- PREPRINT -

Published in

Paleontological Journal, 2014, Vol. 48, No. 14, pp. 1569–1572.

CosmoPhysical Situation in the Epoch of the Cambrian Explosion

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Received August 5, 2013

Abstract—Based on available published paleodata, cosmophysical environment of the Earth during the Cambrian evolutionary explosion is considered. Some astrophysical data demonstrate that, about 500 Ma, the Sun entered into the Perseus arm with the enhanced density of star population and spent there several dozen million years. According to some meteorite data, the average level of the galactic cosmic ray (GCR) intensity during that period was considerably higher than previously, when the Sun passed the space between the galactic arms. The GCR flux varied from 25 to 135%, as the Solar System consequently crossed other galactic arms. Some correlation of the GCR intensity variations with periods of global warming and cooling has been found. However, there was no unambiguous relation between climatic data and the GCR intensity. Unfortunately, an accuracy of estimation of the GCR intensity through meteorite data varies to within 0.30–1.5, which does not allow making definite conclusions. For more reliable conclusions, additional astrophysical data obtaining is needed, and new approaches to modeling of the GCR propagation, which take into account their characteristic lifetime of ~10–100 Ma, should be applied. A possibility of impact of Supernova outbursts and superincreases of solar cosmic ray (SCR) flux on climatic changes are discussed. A possible bioeffective role of the geomagnetic field reversals, oscillations of the position of the Sun in the Galaxy, and other unidentified yet factors is also considered.

Keywords: Cambrian explosion, cosmophysical environment, galactic cosmic ray

DOI: 10.1134/S0031030114140093

INTRODUCTION

From the moment of the origin of life, there were some major events in history of the organic world on the Earth, which have defined further development of the biosphere. First of all, it was the formation of eukaryotic cells and metaphytes. About 500–600 Ma, multicellular organisms obtained an opportunity to build a skeleton for the first time and, from then onward, the organic world of the Earth has been becoming more and more similar to the modern one (Rozanov, 1986). That critical period was named the Cambrian evolutionary explosion. From the point of view of paleontology, the Cambrian explosion, dated about 540 Ma, is a sudden (on the geological time scale) appearance of representatives of many Animal Kingdom divisions in the fossil records of the Early Cambrian deposits. At the same time, their fossils or fossils of their ancestors were absolutely absent in Precambrian deposits.

As paleontological data were accumulated, attempts to explain the causes of "explosive" evolution were repeatedly undertaken and interpretation of the Cambrian explosion repeatedly changed. Among "external" (nonbiological) causes of the explosion, four main hypotheses guided by the changing environment concept are considered up to now: (1) the growth of the oxygen concentration ("oxygen catastrophe"); (2) global glaciations; (3) fluctuations of the carbon isotope composition (global "greenhouse effect"); (4) an external (meteoric, asteroid) impact.

Any of these direct causes alone cannot explain all gained information about the Cambrian explosion. On the other hand, some of the hypotheses, in turn, demand the existence of certain external factors, such as the Earth glaciations because the solar activity variations or passing of the Solar System through an interstellar dust cloud. Therefore, it seems plausible to consider some astrophysical aspects of this problem rarely discussed in literature from the positions of modern knowledge about the structure of Galaxy and star dynamics, about the galactic cosmic rays (GCR), an activity of the Sun, and other extraterrestrial factors. We shortly discuss here cosmophysical (astrophysical) conditions occurred during the Cambrian explosion in order to outline its most possible external causes.

WHAT IS NECESSARY TO CONSIDER?

If to take the age of the Earth, which is 4.8 Ga, as a day, the terrestrial life has existed merely for 17.5 hours, mammals have lived for 30 minutes, and the humankind has existed just for the last 18 seconds.

According to this time scale, the Cambrian explosion happened 2.7 hours ago and the age of galactic cosmic rays (GCRs), coming to the Earth and registered now, does not exceed 30 minutes. This specific timeline must be kept in mind every time when we try to compare any facts from geological history of the Earth and evolution of the biosphere. In this regard, some questions arise. What could be involved in the Cambrian explosion? What astrophysical factors (conditions) can be important for the Cambrian problem solving?

First of all, the position of the Sun and entire Solar System among other stars of our Milky Way Galaxy must be considered as a critical factor of the so-called "space weather" and "space climate." It is known that the Galaxy consists of several "arms," where the star density as well as GCR fluxes is higher than in the space between them (Vallee, 2005). Since supernova outbursts are considered to be the main source of GCR, a frequency of their occurrence is an important factor determining the cosmophysical environment of the Solar System. During its orbital movement round the Galaxy center, the Sun crosses the star arms and slightly changes its position (oscillates) relative to the Galaxy plane (Gillman and Erenler, 2008).

