ARTICLE IN PRESS
CLAY-04002; No of Pages 24
Applied Clay Science xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Applied Clay Science
journal homepage: www.elsevier.com/locate/clay

Research Paper

Clay mineral diagenesis in Cretaceous clastic reservoirs from West African passive margins (the South Gabon Basin) and its impact on regional geology and basin evolution history

Giovanni Zanoni [1], Branimir Šegvić *,[1], Andrea Moscariello

Department of Earth Sciences, University of Geneva, 1205 Geneva, Switzerland

ARTICLE INFO

Article history:
Received 25 August 2016
Received in revised form 26 September 2016
Accepted 27 September 2016
Available online xxxx

Keywords:
Mixed-layer clay minerals
Diagenesis
Berthierine-chlorite
Gabon Basin
Sandstone
South Atlantic
Passive margins

ABSTRACT

The Gabon coastal region located along the western African margin hosts several sedimentary basins that developed prior, during and after the opening of the South Atlantic Ocean. A range of diagenetic processes controlled the distribution of clay paragenesis shown to be of high importance for the understanding of the basin's burial history and geotectonic development. Materials acquired for this study stem from the siliciclastic fluvio-lacustrine-deltaic, petroleum bearing, Early Cretaceous Dentale and Gamba formations cored by two respective wells at depths of ~1500 m. Sampled materials were analysed by X-ray diffraction, automated electron microscopy, and inductively coupled plasma mass spectrometry in order to reconstruct eogenetic and mesogenetic variations directing the formation of clay assemblages in the basin. The clay contents in both cores consist of authigenic mixed-layer minerals like illite-smectite, chlorite-smectite and berthierine-chlorite, and some minor detrital illite/mica and chlorite. I-Sm and C-Sm phase chemistry implied that the original dioctahedral (montmorillonite to beidellite) and trioctahedral (saponite) smectite precursors formed out of acid volcanic feedstock during eogenesis. Different magmatic fractionation degrees, from rhyodacite to trachyandesite, reflected in the uniform REE curves of volcanic glass conform to an active geotectonic development of the Cretaceous margins of Africa. Mesogenesis led to the decrease of smectite and formation of mixed-layered phases; I-Sm composition showed maximal burial depths of sediments to be ~1000 m and ~500 m deeper than today for Gamba and Dentale sediments, respectively. Besides, temperature, a major role in the formation of mixed-layer minerals had the porosity of sediments and geochemistry of smectitic precursors. Thus, Fe-Mg smectite showed higher thermal stability and lower rates of transformations in non-expanding clays during burial compared to Al-rich smectite. Different burial histories of sediments from the two cores can be attributed to rift-related normal faulting and subsequent differential denudation.

1. Introduction

In sandstone reservoir rocks the role of clay minerals, has been extensively studied in the last few decades, owing to the fact that clays readily occlude primary porosity, influence different geophysical parameters of host sandstones and react with drilling fluids thus affecting various oil recovery practices (e.g. Ehrenberg, 1990; Baker et al., 2000; Haszeldine et al., 2000). Clays in sandstones are usually of complex and multifold origin but, in essence, they are either detrital or authigenic, formed through a series of diagenetic reactions (Worden and Morad, 2003 and references therein). The study of clay diagenesis in combination with the regional sequence stratigraphy may yield a range of information related to the burial-thermal history of the basin, its detrital composition and prevailing paleo-climatic conditions (e.g. Stonecipher et al., 1984; Al-Ramadan et al., 2005; Wei et al., 2015).

In the area of the South Gabon Basin in west-central Africa (Fig. 1a) several sandstone formations were formed prior to the widespread deposition of mid-Cretaceous salts linked to the opening of the South Atlantic (Brownfield and Charpentier, 2006). Amongst those sandstones, two prominent formations – Dentale and Gamba – were reported as two of the biggest hydrocarbon-bearing clastic onshore reservoirs in western Africa (Teisserenc and Villemin, 1989). In regard to their clay mineral content, little work has been done so far. The attention to the subject was only partially drawn in the scope of larger study reports (Aramowicz et al., 2011; Tranchet and Ruiz, 2013). Just recently, two cores from the Obangue and Tsiengui Fields (Fig. 1a; onshore South Gabon Basin) were investigated, with preliminary results presented in

