Journal of African Earth Sciences 119 (2016) 102–119

Contents lists available at ScienceDirect

Journal of African Earth Sciences

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

Palaeoclimatic conditions in the Late Triassic-Early Jurassic of southern Africa: A geochemical assessment of the Elliot Formation

Lara Sciscio, Emese M. Bordy*

Department of Geological Sciences, University of Cape Town, Cape Town, South Africa

ARTICLE INFO

Article history:
Received 20 November 2015
Received in revised form
22 March 2016
Accepted 23 March 2016
Available online 28 March 2016

Keywords:
Triassic-Jurassic boundary
Karoo continental sedimentary rocks
Palaeo-climate warming
Weathering indices
Major
Trace and rare earth elements
Southern Africa

ABSTRACT

The Triassic-Jurassic boundary marks a global faunal turnover event that is generally considered as the third largest of five major biological crises in the Phanerozoic geological record of Earth. Determining the controlling factors of this event and their relative contributions to the biotic turnover associated with it is on-going globally. The Upper Triassic and Lower Jurassic rock record of southern Africa presents a unique opportunity for better constraining how and why the biosphere was affected at this time not only because the succession is richly fossiliferous, but also because it contains important palaeoenvironmental clues. Using mainly sedimentary geochemical proxies (i.e., major, trace and rare earth elements), our study is the first quantitative assessment of the palaeoclimatic conditions during the deposition of the Elliot Formation, a continental red bed succession that straddles the Triassic-Jurassic boundary in southern Africa. Employing clay mineralogy as well as the indices of chemical alteration and compositional variability, our results confirm earlier qualitative sedimentological studies and indicate that the deposition of the Upper Triassic and Lower Jurassic Elliot Formation occurred under increasingly dry environmental conditions that inhibited chemical weathering in this southern part of Pangea. Moreover, the study questions the universal validity of those studies that suggest a sudden increase in humidity for the Lower Jurassic record and supports predictions of long-term global warming after continental flood basalt emplacement.

1. Introduction

The Triassic-Jurassic boundary (TJB) marks a global faunal turnover event in the Phanerozoic history of Earth (McGhee et al., 2013), and according to Benton (1995 but cf. Lucas and Tanner, 2007, 2015), it is associated with a mass extinction event that was especially catastrophic in the continental realm (e.g., tetrapods in general), but did not adversely affect other taxa (e.g., dinosaurs). Though the reasons for the underlying causes, nature and timing of the terrestrial faunal and floral changes are most likely complex, it is probable that some of the answers to the origin and success of dinosaurs in the post-Triassic as well as the causes and consequences of global natural disaster(s) around the TJB are to be found in the Triassic-Jurassic rock record (Pálfy and Kocsis, 2014). In southern Africa, this succession, the Stormberg Group (Fig. 1), and more specifically, the Upper Triassic-Lower Jurassic Elliot Formation, is famous for its palaeontological and geological richness and is one of a handful of locations globally where the body and trace fossil assemblages are sufficiently diverse and abundant to meaningfully assess the nature, causes and consequences of the TJB extinction on land (e.g., Knoll and Battail, 2001; Knoll, 2002a, b; Knoll, 2004, 2005, 2010; Knoll et al., 2010; Lucas and Tanner, 2015). Although, the succession contains abundant body and trace fossils, especially on the Jurassic (Hettangian – Sinemurian) side of the boundary, at regional-scale, the terrestrial biotic turn-over across the contact has only been outlined in a handful of preliminary biostratigraphic studies (Kitching and Raath, 1984; Knoll, 2004, 2005). Similarly, modern studies addressing the interactions among organisms and their environment are lagging behind for this region. Furthermore, to date, no quantitative study has been conducted on the Late Triassic - Early Jurassic in southern Africa with a view to determine the potential changing environmental parameters, particularly palaeoclimatic changes. Except for a preliminary, unpublished doctoral study by Eriksson (1984), which only focused on the sandstone composition of the Formation in the northeastern part of the main Karoo Basin, the geochemical