It is known that the earth's atmosphere is constantly bombarded by cosmic rays of a galactic or solar origin (GCRs and SCRs, respectively). Because of temporary variations of the CR fluxes, their interaction with the neutral atmosphere leads to fall/increase of the air ionization. Thereby, cosmic rays can actively impact the structure of the atmosphere, its electric condition, and, consequently, its dynamics, weather and climate. The GCR flux measured at the Earth mainly anticorrelates with the solar activity (SA), demonstrating the period of ~11 years. The GCR intensity has its maximum during a minimum of SA and vise versa. Strong SCR fluxes sporadically occur at the Earth orbit after strong disturbances in the solar atmosphere. However, their relation to the SA level is not as unambiguous as in the case of GCR and the frequency of the events is determined by the dynamics of solar magnetic fields (for more detail, see Miroshnichenko, 2011; Obridko et al., 2013).

It should be taken into account that the effect of cosmic rays on the biosphere significantly depends on the thickness and structure of the atmosphere. At the moment, all living beings on the Earth surface are affected by secondary cosmic rays, which are less intensive than primary ones. However, at the beginning of its development, the biosphere was exposed to direct hard radiation, if not pernicious, but causing widespread mutations. Thus, on the set of the studied effects, cosmic rays may be considered as one of the main constantly acting bio-effective agent of the space weather (Miroshnichenko, 2013).

During the Cambrian explosion, the atmosphere was very different from both modern and primary state. Meanwhile, detalization of its parameters and numerical estimates of the potential mutagen influence of CRs during a certain geological era is still an unresolved task. We will just qualitatively depict changes in the CRs intensity during the period discussed.

Solar activity (SA) is another important cosmophysical factor. In particular, cyclic variations of the general level of SA impact the intensity of galactic CRs inside the Solar System, whereas sporadic variations, such as solar flares and coronal mass ejections (CMEs), are accompanied by strengthened solar CR flux and followed by geomagnetic storms. On the geological time scale, the SA variations superpose with long-term oscillations of the intensity and sign of the magnetic field of the Earth. The abrupt changes in the geomagnetic field polarity, the so-called geomagnetic reversals, are associated with long-term trends in climate fluctuations. We cannot exclude a possibility of impact of some unknown factors on the biosphere either. As a whole, the problem can be solved within the concept of coevolution of the Sun, Earth, and biosphere (Obridko, et al., 2013). In addition to the latest work, we discuss below new facts and reasons supporting this concept.

METEORIC DATA ON COSMIC RAYS

The iron meteorite impact is only source of indirect data on GCR flux changes during the era of Cambrian explosion. Long-lived cosmogenic isotopes, in particular, the ^{40}K isotope with the halflife period of $T_{1/2}$ = 1.3 b.y., the ^{36}Cl isotope ($T_{1/2} = 3.08 \times 10^5$ years), and some others are formed in meteorites at interactions with CRs. As the activity of a sample is measured using, for instance, the $^{41}K/^{40}K$ ratio, it is possible to estimate the intensity of CR flux, exposing the meteorite during its lifetime in the Solar System before falling on the Earth. According to available meteoric data, it is possible to obtain information almost up to 2 Ga along the paleotime scale (Lavrukhina and Ustinova, 1990).

Modern direct measurements of CRs give information about the past of the Galaxy only to 100 Ma due to the lifetime of CRs (see above). Meanwhile, for the last 500 m.y., the Sun has crossed four galactic arms and the terrestrial biosphere has faced at least six considerable mass extinctions that occurred after the Cambrian explosion (Gillman and Erenler, 2008). During that time, there were three superchrons (dated 485–463, 312–264, and 120–84 Ma). Superchrons are long periods when no reversals of the geomagnetic field took place. As for CRs, the first results of the study of 11 iron meteorites allowed to show that roughly averaged total flux of CRs in the Solar System could have been about one-third of the modern level between 300–900 Ma (Lavrukhina, 1969).

Moreover, subsequent detailed studies of the K(41)/K(40) ratio in 74 iron specimens (Voshage and Feldman, 1979) have shown an excellent correlation between strengthening of CR intensity and the Galaxy arms crossing for the last billion years (Shaviv, 2002). Some astrophysical data specify that, about 500 Ma, the Sun entered the Perseus arm with the increased star population density, staying there for several tens million years. There are evidences that the average level of GCRs intensity was much higher during that period than in the inter-arm space, before the entry of the Sun into the Perseus arm. Subsequently, the GCR flux also changed within 25–135%, as other galactic arms were crossed on the way of the Solar System.

It is noteworthy that those variations correlated with the periods of global warming and drop in temperature, but climatic changes and CRs paleo-intensity have not shown unambiguous association. Unfortunately, the accuracy of the GCR intensity estimates via meteorite data varies with a multiplier of 0.3 to 1.5, which impact the accuracy of obtained results and does not allow making certain conclusions. In addition, an important methodical (or physical(?)) question arises, as to which level of the GCR intensity must be considered as "normal" for the biosphere—ancient or modern. In any case, a possibility of considerable changes in CR flux in the past is undoubted (Miroshnichenko, 2013).

