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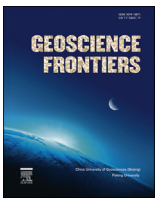

Focus Paper

Episodic events in long-term geological processes: A new classification and its applications

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ABSTRACT

Long-term geological processes are usually described with curves reflecting continuous changes in the characteristic parameters through the geological history, and such curves can be employed directly for recognition of episodic (relatively long-term) events linked to these changes. The episodic events can be classified into several categories according to their scale (ordinary and anomalous events), "shape" (positive, negative, and neutral events), and relation to long-term trend change (successive, interruptive, facilitative, stabilizing, transformative, increasing, and decreasing). Many types of these events can be defined depending on the combination of the above-mentioned patterns. Of course, spatial rank, duration, and origin can be also considered in description of these events. The proposed classification can be applied to events in some real long-term geological processes, which include global sea-level changes, biodiversity dynamics, lithospheric plate number changes, and palaeoclimate changes. Several case examples prove the usefulness of the classification. It is established that the Early Valanginian (Early Cretaceous) eustatic lowstand (the lowest position of the sea level in the entire Cretaceous) was negative, but ordinary and only interruptive event. In the other case, it becomes clear that the only end-Ordovician and the Permian/Triassic mass extinctions transformed the trends of the biodiversity dynamics (from increase to decrease and from decrease to increase respectively), and the only Cretaceous/Paleogene mass extinction was really anomalous event on the Phanerozoic biodiversity curve. The new palaeontological data are employed to reconstruct the diversity dynamics of brachiopods in Germany (without the Alps) and the Swiss Jura Mountains. The further interpretation of the both diversity curves implies that the Early Toarcian mass extinction affected the regional brachiopod faunas strongly, but this event was only decreasing (biotic radiation continued after it, although "restarted" from the lower point) similarly to the end-Triassic and Cretaceous/Paleogene mass extinctions. The number of lithospheric plates decreased in the Early Cretaceous; however, the previous trend to increase in this number re-established after the noted event. The Oi-1 glaciation in the very beginning of the Oligocene was anomalous event, but it only stabilized the earlier trend of temperature decline and did not transform it. Further development of the comprehensive classification of geological events is necessary. For instance, it has become clear that the Silurian environmental perturbations and the Cretaceous oceanic anoxic events should be classified as discrete events that differ essentially from episodic events, the latter of which are relevant to continuous changes in geological processes.

1. Introduction

The modern development of geosciences has been marked by the increased attention of researchers to the development/improvement of classifications of various geological phenomena. For instance, Miall (2016) distinguished four classes of unconformities and Carroll (2017) introduced recently an additional type of unconformities; Blair and McPherson (1999, 2009), Blott and Pye (2012), Farrell et al. (2012), Terry and Goff (2014), Lokier and Al Junaibi (2016), and Bruno and Ruban (2017) contributed to the improvement of sedimentary nomenclatures; Van Daele et al. (2017) classified turbidites; Festa et al. (2016) distinguished many types of olistostromes; Peacock et al. (2016, 2017a,b) normalized the fault nomenclature; Merle (2011) classified continental rifts;

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and Dill (2010) proposed a new scheme for classification of mineral deposits. All these research developments have been fueled by the high demand for systematization of the geological information and interpretations that have accumulated during two past decades, when more attention has been paid to original research based on data collection than to conceptual treatment of multiple particular evidence. Such a situation appears to be very favorable for the further development of new geological classifications.

The geological history can be described in two modes, namely via processes and events. In the first case, attention is paid to the continuous changes. In the second case, discrete changes are considered. However, these two modes of description are not mutually excluding because each process can be understood as a series of events. It should be noted that some events match trends and even constitute them directly, whereas the other events mark significant deviations from these trends or interruptions of the latter. Evidently, geological events deserve to be classified. The fundamental reasons for doing this are the urgency of accurate description of geological events, the necessity of clear distinction between ordinary and catastrophic events (cf. Gutak and Ruban, 2013), and the importance of genetic interpretations of events. The practical reasons include the rise of the event stratigraphy (e.g., Walliser, 1986, 1995, 1996; Wiese et al., 2004; Fan et al., 2009; Moros et al., 2017), the necessity of highly-complex interpretations of biodiversity curves for palaeobiological developments (Aberhan and Kiessling, 2012; Aberhan et al., 2012; Ruban, 2015a) and eustatic curves for discussions of cyclicity regularities (Ruban, 2015b; Plyusnina et al., 2016), and finally, the high value of event recognition for geoheritage and geotourism assessments (Bruno et al., 2014; Sallam and Ruban, 2017).

