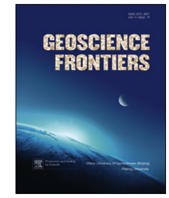
Geoscience Frontiers 5 (2014) 791–799

Contents lists available at ScienceDirect

China University of Geosciences (Beijing)

Geoscience Frontiers

journal homepage: www.elsevier.com/locate/gsf



Research paper

Flood basalt hosted palaeosols: Potential palaeoclimatic indicators of global climate change

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ARTICLE INFO

Article history:
Received 29 December 2012
Received in revised form
27 July 2013
Accepted 16 August 2013
Available online 5 September 2013

Keywords:
Continental flood basalts
Palaeosols
Weathering
Palaeoclimates
Global change

ABSTRACT

Since continental sediments (in addition to the marine geological record) offer important means of deciphering environmental changes, the sediments hosted by the successive flows of the continental flood basalt provinces of the world should be treasure houses in gathering the palaeoclimatic data. Palaeosols developed on top of basalt flows are potentially ideal for palaeoenvironmental reconstructions because it is easy to determine their protolith geochemistry and also they define a definite time interval. The present paper summarizes the nature of the basalt-hosted palaeosols formed on the flood basalts provinces from different parts of the globe having different ages.

1. Introduction

Globally distributed climate change events affect oceanic, atmospheric and terrestrial environments and Earth's history reveals that there were periods when the climate was significantly cooler and warmer than the present and these periods provide unique opportunities for understanding global climatic change. These periods also offer data in modelling and predicting the global climate response to enhanced atmospheric greenhouse gases. This is because the variations in the atmospheric carbon dioxide concentrations are now linked to extreme past climate change record (global cooling to global warming) on almost every time-scale. Climates during Earth's history have remained sensitive to a large number of forcing agents, and the Earth has certainly been responding to such variety of perturbations. Although limited, one can understand the interactions of physical and biospheric systems across multiple time and space scales. Such palaeoclimatic records further reveal the changes in the atmospheric chemistry and the response of natural systems to the climate change as these events are affecting the global oceanic, atmospheric and terrestrial environments. As revealed by the Earth's history there were periods when climate was significantly either cooler or warmer than the present, and those extremes of the past provide unique set of case studies for global change. Although different potential causes have been proposed for the global climatic change events, with a more understanding of the relative phasing of these events, both temporally and spatially, the nature of the cause-effect mechanism can be deciphered. For much of the last 150 Ma Earth has experienced significant warmth, although long-term cooling has dominated the Earth for last 60 Ma. The periods of extreme warmth should offer data in modelling and predicting the global climate response to increases in the atmospheric greenhouse gases. Thus the past warm climates should become the central theme in the future climate change modelling.

Palaeoclimatic research indicates that climate change is produced either by single forcing (e.g. volcanism), or by a combination of multiple forcing events that can bring about climate changes. While climate change during the late Cenozoic has been attributed to the major episode of mountain building (Raymo and Ruddiman, 1992; Raymo, 1994) through enhanced chemical weathering and atmospheric $p(CO_2)$ drawdown, the global cooling of the Eocene–Oligocene transition does not appear to be related to the

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Peer-review under responsibility of China University of Geosciences (Beijing)

Production and hosting by Elsevier

1674-9871/$ – see front matter
http://dx.doi.org/10.1016/j.gsf.2013.08.005

increased mountain building (Rea, 1993). The weathering of continental flood basalts also has been considered as a major sink of the atmospheric CO_2 (Louvat and Allegre, 1998; Dessert et al., 2001). The rapid extrusion of Deccan Traps (~1–4 Ma) and concomitant subaerial weathering of such basalts together with an increased flux of the weathered materials has affected contemporaneous ocean chemistry as recorded in the marine Sr and Os geochemistry (Javoy and Courtillot, 1989; Vonhof and Smit, 1997; Ravizza and Peucker-Ehrenbrink, 2003). However the contribution of basaltic rocks to continental weathering flux is presently poorly constrained since it is difficult to determine the relative contributions of the processes releasing the elements from the basaltic weathering (Kisakurek et al., 2004). Nonetheless, the nature of weathering processes can be understood by stable isotope studies of the light elements like Ca, Si, etc. (De La Rocha et al., 2000; Schmitt et al., 2003). The fundamental question is whether flood basalts (Self et al., 2005) with major out gassing could lead to significant environmental perturbations? For this more accurate modelling of dense atmospheric aerosol clouds and their effects on atmospheric dynamics and chemistry is needed and in this sense the continental flood basalt provinces of the world should provide fundamental palaeoclimatic data from the associated contemporaneous sediments hosted by the successive basaltic flows.

2. Continental flood basalts and climate

Large Igneous Provinces (Table 1) have been formed at various times in the geologic past and covered millions of square kilometres of the Earth's surface (Coffin and Eldholm, 1994). Some erupted in the sub-marine environment while other were erupted on land (Jerram and Widdowson, 2005). Those erupted on the land are referred to as continental flood basalts (e.g. Siberian Traps, Deccan Traps, Parana, Karro, etc.). Whether these eruptions changed the climate and could this then have lead to the mass extinctions is yet to be fully understood. These flood basalts are supposed to be formed in a very short period of geologic time. In most instances the greatest number of individual eruptions and the largest volumes of lava probably occurred within a million year or less (Self et al., 1997). Mafic volcaniclastic deposits exist in many flood basalt provinces, and the eruptions that formed such deposits are meaningful in terms of potential atmospheric impacts and links with mass extinctions (Ross et al., 2005).

