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From detrital heritage to diagenetic transformations, the message of clay minerals contained within shales of the Palaeoproterozoic Francevillian basin (Gabon)

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ABSTRACT

Unmetamorphosed and undeformed marine siliciclastics rocks of the FB, FC and FD of the Francevillian series (Gabon) were deposited in an epicontinental basin. Clay minerals found in black shale, siltstone and sandstone are dominantly illite and chlorite except in two levels of the FB formation, which contain smectite-rich randomly ordered mixed layers. Their survival in a 2.1 Ga old sedimentary series is not related to the abundance of organic matter (total organic carbon or TOC), nor redox conditions at the time of deposition as indicated by the Fe speciation (FeHR/FeT and FePy/FeHR ratios). Rather it results from an incomplete illitization reaction that reflects potassium deficiency. The K_2O/Al_2O_3 ratio of shale, siltstone and sandstone vary along the series, and appear to conserve the signature of the original chemical composition of the rocks. K-feldspars which are present in the FC and FD formations are missing in the FB formation. Consequently, the smectite layers do not appear to be inherited from a detrital input in the basin but must be considered as representative of an intermediate stage of the illitization reaction reached during diagenesis.

1. Introduction

Clay minerals are considered to provide indications of paleoenvironmental conditions, paleoclimatic changes, and depositional setting (Bristow et al., 2009; Weaver, 1989; Chamley, 1989), and are classically related to continental weathering processes. Nevertheless, some early observations did not fit well with this statement. Weaver (1989), however, claimed that smectitic minerals are absent from clay assemblages within Precambrian rocks, although they appear abundant in late Paleozoic ones, and suggested that smectitic weathering products were converted to more stable illite during burial diagenesis. This interpretation has been recently reconsidered by Kennedy et al. (2006) who proposed that the absence of smectite in Proterozoic shale and its appearance near the Proterozoic–Cambrian boundary could be related to fundamental changes in continental weathering processes resulting from the early evolution of land plants.

Here we reconsider the origin of the smectitic clay minerals from black shale of the Francevillian basin in Gabon. Ossa Ossa et al. (2013) attributed the survival of these smectite layers to the formation of clay–organic matter complexes in moderate diagenetic conditions. These authors suggested that the presence of smectite-rich clays could be related to a smectite-rich precursor originating from chemical weathering processes following the rise of atmospheric oxygen at 2.4–2.3 Ga, (Tosca et al., 2010; Kennedy et al., 2006). We re-examined the survival of smectite layers in the light of some geochemical variation observed within these 2.1 Ga deposits. This leads us to determine their mode of origin and the implications for understanding both diagenesis and the long-term evolution of Earth surface environments.

2. Geological setting

2.1. Stratigraphy and sea level change

The Paleoproterozoic Francevillian Basin is a large foreland basin containing 35,000 km^2 of unmetamorphosed and undeformed sedimentary rocks. Strata were deposited in an epicontinental setting and outcrop in the southeastern Republic of Gabon. It consists of

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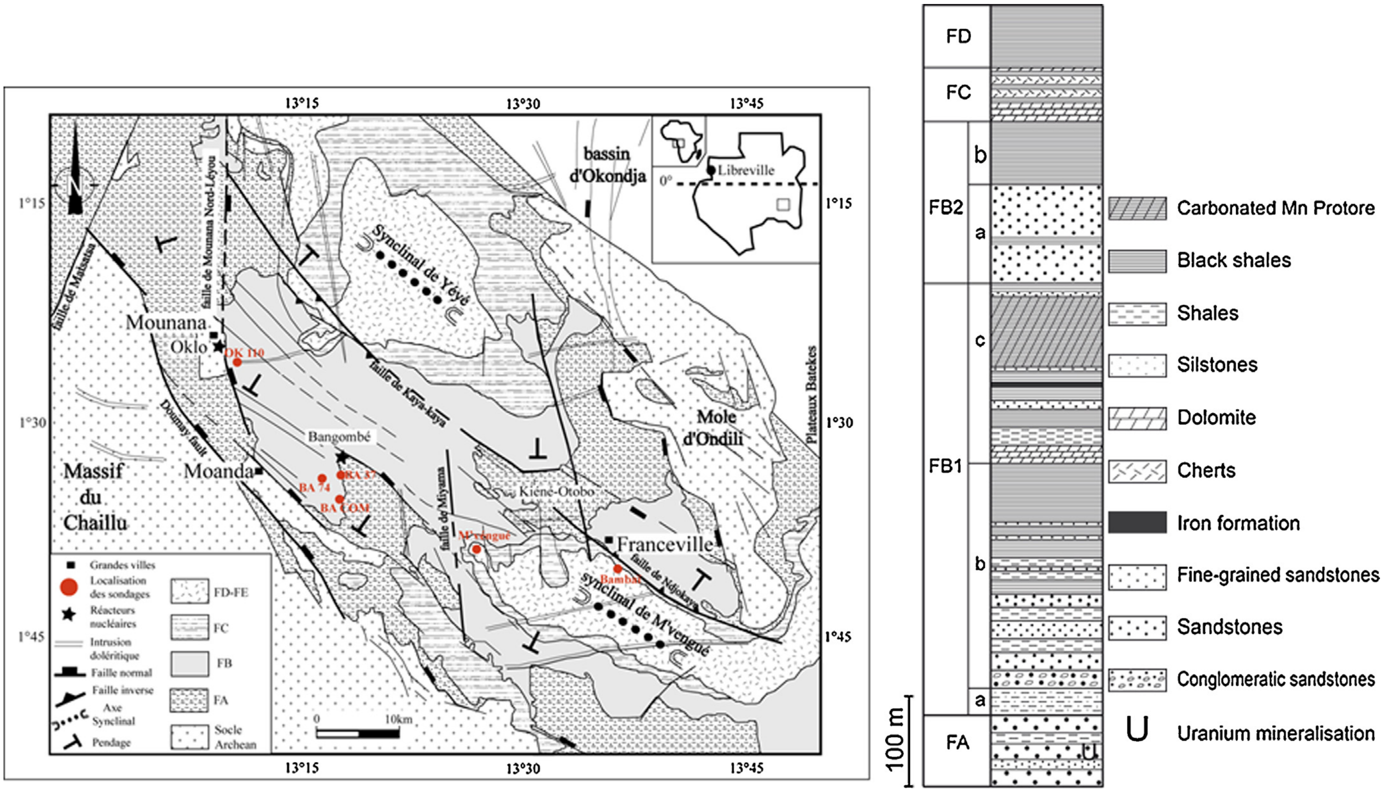