* Corresponding author.
E-mail address: bsegvic@gmail.com (B. Šegvić).
[1] Presently at: Department of Geosciences, Texas Tech University, Lubbock, TX 79409, USA.

http://dx.doi.org/10.1016/j.clay.2016.09.032

Please cite this article as: Zanoni, G., et al., Clay mineral diagenesis in Cretaceous clastic reservoirs from West African passive margins (the South Gabon Basin) and its impact ..., Appl. Clay Sci. (2016), http://dx.doi.org/10.1016/j.clay.2016.09.032

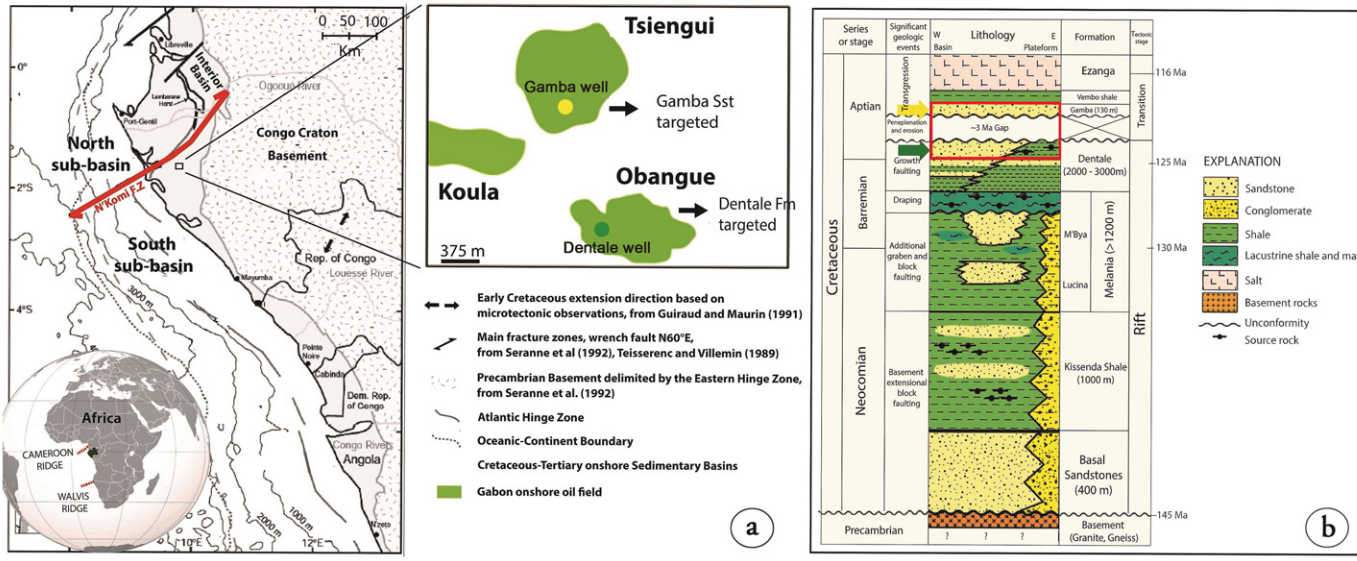

Fig. 1. The location of the studied area along the Gabon Margin (modified after Dupré et al., 2011). Inlet: map with the location of two fields and corresponding exploration wells (Aramowicz et al., 2011) (a). Generalized stratigraphic column with the sampled formations marked in red (modified after Brownfield and Charpentier, 2006) (b). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Zanoni et al. (2015). In this paper, a comprehensive set of information on the mineralogy, chemistry, and microstructure of porous clays from Dentale and Gamba sandstones is presented for the first time.

