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Conjunctive use of spectral gamma-ray logs and clay mineralogy in defining late Jurassic–early Cretaceous palaeoclimate change (Dorset, U.K.)

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Abstract

Detrital clay mineralogy is controlled by weathered source rock, climate, transport and deposition that in turn influence the spectral gamma-ray (SGR) response of resultant sediments. Whilst a palaeoclimate signal in clay mineralogy has been established in some ancient successions, the SGR response remains contentious, largely because the data sets have yet to be collected at the same or appropriate vertical scales to allow comparison. In addition, the influence of organic matter on SGR is not always considered. Here, we present clay mineralogical, total organic carbon (TOC) and SGR analyses from the late Jurassic and early Cretaceous of the Wessex Basin, a period of previously documented palaeoclimate change. The aim of this paper is to estimate the sensitivity of SGR as palaeoclimatic tool, SGR and clay mineral data having been collected at the same sample points, making this one of the most rigorous comparison of clay mineral and SGR to date. Overall, the correlation between high thorium/potassium or thorium/uranium and kaolinite associated with a well-established palaeoclimate change shows that elevated thorium may be used as a proxy for humid palaeoweathering, as suggested by few previous studies.

Keywords: Spectral gamma ray; Clay mineralogy; Palaeoclimate; Purbeck facies; Jurassic–Cretaceous boundary; Dorset

1. Introduction

Previous attempts to relate the response of SGR data to palaeoclimates has relied on the suggestion by Rosholt (1992), Osmond and Ivanovich (1992) and Parkinson (1996) that the mobility of potassium (K) and uranium (U) and the relative concentration of thorium (Th) during weathering should result in clays with elevated Th/K and Th/U ratios. Thus Ruffell and Worden (2000) made a simple test of SGR response to a known period of palaeoclimate

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change, i.e. the Aptian interval, with some generally positive results. This work has yet to be tested against direct measurements of another associated proxy indicator of changing palaeoweathering conditions.

The Jurassic–Cretaceous boundary beds of England, Germany and France have long been known to contain clear evidence of a change from semi-arid to semi-humid climates (Allen, 1998), where plant fossils, spore-pollen, clay minerals, sedimentology and other data support the theory of arid to humid conditions. The late Jurassic and early Cretaceous semi-arid phase (early Tithonian–middle Berriasian) is followed by a wetter phase after the middle-late Berriasian (Allen, 1998). This pattern is widespread and has been recorded on the northern margin of Tethys, as well as on the southern margin and Atlantic realm, based on clay minerals (Hallam, 1984; Deconinck, 1993; Allen, 1998; Daoudi and Deconinck, 1994; Schnyder et al., 2005), as well as on spore-pollen data (Abbink et al., 2001). The climate change has also been recorded on the Russian Platform (Ruffell et al., 2002). The palaeogeographical limit of the climate change are, however, still not known. For example, using clay mineral data, the climate change seems not recorded in East Greenland (Lindgreen and Surlyk, 2000). This could constitute a northern limit of the Jurassic–Cretaceous boundary climate change. Nevertheless, Hallam et al. (1991), Weissert (1989) and Sellwood and Price (1993) all suggest that the widespread and long-lived changes in clastic vs. carbonate deposition documented in the Jurassic–Cretaceous of Europe have a palaeoclimatic origin. Carbonate and evaporite associations are thought to reflect semi-arid climates with clastic and coal associations indicating raised humidities, each of which are reflected in variations in clay mineralogy.

1.1. Outline

The aim of our work is to test the SGR theory by directly comparing our bed-by-bed clay mineral record of environmental change through the Jurassic–Cretaceous of southern England against SGR data. Additional data on the organic carbon content of the rocks are also used in order to control the possible influence of organic matter on SGR measurements.

Our work aimed to provide a half meter to meter-scale sample suite of clay mineralogy as the main proxy indicator of palaeoclimate change (Chamley, 1989; Velde, 1995), that could test whether the SGR data that we obtained showed a commensurate change to both previously published and newly analysed indicators of palaeoclimate. Palaeoclimate signals are so often masked in the rock record we ensured that the depositional and diagenetic environments were well-established before commencing our work.

1.2. Mineralogy and burial

The clay mineral content of a typical Mesozoic mudstone from the study area is controlled by the type of weathered parent material, the weathering regime, the depositional environment and later diagenetic alteration. Diagenesis constitutes a general serious problem in interpreting SGR data. Another problem is possible concentrations of U- or Th-rich heavy minerals in sandy layers. In the two studied locations, we thus have chosen to compare clay mineralogy to SGR logs, using mainly mudstones and argillaceous limestone samples, previous studies (Westhead and Mather, 1996; Allen, 1998) having suggested that the shallow-buried and homogenous mudrock successions show limited clay mineral diagenesis. In the more heterolithic successions, diagenesis is largely confined to the porous rocks, which were avoided here. The successions have been buried to no more than 1000 m. Under the geothermal conditions experienced in NW European sedimentary basins, this would lead to a burial temperature of no more than 45–50 °C. Such temperatures are too low to cause major diagenetic reactions in mudrocks (Hardy and Tucker, 1988). Rock-Eval pyrolysis data (see below) also suggest immature or slightly mature character of organic matter (T_{max} mainly below 435–440 °C) and therefore limited burial.

2. Geological setting

2.1. Wessex Basin

The studied area is located in the Dorset part of the Wessex Basin, one of the extensional sedimentary subbasins that covered much of NW Europe during the Mesozoic. At the Jurassic–Cretaceous boundary, active extension, faulting and crustal subsidence