Lithospheric plate tectonics and mass extinctions of biological species

V V Snakin
Institute of Fundamental Problems of Biology of the Russian Academy of Sciences, Moscow, 142290, Russia

E-mail: snakin@mail.ru

Abstract. The merging of lithospheric plates and the formation of supercontinents are considered to be the main causes of global species extinctions within the Earth’s biosphere. Under those conditions, the factor of geographic isolation is diminished and interspecies competition is accelerated, allowing for the survival of the best-adapted species. The divergence of lithospheric plates triggers a new spurt of speciation that surpasses the previous one, as it involves the participation of the winning species.

1. Introduction
The development of life on our planet, over the billions of years of the biosphere’s existence, has been under the continuous influence of geological processes, both catastrophic in character (e.g., volcanism, earthquakes, etc.) and the much slower but continuously manifesting processes, such as the horizontal and vertical movements of the Earth’s crust. Such movements cause changes in climate, relief, and ecological conditions, affecting also the factor of inter-species isolation.

One of the most interesting evolutionary problems, which has not been solved thus far, is the clarification of the causes of global mass extinctions of biological species, which took place regularly in the evolution of life on the Earth.

The present work aims to analyze the relationship between the slow movements of the Earth’s crust altering the degree of geographical isolation of biological species and mass extinctions, when paleontologists note the disappearance of sometimes more than half of the species in the biosphere.

2. The Global Dynamics of Biodiversity
In the process of biospheric evolution, the number of species has continuously increased: from the Cambrian to the Silurian, the number of marine animal families increased from five to 400 over the course of 200 million years. By the Quaternary, the number of marine animal families alone had increased to 750. At the same time, the dynamics of biodiversity, as well as the whole evolutionary process, were characterized by abrupt starts: there were several large bursts of speciation and extinction, when whole families, orders, and even types of organisms appeared or disappeared. Modern science has identified several mass extinctions that occurred over the past 500 million years.

The best-known, though not the greatest of these, the Cretaceous-Paleogene extinction (~65 million years ago) took out more than half of all the species, including the dinosaurs. During the “great” Permian extinction (~250 million years ago), approximately 90 percent of all the species went extinct.
2.1. Why, what for, and how do extinctions occur?
There are no unequivocal answers as yet to these basic questions that arise when analyzing the dynamics of biodiversity. According to Charles Darwin [1], we needn’t marvel at the fact of extinction, for the extinction of species and entire groups of species, which has played such an outstanding role in the history of the organic world, is an almost inevitable consequence of the principle of natural selection.

According to V.A. Krasilov [2], “extinction is a means of regulating diversity in variable conditions so as to reduce the competition”.

From evolutionary positions, the cause of species extinction is considered to be their constant improvement for the purposes of maximizing the use of environmental resources, even as the environment itself is altered by new species, in their own favor. In the process of the biosphere’s evolution, the number of species increased, while the biosphere expanded into areas previously unoccupied by life, involving new substances in its growing orbit of activity, and utilizing solar energy and chemical compounds more and more efficiently. Academician M.A. Fedonkin [3] noted: “For the biosphere, extinctions were as good as it is good for a species to have aging individuals die naturally from old age. In both cases, carriers of faulty hereditary information that might hamper evolution are cut off”.

In the period accessible to the paleontological record, five mass extinctions are distinguished, as outlined in table 1. Work [4] contains a proposal to add a sixth extinction to this list, that being in the Carnian pluvial period (~233 million years ago). In work [5], the modern period associated with human activity is proposed as the sixth mass extinction.