Diagenesis normally takes place in a broad range of conditions starting with the depositional interface and reaching maximally several kilometres of burial depth (~15 km, Worden and Burley, 2003). The onset of the process is defined by the point when a sedimentary particle finally comes to rest within its current cycle of transportation (Shepard and Moore, 1955). Nowadays, the most widely accepted diagenetic stages are eogenesis and mesogenesis (Choquette and Pray, 1970), where the former refers to the earliest stage of diagenesis taking place under the conditions of the depositional environment, and the latter usually refers to burial diagenesis under the conditions of increased temperature and pressure as well as a variety of formation fluid compositions. Clay minerals are especially susceptible to diagenetic changes, which in turn effectively control the evolution of clay paragenesis during the sediment's life cycle. The purpose of this study was to understand and establish a comprehensive clay mineral diagenetic sequence in the Gamba and Dentale deposits, which feature complex assemblages consisting of anisopachous and discontinuous pore-filling and pore-lining illite-smectite (I-Sm), chlorite-smectite (C-Sm), berthierine-chlorite (B-C), and berthierine with some minor illite, kaolinite, and chlorite (Zanoni, 2015). Such an approach had a goal to shed more light on a multifaceted sedimentary record of the South Gabon Basin, which is embedded in the rapid geotectonic evolution of the western African margin during late Cretaceous. From the point of view of petroleum geology, using clay diagenesis to reconstruct the effects of burial history on physical properties of sandstone reservoirs in the South Gabon Basin, may be considered advantageous in assessing reservoir properties and better defining exploitation practices (e.g. EOR techniques) for an increase of reservoir productivity (Selley and Sonnenberg, 2014). Another aspect of this research was to discuss the vast amount of pyroclastic material recovered throughout the cored succession (Zanoni, 2015). Such a highly reactive geomaterial could have had a decisive role during the initial diagenesis serving as a potential feedstock for the growth of eogenetic clay minerals such as smectite or berthierine (e.g. Boggs, 2009). Furthermore, the geochemistry of analysed pyroclastics yielded new information on an active geotectonic development of the African western margin, which – as of yet – was considered as essentially non-volcanic (Séranne and Anka, 2005).

2. Geological background

The Gabon Coastal Basin is a typical rift basin, which is one of the largest within the West African coastal basins (Ala and Selley, 1997). According to Teisserenc and Villemin (1989), the Gabon basin began to develop during the Berriasian time, having experienced three distinct evolutionary stages: (a) the rifting phase, (b) the transitional phase, and (c) the passive continental margin phase also known as drifting or post-rifting phase. The rifting stage is linked to Early Cretaceous (145 to 125 Ma) when the opened rifting realm was progressively filled by riverine, deltaic, and lacustrine depositional systems that brought up the formation of the Dentale Formation in the Late Barremian to Early Aptian times. The basin subsequently entered a peneplanation stage, which marked a demise of rifting followed by an unconformable deposition of the Gamba sands in the Middle Aptian time. Thereupon, a thick series of evaporites was precipitated (Fig. 1b). The Late Aptian witnessed a gradual separation of the African from the South American Plate which led to the crustal subsidence and the formation of nascent narrow seal lanes that were still connected to the rest of the South Atlantic Ocean (Fodor et al., 1983; Wilson, 1992). During the passive continental margin stage (drifting or post-rifting phase; 116 Ma onwards) the newly opened ocean widened, leading to rapid subsidence of the Gabon basin and its changes with a range of Tertiary post-evaporite sediments (Kingston, 1988; Anka and Séranne, 2004).

The Gabon basin is usually divided into three sub-basins: the North Gabon sub-basin, the South Gabon sub-basin, and the Interior basin (Dupré et al., 2011; Fig. 1a). A wrench fault system, referred to as the N'Komi fault zone, separates the North from the South sub-basins (Wannesson et al., 1991). The Gabon sedimentary basin has a double-layered basement architecture, floored by Precambrian crystalline rocks as well as Pre-Cretaceous sedimentary sequences. The former are granite-like acid igneous rocks and to a lesser extent gneisses, whilst the latter encompasses folded arkosic sandstones and conglomerates (Brownfield and Charpentier, 2006; Chen et al., 2013). So far, no volcanic activity has been documented in the Gabon region during Cretaceous time.

Studied sandstones represent Cretaceous Gamba and Dentale sedimentary formations that were acquired from two wells named respectively after the drilled formation. They were cored in the onshore producing fields of Obangue and Tsiengui located in the South Gabon

Please cite this article as: Zanoni, G., et al., Clay mineral diagenesis in Cretaceous clastic reservoirs from West African passive margins (the South Gabon Basin) and its impact ..., Appl. Clay Sci. (2016), http://dx.doi.org/10.1016/j.clay.2016.09.032