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Exceptional preservation of expandable clay minerals in the ca. 2.1 Ga black shales of the Francevillian basin, Gabon and its implication for atmospheric oxygen accumulation

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ABSTRACT

Clay minerals are exceptionally well preserved in marine black shale of the ca. 2.1 Ga Francevillian Group in southeastern Gabon. The FB Formation of the Francevillian Group is characterized by smectite-rich clay minerals including randomly ordered (R0-type) and ordered (R1-type) mixed layer illite/smectite (I/S). The preservation of R0-type clay minerals suggests unexpectedly slow mineral transformation and a moderate degree of diagenesis, which is unique, considering the Paleoproterozoic age of the sedimentary rocks. R0- and R1-type, smectite-rich particles occur in stratigraphic intervals with high organic carbon content and are associated with carbonaceous filamentous structures, suggesting formation of clay–organic matter complexes. Our data suggests that clay minerals may have enhanced organic matter preservation, providing the oldest example where a link between clay minerals and organic matter sequestration can be established. Our findings are consistent with the hypothesis that clay minerals enhanced organic carbon burial and aided in atmospheric oxygen accumulation through time.

1. Introduction

Many studies of the geological record of the Paleoproterozoic Era (2.5–1.6 Ga) have focused on the chemostratigraphy of sedimentary successions and interaction between the atmosphere and hydrosphere (Karhu and Holland, 1996; Holland, 2002, 2009; Bekker et al., 2003, 2004, 2006, 2008; Bartley and Kah, 2004; Master et al., 2010; Konhauser et al., 2011; Bekker and Holland, 2012). The composition of detrital and early diagenetic clay minerals associated with siliciclastic rocks and deposited during this critical period of Earth's history are as yet poorly constrained. The same applies to a possible major influence of clay minerals on the preservation of organic matter (see Kennedy et al., 2002 and Tosca et al., 2010 for different views). Most Paleoproterozoic and older sedimentary basins have undergone a significant thermal overprint under the combined effects of burial diagenesis and metamorphism, involving substantial changes in clay minerals. This is the case for the Monteville Formation in South Africa, the Mount McRae Shale and the Kombolgie Group in Australia, and the Thelon Formation in Canada (Kyser et al., 2000; Hiatt et al., 2007; Tosca et al., 2010). In contrast, the ca. 2.1 Ga Francevillian Group in Gabon (Bonhomme et al., 1982; Gauthier-Lafaye and Weber, 1989, 2003) represents an exceptional example of unmetamorphosed sedimentary strata, marked by the presence of mixed layer illite/smectite (I/S) clay minerals (Bros et al., 1992; Stille et al., 1993).

Many workers have focused on the interaction between organic matter and clay minerals in marine settings in order to better understand the role of clays and the importance of organo-mineral systems in the preservation of organic matter during sediment burial (Ransom et al., 1998a, 1998b; Bennett et al., 1999). The study of clay minerals and the processes involved in their formation is fundamental due to

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their potential impact on organic carbon burial, which is directly linked to the accumulation of oxygen in the atmosphere through time (Des Marais et al., 1992; Kennedy et al., 2002; Catling and Claire, 2005). In this study, we have investigated the clay mineral composition and the mineral transformation processes in different depositional facies from the Francevillian Group, Gabon. We have specifically used the preservation of smectite-rich clay minerals, previously unknown to exist in sedimentary rocks of this age, to illustrate: 1) the moderate degree of diagenesis likely responsible for the excellent preservation of sedimentary and geochemical features in the Francevillian Group, and 2) the involvement of clay minerals in organic matter (OM) preservation and burial, which may have had a considerable impact on atmospheric oxygen accumulation.

2. Geological background and sampling

The ca. 2.1 Ga Francevillian Group is up to 2 km thick and developed over an area of about 35000 km^2 in southeastern Gabon, referred to as the Francevillian basin (Fig. 1; Gauthier-Lafaye, 2006; Gauthier-Lafaye and Weber, 1989, 2003). It consists of the following structural sub-basins: Booué (or Plateau des Abeilles), Lastoursville, Okondja, and Franceville (Fig. 1A; Gauthier-Lafaye and Weber, 1989, 2003). The sedimentary succession (Fig. 1B) unconformably overlies an Archean granitoid-greenstone basement and consists of five sedimentary formations, FA (bottom) to FE (top), bounded by conformable surfaces (Gauthier-Lafaye and Weber, 1989, 2003).

