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The Italian geo-palaeontological record of major turnovers in the history of life

Massimo Bernardi & Giorgio Carnevale

M. Bernardi, MUSE - Museo delle Scienze, Corso del Lavoro e della Scienza 3, I-38122 Trento, Italy; School of Earth Sciences, University of Bristol, Bristol BS8 1RJ, UK; massimo.bernardi@muse.it
G. Carnevale, Dipartimento di Scienze della Terra, Università degli Studi di Torino, Via Valperga Caluso 53, I-10125 Torino, Italy; giorgio.carnevale@unito.it

Why has not anyone seen that fossils alone gave birth to a theory about the formation of the Earth, that without them, no one would have ever dreamed that there were successive epochs in the formation of the globe?

George Cuvier, 1825

Life as we know it today is the result of more than four billion years of evolution. Hundreds of papers have attempted to identify the main drivers of this long story of "descent with modification" and the relative importance of biotic factors, famously described by the Red Queen model (Van Valen, 1973) or abiotic factors, as in the Court Jester model (Barnosky, 2001) are still matters of controversy (e.g., Benton, 2009). However, nowadays no-one questions the profound impact that major, rapid evolutionary turnovers had on the history of life. These are geologically rapid and dramatic perturbations at the global or (at least) supra-regional scale that result in a profound reshuffling of ecosystems. These events are often accompanied by severe loss of biodiversity and ecosystem disruption which can nonetheless provide substantial opportunities for diversification of life and generation of evolutionary novelty, as Erwin (2019) recalls in the opening paper of this Thematic Issue. These turnovers include the so-called "mass extinctions", i.e. the extinction of a significant proportion of the world's biota in a geologically rapid period of time (definition slightly modified from Hallam & Wignall, 1997), but also major upheavals in life, such as the "innovation" intervals of Wood & Erwin (2018), or in general the phases of substitution of older ecosystems by the rapid rise of younger ones (cf. Sepkoski, 1984; Jablonski, 1986), which might follow or not a mass extinction event. Defined this way, "major evolutionary turnovers" represent neat breaks in the history of life, neither necessarily destructive nor constructive by definition, and are well described by the expression "life revolutions", which recalls the title of one of the milestones in the study of Phanerozoic extinctions "Revolutions in the history of life" (Newell, 1967), but even more properly the concept of "Révolutions" introduced by Georges Cuvier in his remarkable "Discours sur les révolutions" (Cuvier, 1826).

Although several forcing agents (concurrent or alternative, depending on the school of thought) might be involved in bolstering these major turnovers, including biological processes like competition and immigration (e.g., Van Valen, 1973; Alroy, 1998), tectonically driven changes in biogeographic barriers (e.g., Vrba, 1993), and random processes of dispersal, extinction, and speciation (e.g., Hubbell, 2001), climatic and large environmental changes (e.g., Vrba, 1985) are by far the most investigated, and generally regarded as key evolutionary driving forces from a deep time perspective. In this context, the "major turnovers" discussed in this Thematic Issue are more properly defined as "Environmental perturbations and biotic responses in the history of Life", as the title of this Issue states.

In selecting the approach and the topics for this Issue, we decided to focus on the contribution of the Italian geo-palaeontological record (and geoscientists) to the scientific discussion about the major turnovers of life in the Phanerozoic. In his highly influential "Principles of Geology", Charles Lyell (1830) wrote that the Italians preceded the Naturalists of other European countries in their investigations of the ancient history of Earth thanks to the spectacularly diverse outcrops and landscapes that characterise the Italian territory. This is also true for the critical intervals of deep time characterised by environmental perturbations, which, in many cases are exquisitely documented in the Italian geological record.

Many Italian stratigraphic successions have since became references for the Tethyan realm (thereby including the Mediterranean), and some had a key role in the development of new methods and theories.

For example, the Upper Permian and Lower Triassic successions of the Dolomites discussed in this Issue by Posenato (2019) have been extensively investigated since the XIX century for the definition of the Permian/Triassic boundary and, subsequently, for the interpretation of the environmental and biotic events related to the "end-Permian mass extinction" and the subsequent Triassic recovery.

The remarkable climatic perturbation that characterised the "Carnian Pluvial Episode" and its relevant biotic consequences (rise of calcareous nannoplankton, scleractinian corals and dinosaurs, among the others) have been defined in great detail thanks to the sections in the

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Dolomites, Raibl area and Lagonegro Basin, as Preto et al. (2019) document herein.