| Major mass extinction (scale of the extinction) | When it took place (millions of years ago, or “m.y.a.”) | Supposed causes of the mass extinction |
|-----------------------------------------------|-------------------------------------------------------|---------------------------------------|
| Ordovician-Silurian mass extinction (~85 % of all the living species eliminated) | Paleozoic Era, End-Ordovician (~440–445 m.y.a.) | - The onset of glacial cycles on the Earth, with corresponding changes in the sea level; - Changes in atmospheric and oceanic chemistry related to the rise of the Appalachian Mountains |
| Late Devonian mass extinction (~80 % of all the living species eliminated) | Paleozoic Era, End-Devonian (~383–359 m.y.a.) | - Climate change, possibly related to the diversification of land plants; - Decrease in oxygen levels in the deep ocean |
| Permian-Triassic mass extinction (~96 % of all the living species eliminated) | Paleozoic Era, End-Permain (~250–252 m.y.a.) | - Volcanic activity; - Climate change; - Decrease in oxygen levels in the deep ocean; - Changes in atmospheric chemistry; - Changes in oceanic chemistry and circulation |
| Triassic-Jurassic mass extinction (~50 % of all the living species eliminated) | Mesozoic Era, End-Triassic (~200 m.y.a.) | - Volcanic activity |
| Cretaceous-Paleogene (K-T) Mass Extinction (~75 % of all the living species eliminated) | Mesozoic Era, End-Cretaceous (~66 m.y.a.) | - Asteroid impact; - Volcanic activity; - Climate change; - Changes in atmospheric and oceanic chemistry |
The causes of all the just-mentioned mass extinctions are attributed to absolutely different phenomena of predominantly catastrophic nature. The most popular of them are volcanism, trap magmatism, cosmic catastrophes (e.g., collisions with asteroids), change of magnetic poles, climate change, etc. Another cause of one of these extinctions (the Late Devonian) has been recently proposed, that being the influence of a supernova explosion and the correspondingly powerful ionizing radiation on the ozone layer of the planet [8].

The just-listed heterogeneous causes are attributed to different cases of mass extinctions of species, and none of them happens to be universal.

2.2. The peculiarities of mass extinctions
An analysis of the nature of mass extinctions allows us to note two characteristic features:

1. after a sharp decrease in the diversity of biological species in the course of their extinction, biodiversity recovers at the next stage of evolution, subsequently exceeding the pre-crisis level;
2. the duration of mass extinctions, sometimes estimated at millions of years (the Late Devonian extinction, according to estimates in work [9], lasted approximately thirteen million years), a figure incommensurate with the typical durations of catastrophic events and their aftermath (those, as a rule, constitute several years).

It remains an open question why the events indicated in table 1 have caused mass extinctions only some of the time, although they have occurred much more frequently. Giant eruptions of super-volcanoes had occurred regularly: the Yellowstone super-volcano erupted relatively frequently: 640,000 years ago, and before then, 1.3 and 2.1 million years ago.

In our view, since mass extinctions have been repeated many times in the history of the biosphere, there must be a single major cause of global fluctuations in the number of species. Without downplaying the role of catastrophic events in the decline of many species, we try to look at mass extinctions from an evolutionary perspective, taking into account the horizontal and vertical movements of the lithospheric plates. These movements lead to the unification and disconnection of continents and islands and, consequently, to changes in the geographical isolation of biological species. In our earlier works, [10] and [11], we have already put forward some considerations in this regard.

3. The Proposed Mechanism of Mass Extinctions
We propose that the relatively slow movements of the lithospheric plates, due to which continents and islands periodically unite and separate, and large continental associations, up to a single super-continent like Pangea (figure 1), Monogea, Rodinia, etc. are formed, are the main cause of mass extinctions.

The movements of lithospheric plates substantially affect the isolation factor that plays a very important role in speciation. Species populations find themselves either united over vast expanses or isolated on separate continents and islands.

![Figure 1. Wegener's reconstruction of the Pangea super-continent (approximately 200 m.y.a.) and its separation (approximately 60 m.y.a.) (after [12]).](image)

It is important that the periodic merging and divergence of the lithospheric plates had a regular character. One piece of evidence for this periodic merging of the lithospheric plates, with the formation of the super-continents like Pangea, Gondwana, Rodinia, Columbia etc., is represented in figure 2.
3.1. Ecological consequences of the unification of lithospheric plates

In ecological terms, the unification of lithospheric plates leads to the removal of geographical barriers and to a reduction of geographical isolation of species.

This involves not only change in the climatic and geomorphological conditions, but also the unification of several species occupying the same ecological niche, who come together in the unified space. As a result, interspecific competition increases and the rule of competitive exclusion comes into effect (the rule of competitive exclusion, or the Volterra-Gauze principle, was formulated in 1926 by Vito Volterra, based on his study of a mathematical model of the dynamics of two populations competing for the same food resource. In 1931–1935, George F. Gause showed by experiments on protozoa how competitive exclusion of one species by another occurs. The discussion of the competitive exclusion rule played an important role in the development of the ecological niche concept and the ecological and geographic model of speciation, as well as in the evaluation of interspecific competition as a factor maintaining the structure of communities [15]). According to this rule, two or more species cannot coexist stably in a limited space if they occupy the same ecological niche. The process of competition always proceeds towards complete displacement of one species by another. Species less adapted to the environmental conditions then die out.