Previous studies (Gauthier-Lafaye and Weber, 1989, 2003; Gauthier-Lafaye, 2006) have shown that the tectonic history of the Francevillian basin can be divided into three major subsidence phases of unequal duration. Intracratonic extension during the first phase led to a basin where maximum subsidence was confined to areas adjacent to NW–SE and N–S trending faults. Fluvial to fluviodeltaic, grading at the top to tidal-marine, sandstones and conglomerates of the FA Formation were deposited during that time (Pambo et al., 2006). The second phase is characterized by reactivated subsidence along NW–SE and N–S trending faults and the deposition of clastic and chemical sedimentary rocks of the FB and FC formations. The contact between the FA and FB formations is marked by a gradual development of carbonate sedimentation in an open-marine depositional setting. During this phase the Lastoursville, Franceville, and Okondja sub-basins were still separated based on pronounced difference in depositional facies in these areas. The last tectonic phase led to an expansion of the subsidence area across the entire Francevillian basin, resulting in deposition of the predominantly siliciclastic sediments of the FD and FE formations in association

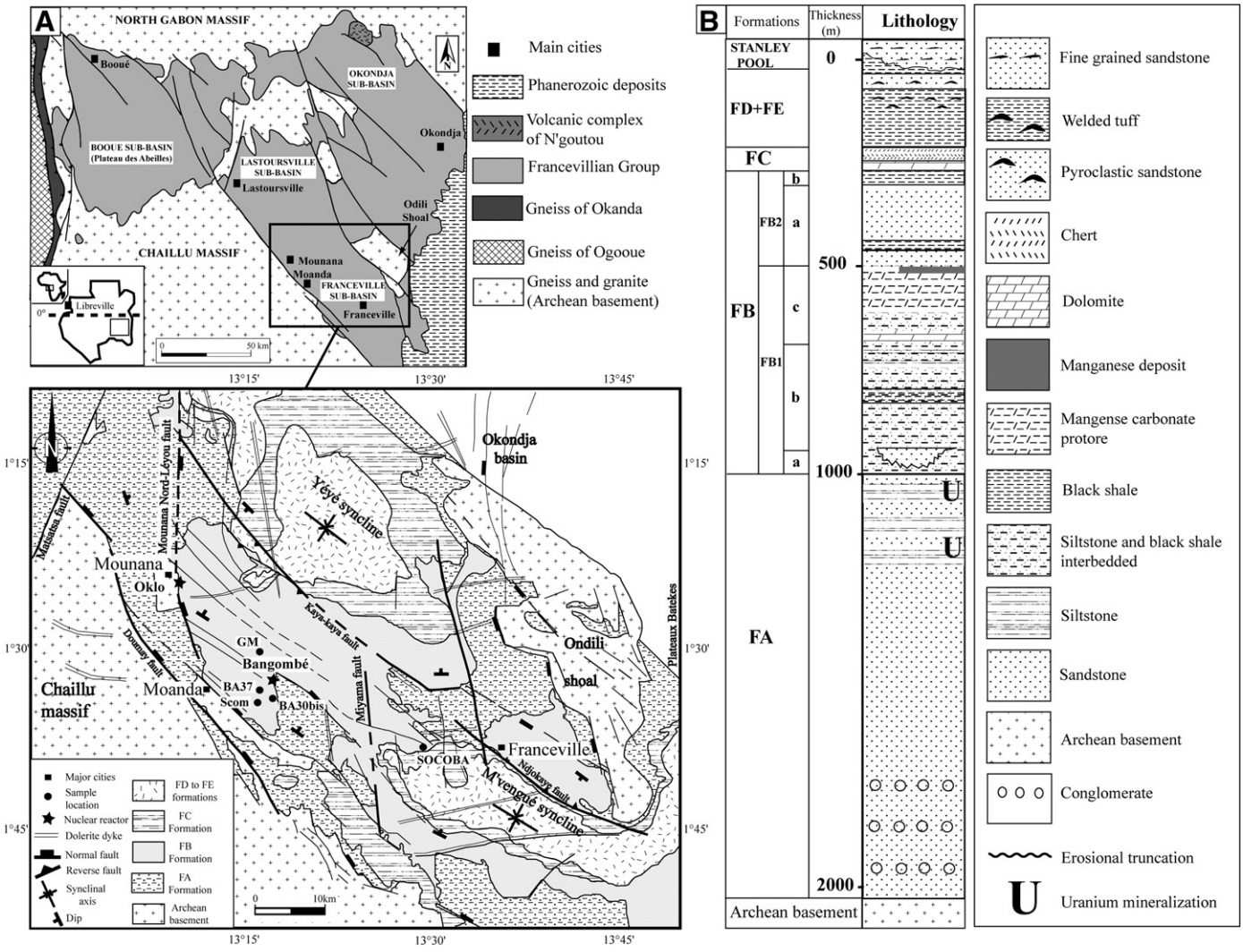

Fig. 1. Geological setting of Francevillian basin and Francevillian sub-basin with locations of samples shown. A: Geological map of the study area and locations of samples. B: Lithostratigraphic column of the Francevillian Group (modified from Gauthier-Lafaye and Weber, 2003).