

Large-scale celestial body collision events widely exist in the solar system [1,2]. In addition to causing natural phenomena such as tsunamis [3], global wildfires [4], volcanic eruption [5], plate ruptures [6], biological extinctions [7], and the formation of mineral resources [8], meteorite impacts may also cause changes in the magnetic intensity of the earth and even reverse the geomagnetic polarity. Among the many celestial body collision events, the most famous one is the meteorite impact event 66 million years ago (Figure 1). This incident is considered to be the real culprit that led to the extinction of dinosaurs. In addition to the impact on the earth's organisms, whether it has a relevant impact on the earth's magnetic field is a question worth considering. Exploring this question is of great significance for improving our understanding of the impact of meteorite impacts on changes in geomagnetic intensity. According to geodynamo theory, the outer core of the earth is mainly composed of liquid iron, the movement of these substances within the earth's initial weak magnetic field.

Figure 1: Schematic diagram of meteorite impact on the Earth.

These substances move at a speed of a few millimeters per second, cutting the original magnetic field lines of the earth, thereby enhancing the original magnetic field [9]. These material movements are thought to be primarily driven by the negative buoyancy of the density gradient created by the cooling of the Earth, while the Earth's rotation also affects the movement of the core [10]. The magnetic field generated by the moving outer core extends through the mantle and crust into outer space, thereby protecting the planet from solar wind radiation [11]. The earth's magnetic poles have reversed many times in the long history of the earth, geomagnetic polarity reversal refers to the phenomenon that the earth's magnetic north and south poles are switched. Why the polarity of the geomagnetic field reverses is also considered one of the most cutting-edge scientific issues [12]. In the early 19th century, European scientists discovered the remanent magnetic direction opposite to the current geomagnetic direction through the ancient magnetic information recorded in rocks. This suggests that the polarity of the Earth's magnetic field has reversed in Earth's history.

Since then, a large amount of petrological and paleomagnetic evidence has shown that the geomagnetic polarity may reverse at regular intervals, and the reversal time usually occurs on a time scale of thousands of years to hundreds of years [13]. As the longest geophysical phenomenon in the history of the earth, the reversal of the earth's magnetic poles can occur for as long as 15 million years. Of course, this reversal period is not fixed. The most recent geomagnetic reversal event was the Songshan-Burong geomagnetic reversal event 780,000 years ago. The geomagnetic reversal occurred less than 100 years ago, and it was an extremely fast reversal event. This result greatly challenged the existing Geomagnetic generator model [14]. The reason for the reversal of the Earth's magnetic field is still inconclusive, as the scientific community has not reached a consensus on the frequency of these geomagnetic field reversals. The only thing that is certain is that the Earth's magnetic field may be extremely unstable [15]. There is no single event in geological history that fits well with a magnetic reversal event.

At present, the academic community has provided many explanations for the reasons for the geomagnetic reversal, such as the mantle convection theory [16], the change of the earth's rotation speed [17], the meteorite impact theory [18] and so on. There are two main viewpoints on the reason why mantle convection leads to geomagnetic polarity reversal. One is that the change of global heat flux drives the dynamo process, and the other is that the change of the structure of the lower part of the lower mantle leads to the emergence of unstable factors in the earth's interior [19,20]. The Earth's rotation theory holds that a change in the Earth's rotation period may trigger a reversal of the Earth's magnetic poles [21]. Previous studies have found that changes in the Earth's rotation speed can affect the westward drift of the Earth's magnetic field and change the strength of the Earth's magnetic field. At the same time, more evidence shows that there is a correlation between the change of the earth's rotation speed and the frequency of geomagnetic reversal in the past 510 million years [22].

However, the causal relationship between the earth's rotation and geomagnetic reversal may need to be further explored, because the earth's rotation is mainly affected by the gravitational tide of the sun and the moon on the ocean [23]. The meteorite impact theory holds that the impact of meteorites causes changes in the relative velocity between the rotation speed of the Earth's mantle and the rotation of the Earth's outer core. This will lead to strong disturbances in the Earth's magnetic field within a relatively short period of time, and even a reversal of the Earth's magnetic poles. According to previous studies, meteorite impact events can be well matched with some geomagnetic reversal events. But whether the meteorite impact has caused the reversal of the earth's magnetic poles requires us to conduct quantitative calculation research and practical exploration.