Another important factor of continental unification is a reduction in the number of ecological niches, due to a decrease in the diversity of climate and other geographical conditions, which also reduces the species’ prospects for continued existence.

Hence, the unification of lithospheric plates entails the association of species in similar ecological niches, and the reduction of their diversity trigger the mechanism of interspecific competition. In the further process of species extinction, a variety of factors take on significance, including physiological characteristics and the degree of adaptation to food resources and to altered climatic and other geographical features. Theoretically, for instance, the union of six continental plates could result in up to six different species sharing the same ecological niche, five of which are evolutionarily doomed to extinction, owing to interspecific competition. Similar processes take place in the oceanic expanses, where several geographically isolated oceans and seas are replaced by a single world ocean (e.g., the Tethys). The area of the life-saturated shelf zone then changes dramatically.

As the continents drift apart, the surviving, most evolutionarily developed, or adapted, species, during continued drift in the conditions of geographical isolation, give rise to a new round of evolution, surpassing the previous one. Following this, continental convergence under new geographical conditions leads to a new cycle of extinction and subsequent increase in biodiversity when the continents diverge. Thus, the unification of continents and the accompanying extinction contribute to the preservation and further evolution of the most adapted species, which, during the subsequent separation of the continents, have given rise to new and even more promising species.

A comparison of the timing of mass extinctions and collisions of lithospheric plates (table 2) shows that almost all of the five mass extinctions under consideration have occurred at the time of significant lithospheric plate unions up to the formation of super-continents.
Table 2. Lithospheric plate collisions during mass extinctions.

| Major mass extinction | The associations of the continents |
|-----------------------|-----------------------------------|
| Ordovician-Silurian   | The formation of Laurussia (Euramerica), a Paleozoic super-continent, as a result of the collision of the North American (ancient continent of Laurentia) and East European (ancient continent of Baltica) platforms during the Caledonian orogenesis (500–400 m.y.a.) |
| Late Devonian         | In the Devonian, the northern continents formed a single large continent, Atlantia, to the east of which was Asia. Gondwana continues to exist |
| Permian-Triassic      | In the second half of the Carboniferous and the Permian (~300–180 m.y.a.), the Pangea formed. This period is long and occurred in several stages |
| Triassic-Jurassic     | The collision of the continents that broke away from Gondwana with parts of Eurasia |
| Cretaceous-Paleogene  | In the Paleogene (~65 m.y.a.) the territory of Eurasia expanded: the Zondian Archipelago joined the continent, the Balkan Peninsula was united with Asia Minor, Europe joined Africa in the area of modern Gibraltar, and in the north-west the conjunction with North America occurred |

4. Vertical Tectonic Movements and Biodiversity

Similarly to the horizontal movements of lithospheric plates, upward and downward movements of the Earth’s crust lead to transgression and regression of the seas or, in other words, to processes of unification and decoupling of territories, with concurrent changes in the factor of geographical isolation and in biodiversity.

The situation with Late Pleistocene megafauna extinction 20–24 thousand years ago (about 36 % of large mammals died out in Northern Eurasia, in North America – about 72 %) may be explained by the periodic formation of “Eurasia-America” supercontinent due to the periodic formation and disappearance of the Bering Isthmus. It is known that, over the past 3 million years, the territory of Beringia has risen and gone underwater about six times [16]. Eurasia and North America separated for the last time 10–11 thousand years ago.

Before that, the isthmus existed for 15–18 thousand years. Of the large herbivores, the mammoth and the woolly rhinoceros became extinct at that time; of the large carnivores, the giant sloths, saber-toothed lions, and cave bears became extinct.

5. Globalization as a Factor in the Extinction of Species

The proposed mechanism of mass extinction is also applicable to explaining the current situation with biodiversity on the planet. The processes of globalization, which are actively developing thanks to human activity, generally act similarly to the effects of unification of continents, reducing the effect of geographical isolation. The intensification of both accidental and deliberate transport of animals and plants with the help of humans (the processes of invasion and introduction) leads to competitive struggle between species that find themselves in the same ecological niche, with the inevitable extinction of the less adapted. There is a steady increase in the number of invasive species (figure 3), which undoubtedly contributes to the extinction of native species. In the context of globalization, island populations are particularly endangered.

