PAST GLOBAL CRISES

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Summary

Occurrence of global crises is an integral part of the evolution of Earth's biota. These major depressions of life have both aspects of catastrophes, and chances conducive for innovation, which is continued by further evolution. These crises were usually connected with environmental changes. Although these crises are as old as the origin of life, the main information refers to Phanerozoic, between 542 million years ago and the present, when numerous fossils witness to diversification of abundant organisms. Six major crises of Phanerozoic life have been recognized:

(a) Late Ordovician,
(b) Late Devonian,
(c) Terminal Permian,
(d) Late Triassic,
(e) Terminal Cretaceous, and

(f) Late Cenozoic to the present, a crisis, which is in its earliest phase.

The largest datasets are related to the late Devonian crisis, the terminal Permian crisis and the terminal Cretaceous crisis, 375, 251, and 65 million years ago respectively. Besides these major global crises, more than one hundred globally traced crises seem to be recorded in the fossil record. Less than one third of these have names according to index fossils, geographical areas or stratigraphic time units, for example, the *murchisoni*, Kacak, or Cenomanian–Turonian crises in Silurian, Devonian, and Cretaceous, respectively.

The global crises of past were triggered by any strong perturbations of the physical, chemical, and biological conditions, which interrupted slowly changing background processes in the pre-existing natural systems on a global or near global scale. The global crisis usually displays a complex structure of developing entities in time and areas. Thus the application of simple models has usually only limited value. The strongest depressions of life after the global crises may persist up to hundreds of thousands of years. However, the first signals of these events and the aftermath of such crises may span several millions of years. The evidence of these global crises in Earth's history is mostly based on fossil organisms, geochemical anomalies and perturbations in sedimentary records. Very close links exist between bio-crises and global change of climate. In sedimentary record, the climatic changes are often reflected by oscillations of sea level that especially reduce extension of shallow shelf seas that strongly affected the feedbacks between biota and environment. Rare, catastrophic events (bolide impacts or huge volcanic eruptions) may contribute to these cataclysms. However, because their distribution displays a weak correlation, if any, with the timing of major global crises, it seems that these rare events need not necessarily result in significant changes to biotic systems. Studies of past ecosystems during crises can provide new insights for environmental management (such as long-term, so-called secular trends) or, more generally, into the behavior of complex systems.

1. Introduction to Past Global Crisis

1.1 Particularity of each Crisis and How to Recognize it

The relatively fast evolution of Earth's life caused that each major crisis of the past was realized on different structure of organisms and had to meet another conditions. In addition, the very complex interactions in ecosystems have also characteristics of chaos, where reactions or survival solutions cannot be copied from one crisis to another but they are usually only canalized to the most probable types of reaction. The global crises gradually emerge from background evolutionary processes and are structured both in time and areas. The main characteristics of culminating stages of these crises are extinction of many normal habitats and depression in diversity of life on a global or near global scale. Because of the structured beginning and aftermath of each global crisis, it is only on decision of each discipline and/or purpose of our studies to select a relevant point in time, and area as a proper start or end of the crisis

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1.2 Common Methods for Determining of Past Global Crises

Paleontologists generally agree, that the global crisis starts, when 50% of organic species is extinct without direct replacement by other organisms. The termination of the crisis corresponds to the state, when the recovery processes re-create the diversity values comparable with the pre-crisis situation. Auxiliary boundaries are placed at both pre-existing and subsequent collapses of groups of organisms, as are documented in the fossil record. Similarly, the geochemists can agree that the start of the global crisis is related to the moment when the perturbation in content of some isotope or geochemical-marker (such as ^{13}C) exceeds two times the normally developing values. However, the delimitation of these formal boundaries has only marginal significance, especially in comparison with studies of the entire crisis, which has many links and feedbacks traceable both in time and areas. The global crises can also reach different magnitudes in connection with chances how deeply can proceed the destruction of the pre-crisis organic communities or destruction of the life environment. Each global crisis has a different magnitude. It means practically, how many groups of organisms was affected by step-wise extinction, one after another, or how large part of marine or continental areas was covered by unfavorable conditions (such as presence of anoxic or poisoned water in marine basins or extreme temperature or precipitation values on land).