Methods

Regarding the physical and mechanical mechanism of the meteorite impact-induced geomagnetic reversal, there are three views [24]:

a) The meteorite impact causes a huge cavity to appear at the impact site, resulting in a loss of volume and mass, resulting in a pumping effect, which causes the material at the core-mantle boundary to surge up, resulting in geological anomalies such

as mantle plumes and reversal of the Earth's magnetic poles. This phenomenon is similar to dropping a stone into the water, and the center of the stone's fall will bounce up and out of the water column. But this situation cannot explain the physical mechanism of geomagnetic reversal.

b) After the impact, a large amount of seawater was migrated to the polar regions and high-latitude glaciers, the earth's inertia changed suddenly, and the mantle and the liquid outer core generated velocity shear force, resulting in the reversal of the earth's magnetic poles.

c) When the meteorite impacts earth, the meteorite itself has a shear component in the same or opposite direction to the earth's rotation, which can accelerate or decelerate the earth, thereby causing the earth's magnetic pole to reverse. How to quantitatively calculate and explore the influence of these factors on the strength of the earth's magnetic field is a problem that needs to be explored. However, the above viewpoints lack theoretical and practical evidence to support them.

In order to explore the mechanism of geomagnetic reversal caused by meteorite impact. In this study, relevant quantitative calculations were performed on the geomagnetic change events caused by meteorite impacts 66 million years ago. The calculation process is as follows. According to previous studies, the reason for the reversal of geomagnetic polarity caused by meteorite impact is mainly due to the speed change of the earth's upper crust and mantle caused by meteorite impact, which makes there is a speed difference between the earth's outer core and upper crust. The velocity change of the meteorite impacting the earth on the earth mainly depends on the relative motion direction between the meteorite and the earth. When the meteorite runs in the same direction as the earth, the impact will accelerate the speed of the crust and mantle, so that the relative speed between the meteorite and the outer core will increase, which is in the same direction as the original speed difference (the original speed of the outer core of the earth is faster than that of the earth's outer core). On the contrary, when the impact direction of the meteorite is opposite to the direction of the earth's movement, the impact of the meteorite may make the speed of the crust and mantle lag behind the outer core of the earth, similar to the brake effect of a car.

In this case, it is possible to induce the occurrence of the earth's magnetic pole reversal phenomenon. Of course, according to previous studies, the difference in the speed of inducing the reversal of the earth's magnetic poles needs to reach a certain value before it can cause the reversal of the earth's magnetic poles. In the case of the earth's rotation, according to the drift rate of the earth's magnetic field, we can calculate the difference in the rotation rate of the core and mantle. If you want to change to a magnetic field in the opposite direction, you need a sufficiently large reverse speed-up. According to existing research, 65 million years ago, an asteroid with a diameter of 10km impact the Yucatan Peninsula at a speed of 12-20km/s from the northeast at an angle of 45 degrees to 60 degrees [24]. When the asteroid impact the earth, its speed Contrary to the direction of the earth's rotation speed (Figure 2), the speed in the shear direction will cause the earth's mantle to form a deceleration effect, which we can call the "mantle braking effect", and the liquid outer core will still maintain the original motion state for a short time due to inertia, so that The speed difference between the rotation of the mantle and the core will cause a strong disturbance in the geomagnetic intensity in a short period of time.

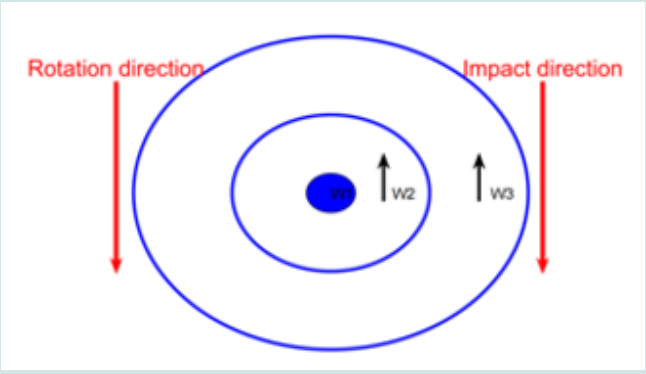

Figure 2: Schematic diagram of velocity components in the direction of meteorite impact and the direction of Earth's rotation.