The marker beds of the first (early Aptian) and second (latest Cenomanian) Cretaceous "Oceanic Anoxic Events" (OAE1 and OAE2), the so-called Livello Selli and Livello Bonarelli, were first described in the Umbria-Marche basin, as discussed in this Issue by Erba et al. (2019), who extend their account also to sections in the Alps, Apennines, Sicily and Sardinia, where these and the early Toarcian and late Valanginian (Weissert) events are well documented.

Possibly the most popular Italian localities for geologists and palaeontologists worldwide are those in the Gubbio area, where the expanded succession of the Scaglia Formation was key in interpreting the events related to the "K/Pg transition" since the 1930s and then most famously by Luis and Walter Alvarez who first hypothesised the extra-terrestrial impact hypothesis for the end-Cretaceous mass extinction, as Premoli Silva (2019) and Montanari & Coccioni (2019) recall in this Issue.

Two decades of research on the sections of the Umbria-Marche and Belluno basins have provided deep insights into the biotic, climatic and environmental impact of the "Palaeocene-Eocene Thermal Maximum", contributing to understand of the overall dynamics of hyperthermal events, as shown by Giusberti et al. (2019).

Finally, the Messinian successions and fossils described throughout Italy have been crucial since the 1950s in the development of the original concept of a latest Miocene desiccation of the Mediterranean, a dramatic palaeoenvironmental event more properly defined as the "Messinian salinity crisis", reviewed in this Issue by Carnevale et al. (2019).

While we hope that this Thematic Issue will be useful to all those interested in the macroevolutionary impact of major environmental perturbations, we also aim to highlight that the great scientific value, and the historic relevance - not rarely associated with spectacular aesthetics - of the sites discussed in the various papers suggest and make it imperative to devote more efforts to developing new projects aimed at preserving and valorising this unique heritage. The vast majority of the sites discussed in this Issue could by any standard be recognised as geosites (see e.g., Brilha, 2016), although very few are protected to date. Protection, as it is well known, is the first step for ensuring accessibility for future studies, and for developing valorisation projects that have the potential to substantially contributing to increase the awareness on the value of the Italian palaeo-geoheritage. A key tenet of geoconservation is the purely democratic idea that local people should know about, protect, and be proud of their local heritage, including such rock sections as these in Italy that have had, and continue to have, such profound influence on our understanding of the origins of Earth and life.

Initiated by the "Chicago School" with David Raup and Jack Sepkoski as the undisputed brilliant promoters, and then flourishing with the remarkable work of James Valentine, Michael Foote, David Jablonski, Douglas Erwin, John Alroy, Peter Wagner, Mike Benton and others, the so-called "palaeobiology revolution" brought numerical methods to the discovery of the major patterns of evolution and diversity trends through time (Sepkoski & Ruse, 2015). These studies have now provided us with a good large-scale view of historical dynamics and were key in bringing the debate on mass extinction to the "high table of evolution". However, they (consciously) overlooked many distinguishing features of the faunas and floras they were investigating as, for example, regional patterns (e.g., fine-scale ecology, palaeoenvironments, palaeogeography) and high-resolution stratigraphy (i.e., precise dating). The study of major turnovers is fully dependent on fieldwork-based data collected in a high-resolution chronological framework and therefore reinforces the importance of geographically restricted studies where the retrieved dynamics are only later compared with those from other sites to eventually come up with global trends. In this historical phase of development of palaeontological studies characterised by the huge increase of metanalytic studies, this Thematic Issue is therefore also a celebration and acknowledgment of the importance, still today, of painstaking field studies that constitute the basis of any major (and minor) palaeontological discovery.

Finally, we note that an Issue about major turnovers and mass extinctions published just a few years ago would have had a different taste. Nowadays, having established that the effects of the ongoing human-caused climate change and habitat destruction are increasingly comparable to the those of the major turnovers in the history of life, and notably the "big five" (Barnosky et al., 2011), we hopefully look at the fossil record as a key archive of the dynamics that can bring life to collapse but also to recover from past major perturbations. Studies like those discussed in this Issue should therefore also contribute to a better understanding of the dynamics of the Anthropocene, our own awkward live-experience of life during a major global perturbation.

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