1.3 Duration - A Dating of Global Crises

The duration of major global crises is also variable. The culminated depressions of diversity with relatively hidden processes of the reconstruction persisted for tens to hundreds of Ka (thousands of years). It departs with timing of singular catastrophes on the Earth, which have not longer aftermath than hundreds to several thousands of years. The dating of the critical events is based on standard stratigraphical methods, which are used in geology for determination of rock ages. These have either sequential, relative character (such as biostratigraphy with its biozones, gamma-ray or magneto-susceptibility stratigraphy, magneto-stratigraphy based on reversals of the Earth's magnetic field, standard chemo-stratigraphy, and stratigraphy based on the changing average contents of isotopes in global oceanic reservoir) or absolute character (the radiometric dating of rocks using the half-time of slowly but continuously transforming, natural radioactive isotopes). As become generally accepted during the last two decades of research, six major crises of Phanerozoic life can be distinguished:

- End-Ordovician, culminating according to most recent radiometric dating approximately 445 million years (Ma) ago,
- Late Devonian, 375 Ma,
- End-Permian, 251 Ma,
- End-Triassic, 200 Ma,
- End-Cretaceous, 65 Ma,
- Late Cenozoic (and the present), a crisis, which is in its early phase.

[International Commission on Stratigraphy - the International Stratigraphic Chart 2004/2008 - http://www.stratigraphy.org/cheu.pdf].

The base of the Phaneroic era, its lowermost Cambrian period, has been recently correlated with the date 542 millions years ago, so that the first major biotic and environmental global crisis (End-Ordovician) emerged 97 millions of years, and the other occurred irregularly with time scale, after intervals of 70, 124, 51, 135 and ?65 Ma. Although the less visible ecological and taxonomical severity of Mid-Carboniferous, Early Ordovician and Jurassic/Cretaceous changes cause these three long or coupled periods, this succession may be indicative of 50-70 million years rhythm. However, a number of secondary wide regional to global crises have been documented in time spans between major crises, and these are at least one decimal order of magnitude shorter than the "Big Six of Crises. "

1.4 Main Differences among the Global Crises

The difference between the pre- and post-crisis life provides another view on the type of the crisis. Especially these crises from the big six that have long post-crisis depression (late Devonian Kellwasser or end-Permian crisis are connected with great changes in the genome and constructions of organisms. Some of the second order global crises are not connected with drastic changes in the composition or construction of successors. The low difference at a glance is connected with the timing of the crisis, which disturbs a major proliferate period in the evolution of life. In Earth's history, when basic part of the life is connected with marine environment, it is usually a time of rising sea levels, warming of the planet, and joining of formerly separated habitats. Middle Devonian Kacak crisis may serve as a good example. It resembles an extensive growth in economy when entire system profits of increased influx of energy and can construct bigger and more effective structures. In such conditions, the depressions are short-lived and aftermath in genome and constructions is small for no reason whatsoever. Conversely, if a similar crisis meet the times of long-term deterioration of life conditions then it usually ends with dramatic consequences for the collapsed structures. These systematic interactions are as obvious as in other systems (economy, system engineering).

1.5 Geological Record of Global Crises in Sedimentary Beds

Worsening of conditions for undisturbed evolution of life has also purely geological signals. Areas on marine shelves are emerged, and are truncated with erosion, so that the sections in sequences of sedimentary strata show significant unconformities covered by so-called condensed sediments, which reflects the low rate of sedimentation. Especially the sedimentological data suggest that many past global crises originated in connection with a fast and extreme oscillation of the sea level, which first consists of a very strong drop of the sea level and then of its strong but short-lived increase. Details of crisis-related intervals in marine sedimentary sequences show the following characteristics:

- The close pre-crisis set of the strata consists of gradually condensed sediments. Truncation of the bedding surfaces is as obvious as direct omission of significant parts of the sedimentary record. Increased proportion of re-worked rock debris contrasts with upward thinning sequence of the beds.