According to the theory that the relative velocity difference between the core and the mantle leads to changes in the strength of the Earth's magnetic poles. The factors that cause the core-mantle rotation rate difference include internal and external factors. The internal factors of the earth generally refer to the change of the material density of the earth's material under the action of the earth's gravity, and the material convection under the change of the earth's heat. External factors mainly refer to the gravitational force of the sun, moon and other planets on the earth. But the mechanical effect caused by this external factor is not enough to cause the core-mantle rotation rate difference to reach a certain value, and the meteorite impact may make the core-mantle rotation rate difference reach a corresponding value. According to the impact theory of theoretical mechanics [25], the change in the angular velocity of the earth's rotation after the impact is equal to the moment of the collision impulse with respect to the rotation axis divided by the

moment of inertia of the object with respect to the coaxial axis. The change in the angular velocity of the earth caused by the impact of the meteorite can be calculated by the following relationship:

$$w - w_0 = \frac{R \times S}{J_z}$$

Among them, represents the angular velocity of the earth after the impact of the meteorite, represents the angular velocity of the meteorite before the impact, represents the radius of the earth, represents the moment of inertia of the earth, and represents the collision impulse of the asteroid hitting the earth. The specific expression is:

$$S = \frac{M_1 \times M_2}{M_1 + M_2}(V_1 + V_2)$$

Among them, represents the mass of the earth, represents the mass of the asteroid, represents the revolution speed of the earth, and represents the tangential velocity of the asteroid hitting the earth, which is the component of the asteroid velocity in the direction of the earth's rotation. The specific values [26] of each quantity in the above formula are shown in Table 1. Based on the above data, we can quantitatively calculate the change in the rotation rate difference between the mantle and the outer core of the earth caused by the impact of the meteorite on the earth 66 million years ago. The calculation results show that the relative angular velocity change of the earth's magnetic pole during this impact is 6.98×10^{-11}rad/s - 7.7601×10^{-11}rad/s, and then we can calculate the corresponding linear velocity change as 0.024cm/s-0.027cm/s, which is consistent with the westward drift of the earth's magnetic pole The velocity of 0.037cm/s is in the same order of magnitude (take the westward drift rate of 0.20/a in 1907-1945 as an example [27]), this velocity difference will lead to rapid changes in the Earth's magnetic field, and may cause the reversal of the Earth's magnetic poles.

Table 1: The corresponding Earth parameters used in this study.

Parameter Symbols	Parameter Name	Parameter Value
J_z	The moments of inertia of the earth	8.117×10^{37}kg.m^2
R	Earth radius	6.37×10^6m
R_2	Core mantle boundary radius	3.48×10^6m
V	Asteroid speed	1.2×10^4m/s-2.0×10^4m/s
V_1	Earth's revolution speed	2.979×10^6m/s
M_1	Earth mass	5.976×10^{24}Kg
M_2	Asteroid mass	2.31×10^{16}kg
α	Impact angle	45^0-60^0