Figure 3. Numerical dynamics of invasive species in Europe [17].
6. Conclusion

The tectonic movements of the Earth’s crust, which cause periodic unification and separation of the lithospheric plates and consequently change the degree of geographical isolation of species, are proposed to be the main factor triggering the process of mass extinctions of species that has repeatedly occurred in the history of the biosphere.

The extinction mechanism is realized by virtue of increased interspecific competition and the death of the less adapted species as the diversity of available ecological niches decreases, and different species find themselves in competition over any given ecological niche, according to the rule of competitive exclusion. This occurs when lithospheric plates merge and especially when supercontinents come into being. When lithospheric plates disconnect once again, a new progressive leap in speciation occurs, as the most competitive among the surviving species now take part in the process.

The removal of the isolation factor also explains the phenomenon of the Late Pleistocene extinction of megafauna in Northern Eurasia and North America, as a result of sea transgression and regression and of the periodic unification of the Old and the New Worlds.

Like the unification of the lithospheric plates, human activity has greatly reduced the degree of species isolation. In the period of globalization, migration processes have significantly accelerated due to species introduction and invasion, which inevitably entail an increase in interspecific competition, a decrease in biodiversity, and may ultimately become the basis of a new mass extinction.

Catastrophic natural processes referred to in the literature as causes of mass extinctions undoubtedly played and continue to play a major role in the reduction of the number of species inhabiting the affected regions, but they cannot fully explain the regularity of global failures in the dynamics of biodiversity and their duration. Such cycles of mass extinction during continental unification, followed by spurts of speciation after continental separation, constitute evolutionary progress for the biosphere, as the most competitive of the surviving species take part in the new round of speciation.

Further clarification of periods of mass extinction and periods of unification and divergence of lithospheric plates will make it possible to create a more accurate model of biodiversity dynamics, which must ultimately be taken into account in the development of conservation policy.

References

[1] Darvin Ch 1859 The origin of species by means of natural selection, or the preservation of favoured races in the struggle for life (London: John Murray) 574 p
[2] Krassilov V A 1992 Nature Conservation: Principles, Problems and Priorities (Moscow: VNIIPriroda) 173 p
[3] Fedonkin M A 1991 Biosphere: the fourth dimension Priroda 9 pp 10–18
[4] Dal Corso J et al 2018 Multiple negative carbon-isotope excursions during the Carnian Pluvial Episode (Late Triassic) Earth-Science Rev. 185 pp 732–750
[5] Ceballos G et al 2015 Accelerated modern human–induced species losses: Entering the sixth mass extinction Science Advances 1 5 pp 1–5
[6] Greshko M and National Geographic staff 2019 What are mass extinctions, and what causes them? IOP Publishing PhysicsWeb https://www.nationalgeographic.com/science/prehistoric-world/mass-extinction/
[7] Scoville H 2020 The 5 Major Mass Extinctions IOP Publishing PhysicsWeb
[8] Brian D Fields et al 2020 Supernova triggers for end-Devonian extinctions PNAS
[9] Grzegorz Racki 2020 A volcanic scenario for the Frasnian–Famennian major biotic crisis and other Late Devonian global changes: More answers than questions? Global and Planetary Change 189 pp 103–174
[10] Snakin V V 2016a Geographic isolation of species as a factor of global biodiversity dynamics Zhizn’ Zemli 38 pp 52–61
[11] Snakin V V 2016b. Mass Extinctions in Biosphere History: Another Hypothesis Izvestiya RAN Ser. Geograph 5 pp 82–90
[12] Sorokhtin O G, Chilingarian G V and Sorokhtin N O 2011 Evolution of Earth and its Climate. Birth, Life and Death of Earth *Developments in Earth & Environmental Sciences* (Elsevier) 10 353 p

[13] Meert J G 2012 What's in a name? The Columbia (Paleopangaea/Nuna) supercontinent *Gondwana Research* 21 pp 987–993

[14] Nance R D Murphy J B and Santosh M 2014 The supercontinent cycle: A retrospective essay *Gondwana Research* 25 pp 4–29

[15] Snakin V V 2020 Ecology, global environmental processes and biosphere evolution: Encyclopedic dictionary (Moscow University Press) 528 p

[16] Lorenzen E D et al 2011. Species-specific responses of Late Quaternary megafauna to climate and humans *Nature* 479 pp 359–364

[17] Global Biodiversity Outlook 3 2010 (Montreal: Secretariat of the Convention on Biological Diversity) 95 p