- The erosional or non-sedimentation sequence boundary represents either emergence (close to land) or low influx of rock debris, respective organic skeletal clasts (on the slope of the marine basins). This disconformity between the underlying and overlying beds reflects the fast sea level lowering, including the subsequent transition from the lowstand to flooding phase. Horizons close to this sequence boundary are rich in condensed products of weathering, where aeolian silt corresponds to arid conditions but clay signalizes the humid episodes. Such sedimentary starving boundaries contain also re-worked volcanic ash, meteoritic material or other background sedimentation components. Typical is enrichment in iron, phosphate, transition metals and rare elements. Good event markers are also spikes in plots of contents of metals as well as increased radioactivity (uranium VI for example).

- The overlying sediments are often breccias or megabreccias. The rapidly flooded mass of coastal weathering products tends to slide into the basin. The overlying set of sediments is usually anoxic because the flooding mass of seawater tends to be stratified and accompanied fertilization of seawater is connected with increased burial of phytoplankton. Cherts and glauconite are common components of in these sediments. As blooms of autotrophic microorganisms consume preferentially the light carbon isotope ^{12}C, the crisis-relevant carbonates are conversely enriched in ^{13}C. However, the total production of carbonates near the crisis is very low, because the reef-building organisms usually collapsed and calcareous shelly organisms, including plankton, are replaced by organisms with silica, phosphate, and/or organic-walled organisms that are accustomed in low-energy, calm water environments.

1.6 Environmental Perturbations before and after the Global Crisis

Instability of the environment near the global crisis horizons in the geological record is documented by rising both the frequency and amplitudes in geochemical, and also geophysical perturbations. There is no reason whatsoever why we would not believe that it is a direct reflection of strongly oscillating climatic conditions, where cold and warm episodes rapidly fluctuate on large areas of the Earth’s surface. Considering the energetic requirements of the modern life, where the main power is the energy of the Sun, there are good reasons to suggest that Phanerozoic biotic crises must be preferentially linked with the global climatic changes. According to geological and paleontological dating of the main crisis-related oscillations, many of them can hardly be explained by simple accumulation of the effects of changes in the eccentricity of the Earth’s orbit, the tilt of its axis and the precession of the equinoxes. The cycling at about 100 thousands of years, which is recorded in sediments before the late Devonian crisis or in pelagic deposits on the floor of modern (Cenozoic) oceans, especially needs other explanation than the above mentioned Milankovitch parameters of insolation. One plausible explanation is accumulated dust in the stratosphere. This theory is based on the tilt of the Earth’s orbit and its periodic contact with different parts of the solar zodiacal ring. Similarly, a contact with hypothetical, extra-solar stardust veils has been suggested as a possible reason for rapid decreases in insolation.