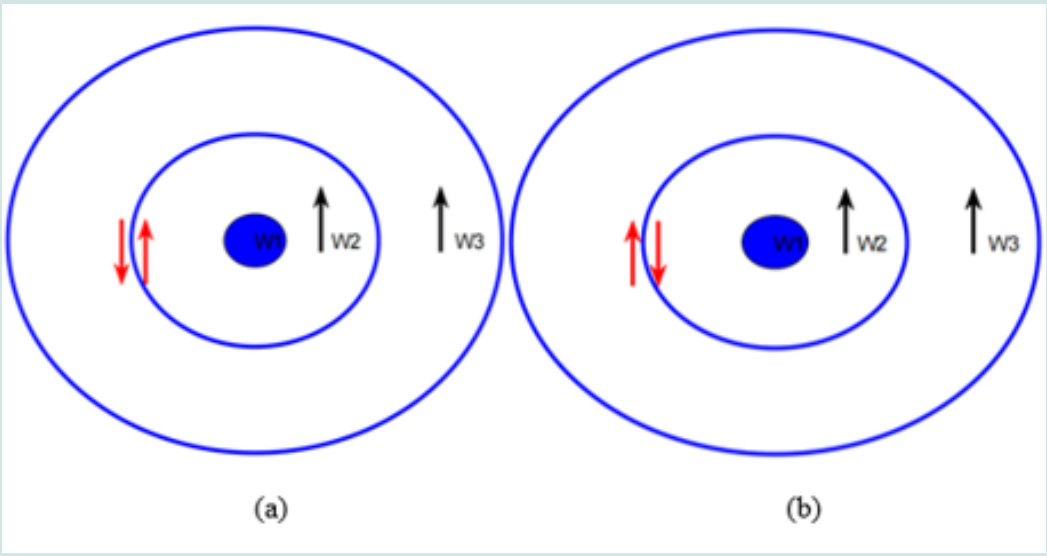

Figure 3: Schematic diagram of relative motion between the Earth's outer core and mantle, where (a) represents w2<w3, and (b) represents w2>w3.

Whether the earth's magnetic pole reverses or not is related to the rotation rate of the core and mantle layers. Since the impact direction of the meteorite is opposite to the direction of the earth's rotation, the rotation speed of the mantle will become smaller after the impact. When the original rotation speed of the core is lower than the rotation speed of the mantle, that is, when w2<w3, the difference between the rotation speeds of the core and the mantle becomes smaller after the impact, and even causes the phenomenon that the earth's magnetic poles are reversed (Figure 3A). When the original rotation speed of the core is greater than the rotation speed of the mantle, that is, when w2>w3, after the impact, the rotation speed of the mantle decreases, resulting in a further increase in the difference in the rotation speed of the core and the mantle, which will lead to the phenomenon that the strength of the Earth's magnetic field increases(Figure 3B).

Results and Discussion

Through quantitative calculations, this study shows that the impact of meteorites 66 million years ago caused abnormal changes in the strength of the Earth's magnetic poles, and even a natural phenomenon of geomagnetic polarity reversal. According to relevant information, it was found that about 66 million years ago, paleomagnetism changed accordingly, theoretical calculations correspond well to actual observations. The results of this study show that meteorite impacts will indeed trigger anomalous changes in the Earth's magnetic poles. For the occurrence of many irregular geomagnetic polarity reversal phenomena in the history of the earth. Not all reversals of the Earth's magnetic poles are associated with meteorite impacts, and not all meteorite strikes cause the reversal of the Earth's magnetic poles. The theory that meteorite impacts lead to reversal of the Earth's magnetic poles believes that only when the Earth's magnetic field is in an unstable state and the scale and speed of the meteorite are large enough can it be possible to induce the reversal of the Earth's magnetic poles.

When the earth's magnetic field is relatively stable, meteorite impacts are not likely to induce the reversal of the earth's magnetic poles. The most serious consequence of the geomagnetic polarity reversal may be the occurrence of extinction events on the earth. Due to the existence of the earth's magnetic field, the earth's organisms are protected from the solar wind and high-energy rays of the extraterrestrial universe, and also prevent the volatilization of life-related substances such as oxygen and water, which provides a guarantee for the survival and reproduction of organisms [28,29]. Therefore, the reversal of geomagnetic polarity will weaken the barrier to protect the earth's environment, which will have a negative impact on the development of the biosphere, and thus trigger a mass extinction event. When the earth's magnetic field reverses, the strength of the magnetic field decreases, which reduces the ability of the earth to resist solar storms, which will greatly increase the probability of earth space disasters (such as the failure of space satellites).

