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Origin of Lower Ordovician dolomites in eastern Laurentia: Controls on porosity and implications from geochemistry

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ABSTRACT

The Catoche Formation of the St. George Group in eastern Laurentia (western Newfoundland) consists of early Ordovician (Arenigian) shallow marine platform carbonates (~160 m thick), which were extensively dolomitized during the course of their diagenetic history. The dolomites occur as both replacement and pore-filling cements and are a major control on porosity distribution in the formation. The origin and diagenetic history of the Catoche dolomites at Daniel's Harbour (western Newfoundland) were analysed in comparison to equivalent successions at Port au Choix (PaC) and Port au Port Peninsula (PaP) to assay the reservoir potential of these dolomites in eastern Laurentia. Petrographic examination identified at least three generations of dolomites in the Catoche Formation, which are: (1) an early replacement sub- to eu-hedral micritic dolomite (<4 μm–30 μm, D1), (2) eu- to sub-hedral dolomite (70 μm–1 mm) often with cloudy cores and clear rims (D2), and (3) subhedral to anhedral saddle dolomite cement (200 μm–3 mm, D3). The micritic dolomite (D1) exhibits a dull cathodoluminescence (CL) under cathodoluminoscope, whereas dolomite D2 exhibits consistent concentric CL zonation. Some subhedral crystals of D3 appear zoned both in plane polarized light and cathodoluminoscope, otherwise D3 exhibits a dull CL. Stoichiometric dolomite occurs in all three generations with D2 as the dominant dolomite by abundance.

The low strontium (47 ± 25 ppm) content coupled with depleted $\delta^{18}O$ value of dolomitizing fluids (−10 to −11.2‰ VSMOW) and near-micritic grain size, suggests an early precipitation of dolomite D1 at low temperatures of near-surface conditions from solutions likely formed by mixing of early Ordovician sea and meteoric waters. In contrast, microthermometric measurements of primary two-phase fluid inclusions in dolomite D2 (homogenization temperatures of 102–168 °C with a salinity range of 19.8–25 eq wt% NaCl) and dolomite D3 (homogenization temperatures of 158–190 °C with a salinity range of 20.2–22.2 eq wt% NaCl), suggest that both dolomite generations were generated in mid to deep burial settings from high salinity, low temperature (<200 °C) hydrothermal fluids likely under suboxic conditions. This is consistent with the low Sr concentrations for D2 (36.4 ± 8 ppm) and D3 (38.7 ± 9 ppm), $\delta^{18}O$ values of dolomitizing fluids for D2 (+2.1 to +8.1‰ VSMOW) and D3 (+6 to +8.1‰ VSMOW), coupled with Fe contents of D2 (1684 ± 1096 ppm) and D3 (1783.7 ± 618 ppm) as well as the respective Mn (D2 = 131.2 ± 50 and D3 = 197.5 ± 55 ppm) concentrations.

ΣREE and shale normalized (REE_{SN}) values of Catoche carbonates indicate enrichment in rare earth element (REE) composition of the earliest calcite (C1) relative to those of Arenig seawater, whereas the REE_{SN} profiles of the dolomite generations mimic that of calcite C1. The Ce $(Ce/Ce^*)_{SN}$ and La $(La/La^* = Pr/Pr^*)_{SN}$ anomalies of the Catoche dolomites are consistent with precipitation in equilibrium with source fluids in slightly oxic to suboxic conditions whereas Eu $(Eu/Eu^*)_{CN}$ anomalies suggest similar source fluids for D2 and D3. Results of fluid inclusion gas analysis are consistent with petrographic features and geochemical compositions and support the exclusion of magmatic fluids during dolomitization. Visual estimates of porosity (ϕ) from thin sections indicate four porous (ϕ = 4–12) horizons. Vugs and intercrystalline pores are two types of porosity associated with the dolomites with the latter being the dominant type and associated mainly with dolomite D2.

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1. Introduction

Dolomitization of carbonates in sedimentary sequences have been the focus of many studies particularly in the last few decades. Chemical reactions between magnesium-bearing solutions and calcium carbonate sediments form dolomites via dolomitization. Several models have been put forth to explain the mechanism(s) via which dolomitization occurs, however all models must explain the source of magnesium and method(s) of pumping dolomitizing fluids through pore spaces of rocks. Dolomitization is a significant diagenetic process that influences porosity development and hence the flow of hydrocarbon in carbonate reservoirs. The occurrence of major hydrocarbon accumulations in Palaeozoic hydrothermal dolomites on the eastern Laurentian margin have recently directed studies to western Newfoundland (cf. Haywick, 1984; Lane, 1990; Cooper et al., 2001; Lavoie et al., 2005; Azmy et al., 2008, 2009; Conliffe et al., 2009; Azmy and Conliffe, 2010). Hydrothermal dolomites are formed under burial conditions from high salinity fluids at temperatures higher than the ambient temperature of the host formation (e.g., Davies and Smith, 2006). Temperature(s) of dolomitization must be at least 5 °C greater than the maximum burial temperature of the host formation for the resultant dolomites to be classified as hydrothermal in origin (e.g., Davies and Smith, 2006; Conliffe et al., 2010).