Fig. 1. Geological map of the Franceville basin (Ossa Ossa et al., 2013) showing the location of drill cores and quarry, and the lithostatigraphic column of the studied section (modified from Gauthier-Lafaye and Weber, 2003).

four sub-basins: Booué (Plateau des Abeilles), Lastourville, Okondja and Franceville (Gauthier-Lafaye and Weber, 2003). Within the Franceville sub-basin, 1000 to 2500 m of strata is subdivided into 5 lithostratigraphic units, FA to FE (Fig. 1), which rest unconformably on Archean basement rocks (Weber, 1969). The FA consists of fluviatile and deltaic sandstone deposits, and at the top of this formation are the well-known Oklo nuclear reactors (Gauthier-Lafaye et al., 1989; Gauthier-Lafaye and Weber, 1989, 2003). The transition from siliciclastic dominated fluvial-deltaic to marine sedimentation is systematically observed at the top of the FA Formation (Préat et al., 2011; Gauthier-Lafaye and Weber, 2003).

The marine-dominated FB unit rocks were deposited after a period of rifting and basin deepening. They are dominated by black shale, which are interbedded with sandstone typical of shoreface to offshore environments. Four sedimentary facies are representative of the FB formation: 1 – more or less organic-rich clayey-siltstone; 2 – organic-rich silty-sandstone; 3 – organic-rich clayey; 4 – organic-poor sandstone. Offshore facies alternate with shoreface facies. Transgression–regression episodes are marked by deposition of thin dolomite and sandstone layers, and chert (few meters thick), and dolomite form at the basin edges and shelves (Préat et al., 2011; Gauthier-Lafaye and Weber, 2003). The FB formation has been divided into two units (Fig. 2): FB1 (mainly black shale) and FB2 (a and b sub-units). The FB1 upper part (FB1c) consists of a thick black shale layer cemented by Mn-rich carbonates (Weber, 1997). They overlie a thin iron-rich formation which consists of siderite, pyrite and greenalite. The upper part of FB2 unit consists of finely laminated black shale (FB2b sub-unit) with interbedded thin siltstone layers which were deposited by waning storm surge (El Albani et al., 2010; Ossa Ossa et al., 2013). The FB2b black shale hosts large colonial organisms reported by El Albani et al. (2010). The biota has been shown to live in a shallow water oxygenated environment. The FB2b deposits sharply overly the Poubara sandstone (FB2a sub-unit), which was deposited in channels near the fair-weather wave base.

The FC formation is a massive dolomite formed of thick-banded stromatolitic-chert interbedded with thin black shale layers. All were deposited in shallow and restricted areas. Francevillian dolomite is typical of shallow-marine and supratidal-sabkha environments. The predominant facies are laminated dolomudstone, dolobindstone and medium- to coarse-grained dolomite that have been linked to an evaporitic diagenesis (Préat et al., 2011). Stromatolitic chert with a few oncolites and oolites are commonly associated with the dolomite (Bertrand-Sarfati and Potin, 1994; Amard and Bertrand-Sarfati, 1997; Thiéblemont et al., 2009) and correspond to a very shallow water depth.

The FD formation starts with silicified black shale. It is characterized by the occurrence of rhyolitic tuffs and epiclastic sandstone with interlayered shale at the top. (Gauthier-Lafaye and Weber, 2003). The depositional environments of this black shale represent shallow reducing conditions with volcanic input (Thiéblemont et al., 2009).

After a period of rifting and basin deepening, deep-water marine-dominated sediments of the FB unit began to settle down. These sediments were deposited below storm wave base. Sea level began to rise again near the bottom of the FB1c subunit, reaching maximum depth below storm wave base with deposition of a thin iron formation in the middle of the subunit. This, in turn, is overlain by black shale and a thick Mn-rich sediment package. After the deposition of the iron formation, sea level dropped through the deposition of the FB2 subunit, which consists of sandstone beds deposited in channels near the fair-weather wave base (Pambo, 2004). These are sharply overlain by finely laminated black shale interbedded with thin siltstone layers deposited by waning storm surge (FB2b). Stromatolites are found in topographic highs at the base of the FC formation (Gauthier-Lafaye and Weber, 2003), after