However it is necessary to correlate flood basalt episode with the host of related global geological factors like change in sea floor spreading rates, rifting events, increased tectonism and volcanism, sea level variations (Rampino and Self, 1999) and the reorganization of the tectonic plates (Cohen and Coe, 2002) that may be associated with unusual climatic and environmental fluctuations leading to significant faunal changes. In at least three cases (Deccan, Newark and Siberian flood basalts) a correlation with major extinction events is feasible (Courtillot et al., 1996; Oslen, 1999), however, extinctions are also linked with the extraterrestrial impacts (Alvarez et al., 1980; Retallack et al., 1998).

The work by Alvarez et al. (1980) truly began the debate between the volcanically caused extinctions and bolide impact extinctions. Ever since the discovery of the Ir anomaly at Cretaceous-Tertiary boundary (Alvarez et al., 1980) there were many announcements that most other mass extinctions have been correlated to impacts as well. At one time or another, the Eocene-Oligocene, Triassic-Jurassic, Permian-Triassic, and late Devonian extinctions were all attributed to impacts (Prothero, 2004) although the evidence for these has diminished as it was more critically examined. Recently, however, the impact-volcanism debate has reopened in a new formulation (Courtillot, 1999; Wignall, 2001) as the link between mass extinctions and the flood volcanism has been strengthened by the discovery of the temporal relationship between them (Wignall, 2001 and references therein). In this view, foreshadowed by an early correlation of flood basalts and mass extinctions (Rampino and Stothers, 1988), flood basalts provide a general causal explanation for mass extinctions. An impact did coincide with the Cretaceous–Tertiary boundary (KTB) causing the extinction of one-third to one-half of the species. At KTB a large impact also occurred during a time of flood basalt eruption, producing a sudden spike of extinctions within a fauna already stressed and undergoing more gradual extinction due to the effects of Deccan volcanism (Alvarez, 2002). Keller et al. (2002) argued the extinction event was already under way as a result of Deccan volcanism and so the projected environmental and climatic effects of these mega-eruptions may be severe, and flood basalt events may have played a larger role in the mass extinctions than is commonly believed (Haggerty, 1996). If the evidence for a flood basalt-extinction link is compelling, we should accept that conclusion (Alvarez, 2002) after carefully examining the evidence. Although it is established that both impacts and volcanism occurred and correlate with some mass extinctions, many aspects remain to be tested (Courtillot, 2002). There are inherent asymmetries in comparing the evidence for impact and volcanism, as recognized by Alvarez (2002), as competing explanations for mass extinctions.

Flood basalts erupt over intervals of one to a few million years, as against instantaneous impacts, and if an extinction occurs in that interval, the flood basalt will be considered a candidate explanation for the extinction. Further absence of ejecta at mass extinction horizons also weakens the impact-extinction link claims.

While not ruling out the contributions of impacts in some mass extinctions White and Saunders (2005) do not consider the impacts as the primary cause but the outcome is strongly dependent upon the conditions of the systems at the time of impact. These conditions include whether the biosphere was already under stressed state due to the effects of flood basalts, or other terrestrial processes

Table 1
Correlations between flood basalts and mass extinctions (after Haggerty, 1996).

Continental Flood Basalt Province	K/Ar (Mys)	$^{40}Ar/^{39}Ar$ (Mys)	Extinction boundaries	(Mys)
Columbia River	17 ± 1	16.2 ± 1	Lower/Mid Miocene	14 ± 3
Ethiopian	35 ± 2	36.9 ± 0.9	Eocene/Oligocene$^{Ir,\ mt/t,\ q}$	36 ± 1
North Atlantic	62 ± 3	60.5	Late Paleocene	59 ± 1
Deccan	66 ± 2	65.5 ± 2.5	Cretaceous/Tertiary$^{Ir,\ mt/t,\ q}$	65 ± 1
Madagascar	94 ± 1	87.6 ± 0.6	Cenomanian/Turonian^{Ir}	91 ± 1
Rajmahal	110 ± 5	116 ± 1	Aptian/Albian	113 ± 3
Serra Geral	130 ± 5	132 ± 1	Jurassic/Cretaceous	137 ± 7
Antarctic	170 ± 5	176 ± 1	Bajocian/Bathonian	173 ± 3
Karoo	190 ± 5	190 ± 3	Pliensbachian	193 ± 3
Newark	200 ± 5	201 ± 1	End-Triassic$^{q,\ Ir}$	211 ± 8
Siberian	250 ± 10	250 ± 1	Permian/Triassic$^{Ir?}$	250 ± 1

Several boundaries show stratigraphic evidence of large impact: shocked quartz (q), Microtektites/tektites (mt/t), and/or iridium (Ir).