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Research paper

Diagenesis and origin of calcite cement in the Flemish Pass Basin sandstone reservoir (Upper Jurassic): Implications for porosity development

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ABSTRACT

The Flemish Pass Basin is a deep-water basin located offshore on the continental passive margin of the Grand Banks, eastern Newfoundland, which is currently a hydrocarbon exploration target. The current study investigates the petrographic characteristics and origin of carbonate cements in the Ti-3 Member, a primary clastic reservoir interval of the Bodhrán Formation (Upper Jurassic) in the Flemish Pass Basin.

The Ti-3 sandstones with average $Q_{86.0}F_{3.1}R_{10.9}$ contain various diagenetic minerals, including calcite, pyrite, quartz overgrowth, dolomite and siderite. Based on the volume of calcite cement, the investigated sandstones can be classified into (1) calcite-cemented intervals (>20% calcite), and (2) poorly calcite-cemented intervals (porous). Petrographic analysis shows that the dominant cement is intergranular poikilotopic (300–500 μm) calcite, which stared to form extensively at early diagenesis. The precipitation of calcite occured after feldspar leaching and was followed by corrosion of quartz grains. Intergranular calcite cement hosts all-liquid inclusions mainly in the crystal core, but rare primary two-phase (liquid and vapor) fluid inclusions in the rims ((with mean homogenization temperature (T_h) of 70.2 ± 4.9 °C and salinity estimates of 8.8 ± 1.2 eq. wt.% NaCl). The mean $\delta^{18}O$ and $\delta^{13}C$ isotopic compositions of the intergranular calcite are −8.3 ± 1.2‰, VPDB and −3.0 ± 1.3‰, VPDB, respectively; whereas, fracture-filling calcite has more depleted $\delta^{18}O$ but similar $\delta^{13}C$ values. The shale normalized rare earth element (REE_{SN}) patterns of calcite are generally parallel and exhibit slightly negative Ce anomalies and positive Eu anomalies. Fluid-inclusion gas ratios (CO_2/CH_4 and N_2/Ar) of calcite cement further confirms that diagenetic fluids originated from modified seawater. Combined evidence from petrographic, micro-thermometric and geochemical analyses suggest that (1) the intergranular calcite cement precipitated from diagenetic fluids of mixed marine and meteoric (riverine) waters in suboxic conditions; (2)the cement was sourced from the oxidation of organic matters and the dissolution of biogenic marine carbonates within sandstone beds or adjacent silty mudstones; and (3) the late phases of the intergranular and fracture-filling calcite cements were deposited from hot circulated basinal fluids.

Calcite cementation acts as a main controlling factor on the reservoir quality in the Flemish Pass reservoir sandstones. Over 75% of initial porosity was lost due to the early calcite cementation. The development of secondary porosity (mostly enlarged, moldic pores) and throats by later calcite dissolution due to maturation of organic matters (e.g., hydrocarbon and coals), was the key process in improving the reservoir quality.

1. Introduction

Calcite cement is a significant factor controlling sandstone reservoir quality through reduction of porosity and permeability. However, when it starts to form during early stages of diagenesis, it provides a framework that may resist burial compaction and retains porosity until decarbonatization at greater depth (Hesse and Abid, 1998; Liu et al., 2014). Earlier studies have documented early-formed calcite cement and examined its origin by traditional geochemical method, such as stable isotope and major and minor