1.7 Rare Events or True Catastrophes

A special chapter of the global crises is connected with so-called rare events or real catastrophes. These catastrophes (bolide impacts or huge volcanic eruptions) may contribute to biotic crises, but need not necessarily do so, since their temporal distribution displays little, if any, correlation with the timing of past global crises. Periodicity of these volcanic and bolide catastrophic events is slightly documented, and used, to be only hypothesized. It seems that they have for systematics of the major global crises of the past even less importance than orogenic and geotectonic events, which represents the significant endogenic factors on the Earth. Of course, if such catastrophes largely deteriorated the global environment in critical times (as was a reality after the late Devonian Kellwasser crisis, in Early-Middle Famennian, or during the Cretaceous–Tertiary crisis), it had to imply some significant deepening of the crisis and/or its aftermath. The effects of a huge collisions with bolides with similar or coupled extraordinary large volcanic eruptions are compared with a scenario of so-called nuclear winter when the expulsion of the dust into the stratosphere caused a freezing on Earth's surface as well as a consequent collapse of the light-dependent food chains both on land and in the sea. However, the absence of well-structured, gradual beginning of the crisis may serve as a good criterion for separation of the usual past global crises from these abruptly coming catastrophes. Although a big world catastrophe may imply an overkill of many organisms, the organic life can cope with the catastrophic situations much better than with complicated intrinsic problems of the global crises. It is because of the fact that organic communities meet more than not the regional wild fires, volcanic effusions, catastrophic flooding, cool periods, tsunami, and other regional destruction events. Some of them have special strategies how to survive bad climatic years (to burrow in soft rocks, to shelter in rock cavities, producing resistant cysts). Scarce organisms directly calculate on catastrophes since they are part of their long-term life, (for example, some plants in semi-arid environments cannot seed without a regional fire) and some biotic systems do the same, because the rejuvenation of their succession stages helps to their vitality. It is required by their adaptation to quasi-periodical dynamics in ecosystems.

1.8 Strong Climatic Control and Dominant Role of the Complex System Behavior

The climatic change represents a really dominant control on evolution of biocrises, because the connection with glacieustatic change of the sea level has been documented at many of the major crises. Usually, an extreme freezing was followed by an extreme melting of polar ice for no reason whatsoever. Another reason to believe this climatic control is the analysis of energy flows in the biosphere, where the inputs from energy of the Sun are incomparably higher than all other primary resources. However, there are many transformers of this energy (mostly paleogeographical, hydrospheric–atmospheric parameters, and also land coverage by vegetation). These transformers produce complex network of feedbacks, which regularly becomes unstable in times of the coming crises. Possible connection with fluctuating, proper sun's radiation is also promising subject of many present discussions. The connection between organisms and their proximal environment in hydrosphere and atmosphere is also very significant for the biocrises. Many people have understood the passive reaction of the life to be a mirror of the environmental change and that is not true at all. For one thing it not true because the organisms largely produce useful as well as detrimental agents (such as oxygen, humus, heat, and/or organic poisons) and for another thing it is not true because the organisms have to evolve in some canalized ways, where new modifications are based on quality of their precursors, and many theoretical directions of evolutions are practically impossible. Therefore, we can hardly neglect the intrinsic factors in evolution of life. Many of partial links and feedbacks remain underestimated. It is no doubt, that all effective variables affect the background setting of emerging global crises to modify the chance for their triggering by little, partial mechanisms. This departs from the usual theorizing about the biocrises from the 1960s to 1980s, where a uniform view prevailed (i.e. where processes remain constant over vast stretches of time). The theories about the simple dependence of global biocrises on bolides, volcanoes or other types of the exclusive control appear to be at least doubtful in present times.

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Biographical Sketch

Jindrich Hladil is engaged with basic research within the framework of the Academy of Sciences in Praha and is teaching as an associated professor at the Masaryk University in Brno. He was born in 1953 and consequently had been living and educated in Brno in Moravia for many years until he moved to Praha. He get through the entire local stairs of academic degrees in geology, paleontology and earth sciences - M. Sc. 1976, R. N. Dr. 1978, Ph. D. 1986 and D. Sc. 2000. His native language is Czech. After short assistant contracts on universities and in companies, a substantial part of life was connected with the Czech Geological Survey, i.e. with drilling survey, mapping of Czech and foreign terrains. Positions of chief stratigrapher and later also head of division can exemplify other relevant activities. Research experience is extremely diversified, being spread from subjects relevant to sedimentology, geochemistry, geophysics, carbonate petrology, stratigraphy, paleobasin analysis in orogens, deformation, and tectonics, but also paleontology, global crises of biota, or entire environmental systems. His special fad is the investigation of coral reefs, especially the tabulate and scleractinian corals. A major part from 200 published papers and communications deals with the Devonian, in both the theoretical, and the application levels.