* Corresponding author.
E-mail addresses: l.sciscio@gmail.com (L. Sciscio), emese_bordy@yahoo.com (E.M. Bordy).

http://dx.doi.org/10.1016/j.jafrearsci.2016.03.014
1464-343X/

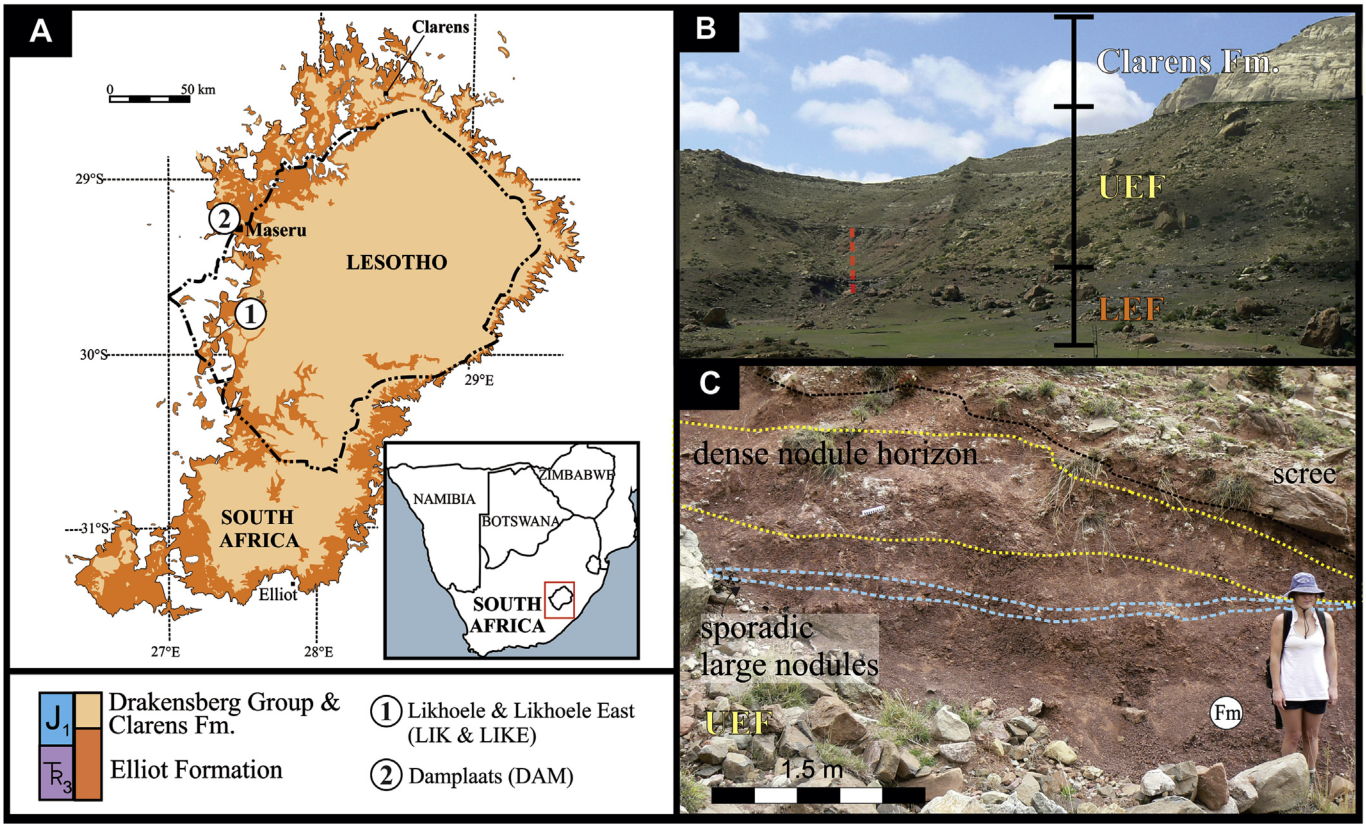

Fig. 1. (A) Study localities in the Elliot Formation from where a total of 126 samples were taken for geochemical analysis at Likhoele Mountain (sites LIK and LIKE) and at Damplaats Farm (site DAM). The former two sites, ~1.4 km apart, are in Mafeteng District (Lesotho) and some ~70 km to the south-east of the DAM site in the Free State Province (South Africa). Together with the underlying Molteno, and overlying Clarens Formations, the continental red bed succession of the Elliot Formation is part of the Upper Triassic-Lower Jurassic Stormberg Group which is conformably overlain by the Lower Jurassic Drakensberg Group (~183 ± 1 Ma; Duncan et al., 1997). The latter comprises mainly continental flood basalts and an extensive subvolcanic complex that form part of the Karoo Large Igneous Province. (B) Likhoele and Likhoele east outcrop illustrating the overlying Clarens Formation and the continental red bed succession of the Elliot Formation (LEF - lower Elliot, UEF - upper Elliot Formation). (C) Outcrop view at LIK at the second palaeosol horizon. Note the two horizons of pedogenic nodules in pedogenically altered massive mudstone. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

composition of the Upper Triassic-Lower Jurassic succession in southern Africa is unknown.

Previous studies (Haughton, 1924; Beukes, 1970; Ellenberger, 1970; Eriksson, 1984, 1985) have repeatedly stated, mainly based on qualitative sedimentological and palaeontological data, that the Upper Triassic-Lower Jurassic Stormberg Group (Fig. 1) records a climatic change from subtropical, fluvial to marsh-like conditions (i.e., Molteno Formation) to more arid systems with perennial rivers and lakes (i.e., lower Elliot Formation). The latter is thought to have then changed to a semi-arid, ephemeral fluvio-lacustrine environment (i.e., upper Elliot Formation) that were gradually replaced by a dry, desert-like, aeolian setting (i.e., Clarens Formation). In recent years, sedimentary facies analysis of the Elliot Formation in southern Africa concluded that a regionally extensive sedimentological contact between the lower and upper Elliot Formation was associated with not only climatic, but also tectonic reasons (Bordy et al., 2004a, b, c; 2010).