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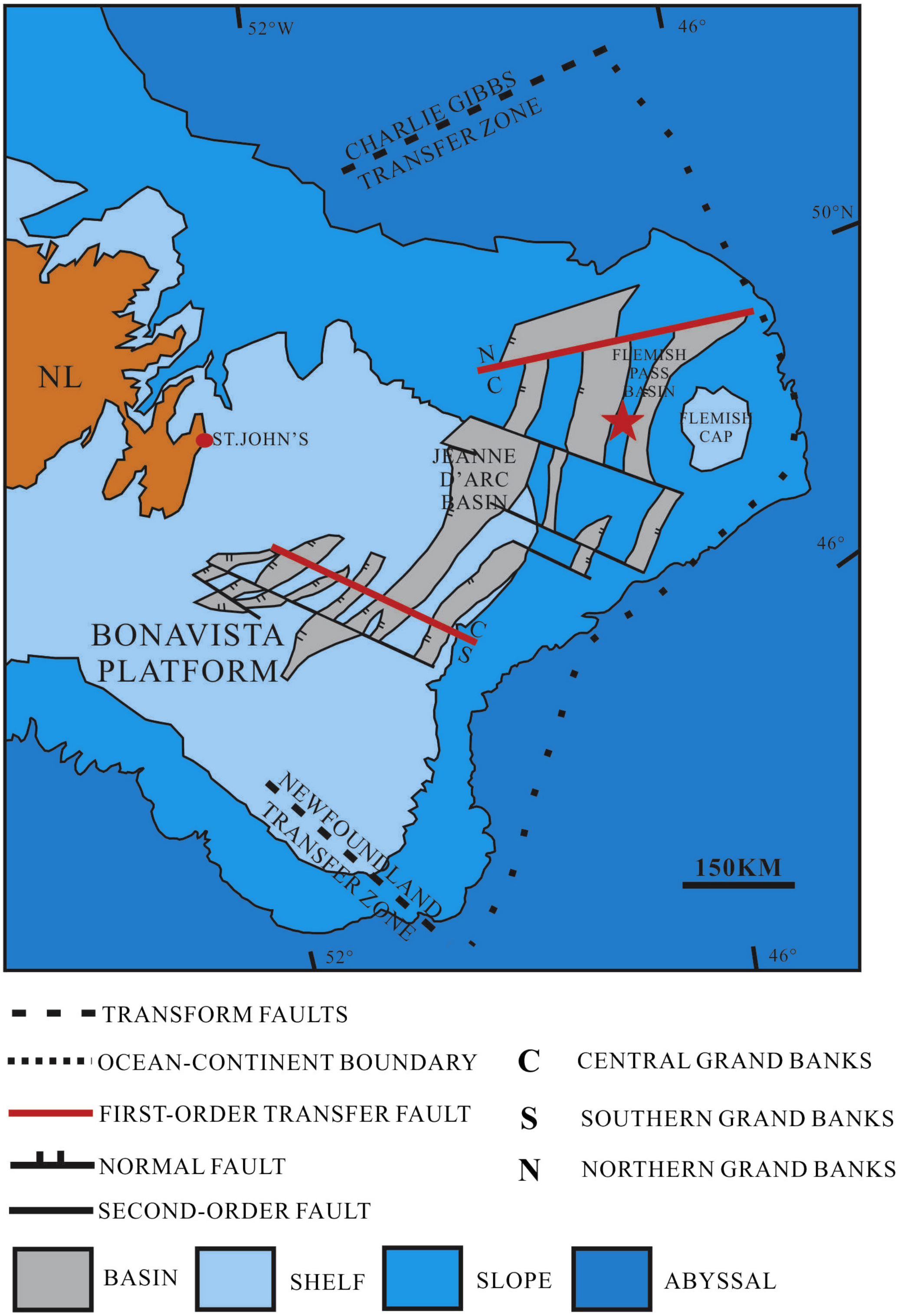

Fig. 1. Mesozoic sedimentary basins and structures of offshore Newfoundland and location of the Flemish Pass Basin (modified from Tankard and Welsink, 1989; Hesse and Abid, 1998; Normore, 2006; Lowe et al., 2011).

element analysis (e.g., Saigal and Bjørlykke, 1987; Brown et al., 1989; Hesse and Abid, 1998; Baker et al., 2000; McBride et al., 2003; Odigi and Amajor, 2010; García-García et al., 2013; Nyman et al., 2014). However, very recent studies (Azmy et al., 2011) investigated that the utilization of the rare earth element (REE) in carbonates to better understand their diagenetic environment and REEs have been found to be a useful proxy in studying the origin of diagenetic fluids in sedimentary rocks (e.g., Azmy et al., 2011; Azomani et al., 2013).

Unlike fluid-inclusion microthermometric data, fluid-inclusion