In the future, it will play an important role in summarizing the laws of geomagnetic reversals in the history of the earth, so as to predict future changes in magnetic field strength and improve our ability to deal with the hazards caused by geomagnetic reversals. For the discovery of the law of reversal of the Earth's magnetic field. The changing law of the Earth's historical magnetic field can be preserved by ancient rocks [30]. At the same time, we can also study isotopes to determine the phenomenon of geomagnetic reversal. The isotopes are produced by the bombardment of heavy atoms such as carbon and nitrogen in the atmosphere by high-energy cosmic rays, which in turn are affected by the Earth's magnetic field [31]. The development of paleomagnetic identification technology in the future will further promote the progress of research on the earth reversal phenomenon. In fact, as a global geological event, the earth's magnetic pole reversal should be found more evidence from the globally unified petrology, paleomagnetism and other evidence.

Most of the existing research on the geomagnetic reversal phenomenon is relatively one-sided. Development may also depend on the joint efforts of scientists from different regions of the world (similar to the Human Genome Project [32] etc.). This study mainly shows that large-scale meteorite impacts may induce the reversal of geomagnetic polarity, and meteorite impact is one of the causes of geomagnetic polarity reversal, not the only reason. In fact, as an irregular and complex phenomenon, the earth's magnetic reversal can be induced by various internal and external reasons [33-36]. At present, there is no theory that can explain this phenomenon well. In the future, summarizing the law of geomagnetic reversal and finding convincing reasons for the reversal will be of great significance for us to decipher the law of earth's magnetic pole reversal.

References

1. Kimi KB, Vijayan S (2023) Mare filled craters on the Moon. Icarus 390: 115298.
2. Deng YF, Luo H, Zhang Z, Zhu S, Huang RQ, et al. (2023) Recent progress of geophysical exploration in Earth's impact craters. Reviews of Geophysics and Planetary Physics 54: 1-11.
3. Range MM, Arbic BK, Johnson BC, Moore TC, Titov V, et al. (2022) The Chicxulub impact produced a powerful global tsunami. AGU Advances 3(5): e2021AV000627.
4. Venkatesan MI, Dahl J (1989) Organic geochemical evidence for global fires at the Cretaceous/Tertiary boundary. Nature 338(6210): 57-60.
5. Hull PM, Bornemann A, Penman DE, Henehan MJ, Norris RD, et al. (2020) On impact and volcanism across the Cretaceous-Paleogene boundary. Science 367(6475): 266-272.
6. Zhang Shaobing (2022) When and how did plate tectonics start. Earth Science 47(10): 2.
7. Schulte P, Alegret L, Arenillas I, Arz JA, Barton PJ, et al. (2010) The Chicxulub asteroid impact and mass extinction at the Cretaceous-Paleogene boundary. Science 327(5970): 1214-1218.
8. James S, Chandran SR, Santosh M, Pradeepkumar AP, Praveen MN, et al. (2022) Meteorite impact craters as hotspots for mineral resources and energy fuels: a global review. Energy Geoscience 3(2): 136-146.
9. Gubbins D (2008) Geomagnetic reversals. Nature 452(7184): 165-167.
10. Bono RK, Tarduno JA, Nimmo F, Cottrell RD (2019) Young inner core inferred from Ediacaran ultra-low geomagnetic field intensity. Nature Geoscience 12(2): 143-147.