The Catoche Formation of the St. George Group in western Newfoundland consists of subtidal carbonate sediments that were affected by dolomitization during the course of its burial. The process of dolomitization in the Catoche Formation was pervasive and independent of lithology or stratigraphic position in the sequence as well as geologic structures (Knight et al., 2007, 2008; Azmy et al., 2008, 2009; Conliffe et al., 2009, 2010; Azmy and Conliffe, 2010). Hydrothermal fluids played an important role in this process and the resulting dolomites exhibit a major control on the distribution of porosity in the St. George Group carbonates (Azmy et al., 2008, 2009; Conliffe et al., 2009, 2010; Azmy and Conliffe, 2010). The porosity associated with the dolomites of the St. George Group coupled with the geological proximity of the Cow Head Group (organic-rich shales), presence of structural and stratigraphic traps, as well as reported seeps containing live oil, suggests that the St. George Group and porous equivalent Lower to Middle Ordovician carbonates at Daniels Harbour and neighbouring areas are potential reservoirs for hydrocarbons (Fowler et al., 1995; Stockmal et al., 1998; Cooper et al., 2001; Azmy and Conliffe, 2010; Knight et al., 2007, 2008).

The current study focuses on the Catoche Formation (upper St. George Group) at Daniel's Harbour on the Northern Peninsula in western Newfoundland and the main objectives are:

- To decipher and describe the origin and diagenetic history of the dolomites in the formation.
- To evaluate the reservoir characteristics of Catoche carbonates and the hydrocarbon potential of the succession.
- To correlate results from current study with other successions of the Catoche Formation across western Newfoundland to better understand the pattern of porosity distribution.

2. Geological setting

The St. George Group of western Newfoundland extends approximately 400 km from the Port au Port Peninsula in the south to Cape Norman on the Great Northern Peninsula (Fig. 1). It consists

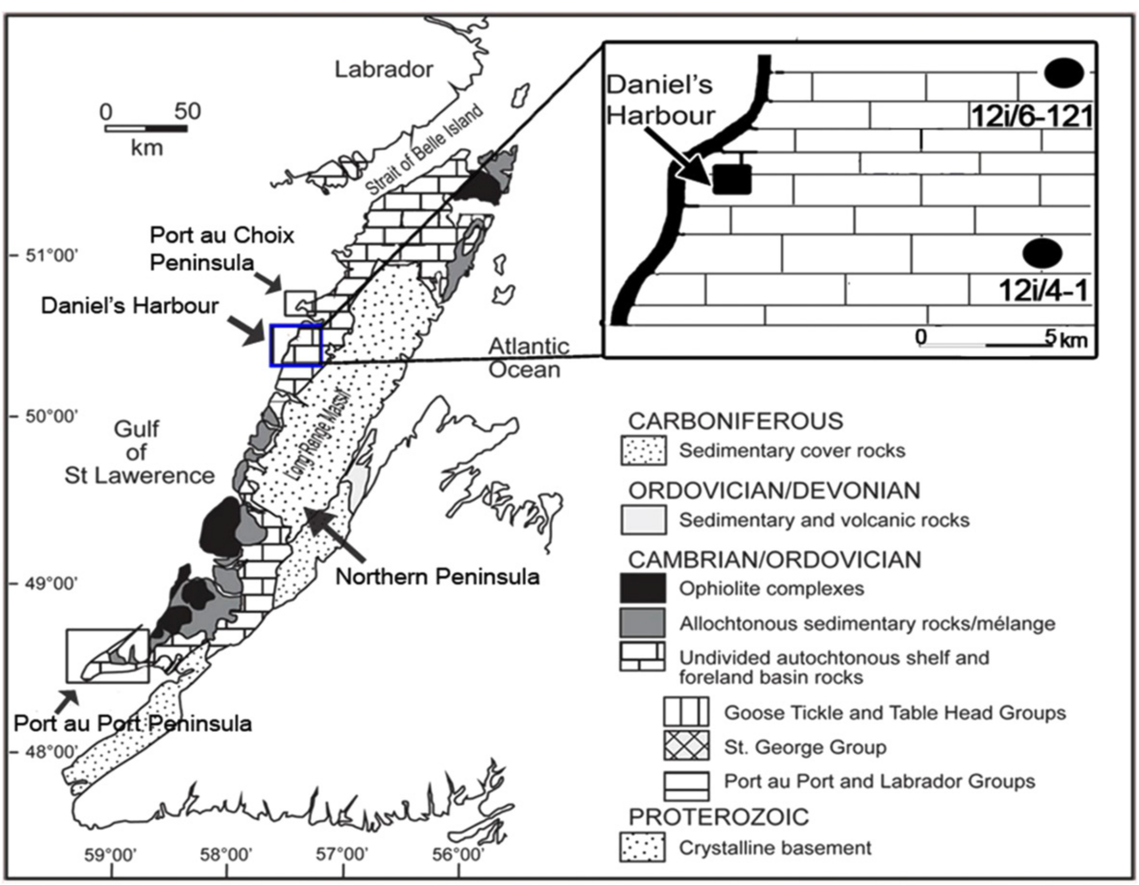

Figure 1. Map of Western Newfoundland showing approximate locations of investigated cores 12i/4-1 and 12i/6-121 near Daniels Harbour and the locations of the counterpart sections in Port au Choix and Port au Port Peninsula (modified Zhang and Barnes, 2004). See text for details.