More than a decade ago, Ruban (2006) attempted to systematize the knowledge of geological events, but his very tentative ideas (published in Russian and in a very local edition) need justification and testing. The main objectives of the present paper are to propose the new classification of episodic events in long-term geological processes and to demonstrate its application to different phenomena, including biodiversity dynamics, global sea-level changes, etc. It should be stressed that the purpose of this classification is provision of template for easy distinction of episodic events on the available curves reflecting the dynamics of various long-term geological processes. Moreover, the present paper aims to show that the circle of geological events is very broad, and there are many other events in addition to such well-known events as mass extinctions and oceanic anoxic events.

2. Classification of episodic events

2.1. Conceptual remarks

Geological events are essentially changes of the geological environment or its particular constituents. On the long-term scale, each geological process can be described as a series of continuous changes of any characteristic parameter. For instance, eustasy is a permanent change of the global sea level measured in meters relatively to its present position; in this case, events are global sea-level rises and falls, cycles of which repeat permanently. Of course, very different changes can be distinguished as events. The latter can be (almost) immediate and, thus, look like “points” on the curve describing any geological process. However, detecting such events is complex task, successful solution of which depends on the resolution of the available data and the methodological errors linked to the curve reconstruction. More often, geologists deal with the events that lasted reasonable time, i.e., which may be recognized on a regular basis on the more or less long-term scale. These events correspond to episodes of the geological time, and, thus, these can be called *episodic events*. However, such a simple definition is not enough. Sea-level rises and falls, changes in biodiversity, and other events occurred permanently in the Earth’s history. In contrast, the well-known Silurian environmental perturbations (Aldridge et al., 1993; Jeppson et al., 1995; Jeppson and Aldridge, 2000; Calner, 2005; Johnson, 2006; Lehnert et al., 2010; Spiridonov, 2017) and the Cretaceous oceanic anoxic events (Schlanger and Jenkyns, 1976; Erba, 2004; Takashima et al., 2006; Faucher et al., 2017; Li et al., 2017) were individual events in the Earth’s history. This is why it is sensible to make a distinction between continuous and discrete changes and the relevant events. Moreover, many discrete changes were highly-complex in nature, and they cannot be attributed to any single geological process. In fact, the oceanic anoxic events were associated with striking perturbations in carbon cycle, geochemical anomalies, palaeobioproductivity changes, fossil diversity declines, etc. Provisionally, it is suggested to assign to the episodic events only those events that were relevant to the continuous changes linked to any single process. The OAEs are discrete events, i.e., they are not considered as episodic events *sensu stricto*.

There may be different approaches for the recognition of episodic events, and the choice of the proper approach is determined by the analytical needs of a particular study. If the given geological process leads to apparently chaotic (e.g., non-cyclic) changes, the episodic events can be related to each principal change, e.g., increases, decreases, accelerations, etc. of any parameter (Fig. 1A). If the process is more or less cyclic, episodic events correspond to the half cycles (Fig. 1B). Finally, in the case of processes characterized by multiple minor changes superimposed by a few strong changes, the latter entirely can be understood as episodic events (Fig. 1C).

Episodic events can be analyzed with two approaches. The first approach is the simple analysis of the curves describing geological processes. In this case, the sequence of events is established, and each of these events has to be described “as is”. For instance, the event 1 on Fig. 1A can be defined as rise, the event 2 is slight fall, and the event 3 is accelerated fall. Of course, changes between these episodes can be also treated as events depending on the research needs. The second approach is more advanced, and it is suitable when a long-term geological process is studied. In this case, it is necessary to analyze episodic events with the reference to trends (tendencies). The changes relevant to some events are the only expressions of the long-term trend, but the other changes may mark changes of the trend (e.g., from long-term increase to long-term decrease). These elementary considerations form the basis for further distinction of numerous types of the episodic events.

2.2. Types of events

Several categories of episodic events can be distinguished with regard to their scale, “shape”, and relation to trend change (consideration of some other parameters is also possible – see below). According to their scale, all events can be either ordinary or anomalous (Fig. 2). The former are the events that constitute significant part of the trend, and the relevant changes do not mark serious deviations from this trend. In contrast, the anomalous events are serious deviations from the trend.

“Shape” means the appearance of the event on the analyzed curve describing changes in the characteristic parameter of the given geological process. In this case, episodic events can be positive, negative, and neutral. Positive events mark changes that lead to the higher value/position of the parameter. A typical example is the event 2 on Fig. 1B. In contrast, negative events mark changes

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