11. Erdmann W, Kmita H, Kosicki JZ, Kaczmarek Ł (2021) How the geomagnetic field influences life on Earth–an integrated approach to geomagnetobiology. Orig Life Evol Biosph 51(3): 231-257.
12. Li Yongxiang, Liu Xinyu (2021) Paleomagnetic field research: challenges and opportunities. Journal of Geology 95(1): 11.
13. Zhu R, Pan Y, Liu Q (1999) Geomagnetic excursions recorded in Chinese loess in the last 70,000 years. Geophysical Research Letters 26(4): 505-508.
14. Qiang XK, Xu XW, Chen T, Zhao H, Zheng HT (2016) Spatial characteristics and influence factors of Matuyama-Brunhes polarity reversal boundary (MBB) in eolian sequences from the Chinese Loess Plateau (in Chinese). Quat Sci 36(5): 1125-1138.
15. Gubbins D (2008) Geomagnetic reversals. Nature 452(7184): 165-167.
16. Mohamed AR, Radhakrishna T, Venkateswarlu M, Sowmya GS (2020) Low geomagnetic field strength during End-Cretaceous Deccan volcanism and whole mantle convection. Sci Rep 10(1): 10743.
17. Lockwood M, Haines C, Barnard LA, Owens MJ, Scott C J, et al. (2021) Semi-annual, annual and Universal Time variations in the magnetosphere and in geomagnetic activity: 4. Polar Cap motions and origins of the Universal Time effect. J Space Weather Space Clim 11: 15.
18. Burns C A (1989) Timing between a large impact and a geomagnetic reversal and the depth of NRM acquisition in deep-sea sediments. In Geomagnetism and palaeomagnetism pp. 253-261.
19. Olson P, Deguen R, Hinnov LA, Zhong S (2013) Controls on geomagnetic reversals and core evolution by mantle convection in the Phanerozoic. Phys Earth Planet Inter 214: 87-103.
20. Li L (2016) What causes geomagnetic reversals? Chinese Science Bulletin 61(13): 1395-1400.
21. Muller R A, Morris DE (1986) Geomagnetic reversals from impacts on the Earth. Geophys Res Lett 13(11): 1177-1180.
22. Pacca I G, Frigo E, Hartmann GA (2015) Possible relationship between the Earth's rotation variations and geomagnetic field reversals over the past 510 Myr. Frontiers in Earth Science 3: 1-5.
23. Shaoquan Z (1988) An Introduction of Geophysics. Seismology press.
24. Collins GS, Patel N, Davison TM, Rae AS, Morgan JV, et al. (2020). A steeply-inclined trajectory for the Chicxulub impact. Nat commun 11(1): 1480.
25. Bopohkob NM, Lü M (1958) Theoretical mechanics. Heavy Industry Press Beijing pp. 321-329.
26. Murgatroyd C, Mott D, Kinsman C, Stinton J (2021) P2_3 PREM reigns suPREMe. Physics Special Topics 20(1).
27. Mandea M (2022) Spatial Evolution: Westward Drift. In The Magnetic Declination: A History of the Compass pp. 91-95.
28. Wei Y, Pu Z, Zong Q, Wan W, Ren Z, et al. (2014) Oxygen escape from the Earth during geomagnetic reversals: Implications to mass extinction. Earth Planet Sci Lett 394: 94-98.
29. Tarduno JA, Cottrell RD, Bono RK, Oda H, Davis WJ, et al. (2020) Paleomagnetism indicates that primary magnetite in zircon records a strong Hadean geodynamo. Proc of the Natl Acad of Sci U S A 117(5): 2309-2318.
30. Panovska S, Korte M, Adolphi F, Scherler D, Nowaczyk N (2023) Complementing global geomagnetic field reconstructions with cosmogenic isotope production rates. XXVIII General 7Assembly of the International Union of Geodesy and Geophysics (IUGG) (Berlin 2023).
31. Watson JD (1990) The human genome project: past, present, and future. Science 248(4951): 44-49.
32. Andreas N, Neil S, Monika K, Richard H, Mimi H (2020) Persistent westward drift of the geomagnetic field at the core–mantle boundary linked to recurrent high-latitude weak/reverse flux patches. Geophys J Int 222(2): 1423-1432.
33. Kaiho K, Oshima N, Adachi K, Adachi Y, Mizukami T, et al. (2016) Global climate change driven by soot at the K-Pg boundary as the cause of the mass extinction. Scientific reports 6(1): 28427.
34. Kring DA (1997) Air blast produced by the Meteor Crater impact event and a reconstruction of the affected environment. Meteorit Planet Sci 32(4): 517-530.
35. Morgan JV, Bralower TJ, Brugger J, Wünnemann K (2022) The Chicxulub impact and its environmental consequences. Nature Reviews Earth & Environment 3(5): 338-354.
36. Spivak A A, Riabova S A (2019) Geomagnetic variations during the fall of meteorites. Geomagnetism and Aeronomy 59(5): 612-622.

DOI: 10.32474/OAJESS.2022.06.000250