HUGE SOLAR FLARES AND SUPERNOVA EXPLOSIONS

Since solar flares are sources of intense solar CRs, a probability of huge flares at the Sun at other levels of solar activity nowadays and far back in the past is of particular interest. Recent estimates of the solar flares intensity demonstrated a sharp break of the events distribution function in the area of small probabilities, which corresponds to large SCR fluxes (Miroshnichenko and Nymmik, 2013). This follows from the analysis of indirect and direct data on the solar cosmic rays for the last 1200–1300 years. Extrapolation of these results to the past and to the future requires adequate models of the "young" and "old" Sun.

A bit different problems arise in the analysis of frequency of supernova explosions, which are the main sources of galactic CRs. The estimates of the supernova (SN) outburst frequency for the past ~500 m.y. were compared with biological diversity of sea animals for the same period in one of the latest works in this field (Svensmark, 2012). The curve for the (SN) explosion frequency was calculated for each time interval when the Sun crossed a particular Galaxy arm. The quantity of fossil marine organisms was estimated similarly, taking into account the effect of the ocean level variations on the deposition rate. The two curves show a close correlation. Such a close correlation of astrophysical and biospheric processes is an argument in favor of the hypothesis of strong influence of GCRs and SCRs on the evolution of the biosphere.

However, the results discussed by Svensmark (2012) cannot be considered as indisputable. The high precision of calculation of the SN explosion rate raises doubts. There are also discrepancies with the data on extinction that occurred about 20 Ma. Further, the correction for the ocean level apparently significantly changed the initial series of paleontological data and this point deserves an additional check. On the other hand, there are independent climatic data on the variations of oxygen ^{18}O isotope concentration (as one of the best climatic indices) through a large time scale (Veizer et al., 1999). Thus, all maxima obtained in the work (Veizer et al., 1999) coincide with the curve peaks calculated by Svensmark (2012) for the SN explosion frequencies.

A new aspect of the "Cosmic rays and the biosphere" problem has recently arisen in connection with high-precision data of the PAMELA experiment (Adriani et al., 2011). Since June 15, 2006, the CRs detectors of this spacecraft have registered, in particular, streams of protons, helium, electrons, and positrons in the energy range from ~80 MeV up to 190 GeV for protons and from ~50 MeV to 270 GeV for positrons. The dominating part of GCRs consists of protons and helium nucleus. Exact measurements of their fluxes are necessary for gaining an understanding of processes of acceleration and transfer of CRs through the Galaxy. It has been found out that some features of proton and helium spectra can be explained by neither solar flares nor SN explosions. In other words, it is necessary to accept a hypothesis of additional sources of cosmic rays that possess such high energies.

According to Dr. Yu.I. Stozhkov (who is one of participants of the PAMELA experiment), the main candidates for the role of such sources are so-called dwarf stars from the nearest environment of the Sun/Solar System. A lot of flares are observed at those stars (Shakhovskaya, 1989). Many dwarfs are much more active than our Sun, and flares occur there more often in comparison with the Sun. About 1% of all dwarf stars can accelerate particles to $\sim 10^{13}$ eV, while the maximum possible energy of the solar CRs is probably at most 10^{11} eV at the relative brightness of the Sun of 10^{32}–10^{33} ergs. Other stars can radiate up to 10^{37} ergs during a flare.

Knowing the lifetime of CRs, number of dwarf stars, and frequency of flares, it is possible to estimate a total allocation of their energy in the form of cosmic rays, which is $\sim 10^{54}$ ergs. Those stars are CR sources at distances of tens or hundreds of parsec, which is very close to the Earth in comparison with our Galaxy size (~30 000 parsec). Therefore, the role of CRs in the evolution of the biosphere might be even more essential than it follows from the traditional ideas of the external cosmophysical factors impact, and the Cambrian explosion period is not exception.

FINAL REMARKS

This short review was aimed to demonstrate that environmental factors (in particular, cosmophysical factors) had huge impact on development of the biosphere during the entire period of its evolution. As some space factors have the casual or sporadic nature, it seems undoubted that development of the biosphere was unsteady.

On the other hand, natural processes demonstrate a certain rhythmic and various processes can be hierarchically synchronized under the influence of a strong rhythm-giving source as seen under large-scale temporal approach. The variation of solar activity is one of such quasiperiodic sources. In this light, many results obtained in heliobiology can be adequately interpreted on the basis of the concept of an evolutionary and adaptation syndrome (Miroshnichenko, 2011; Obridko et al., 2013). Thus, along with a search for new data on cosmophysical bio-effective factors, there are two actual tasks:

(1) Development of theoretical models that consider any possible intensities of radiation that influenced the biosphere in the past;

(2) Investigation of a response of modern biosystems on changes in space (cosmophysical) factors under the view that such a response is an atavistic reaction of organisms to variations of environmental conditions.

ACKNOWLEDGMENTS

This work is supported by the Program of the Presidium of the Russian Academy of Sciences “Problems of the Origin of Life and Formation of the Biosphere” (no. 28).

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