All in all, to-date the above mentioned evidence of palaeoclimatic changes in the Upper Triassic-Lower Jurassic of southern Africa has never been quantitatively evaluated and a detailed assessment of this is therefore long overdue. Furthermore, the local Hettangian to Pliensbachian record also needs to be investigated in the light of recent advances in understanding the global biogeochemical perturbations, especially climate warming from extensive volcanic emissions of CO_2 and other thermogenic greenhouse gases associated with the emplacement of continental flood basalts at 201.566 ± 0.031 Ma in the Central Atlantic Magmatic Province (e.g., Bond and Wignall, 2014; Mussard et al., 2014). Last but not least, the geochemical proxies of southern Africa ought to be tested against reports that suggest a sudden increase in humidity and enhanced seasonality for the northern Tethyan realm and adjacent areas during the Early Jurassic (e.g., Ruckwied et al., 2008; Ruckwied and Götz, 2009; Götz et al., 2009; Bonis et al., 2009, 2010; Ryseth, 2014; Pálfy and Kocsis, 2014). By applying a quantitative geochemical approach, this study therefore aims to characterize and refine the palaeoclimate in southern Africa for better constraining the ecosystems changes in the region in the Late Triassic - Early Jurassic. Furthermore, by synthesizing our newly gathered geochemical proxy data with existing sedimentological evidence, we fill the glaring palaeoclimatic data gap that characterizes the vast majority southern Pangea for the Late Triassic - Early Jurassic, a critical period in the evolutionary history of life on Earth.

2. Materials and methods

This geochemical assessment of the Elliot Formation is based on the premise that the chemical composition of the sediment samples is dependent on the prevailing palaeoenvironmental conditions as well as the mineralogy of the sediment, which in turn is a function of the composition of the source rocks as well as weathering, erosional, transportational, depositional and diagenetic