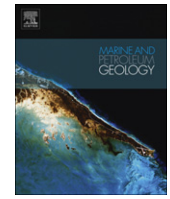
Marine and Petroleum Geology 43 (2013) 409–422

Contents lists available at SciVerse ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo



Petrologic and geochemical attributes of fracture-related dolomitization in Ordovician carbonates and their spatial distribution in southwestern Ontario, Canada

Omid Haeri-Ardakani [a,*], Ihsan Al-Aasm [a,1], Mario Coniglio [b,2]

[a] Department of Earth and Environmental Sciences, University of Windsor, 401 Sunset Ave., Windsor, Ontario, Canada N9B3P4

[b] Department of Earth and Environmental Sciences, University of Waterloo, 200 University Ave. W, Waterloo, Ontario, Canada N2L3G1

ARTICLE INFO

Article history:
Received 9 July 2012
Received in revised form
30 October 2012
Accepted 21 December 2012
Available online 2 January 2013

Keywords:
Trenton Group
Middle Ordovician
Hydrothermal dolomitization
$^{87}Sr/^{86}Sr$ ratios
Fluid inclusions
Rare earth elements
Fluid flow

ABSTRACT

Middle Ordovician Trenton Group carbonates are fractured and extensively dolomitized along the axis of the Algonquin Arch in southwestern Ontario. Hydrocarbon reservoirs formed where these dolomitized fracture zones penetrate otherwise impermeable host limestones.

Three different types of dolomite (D1, D2 and D3) are distinguished. Petrographic characteristics and $\delta^{18}O$ values indicate that D1 formed during early diagenesis from Middle Ordovician seawater and recrystallized during progressive burial, whereas fracture-related, replacive matrix dolomite (D2) formed by hydrothermal fluids (68–99 °C). Late-stage saddle dolomite (D3) and calcite (C3) cements occlude fractures. Based on petrographic, fluid inclusion, and stable isotope data, D3 dolomite and C3 calcite formed from warm (68–144 °C), saline (22–24 wt. % NaCl + $CaCl_2$) hydrothermal fluids.

The least radiogenic $^{87}Sr/^{86}Sr$ values (0.70830–0.70842) of D2 are consistent with estimated values of Devonian and Silurian seawater, whereas the slightly enriched $^{87}Sr/^{86}Sr$ ratios of D2 and D3 (0.70902–0.70918) suggest their precipitation from fluids similar in composition to oil field brines. Rare earth element (REE) results of D2, D3, and C3 indicate enrichment in REEs content of these mineral phases relative to undolomitized host rock. The similarity in the average REEs pattern of D2, D3, and C3 and the overlying Blue Mountain shale and basement rocks suggest progressive water/rock interaction.

Magnesium required for dolomite precipitation was supplied by Mg-rich seawater-derived (Silurian and/or Devonian) saline waters from dissolution of Silurian evaporites which descended along faults and fractures, to reservoir depths at the center of the basin while being heated. Hot basinal brines migrated laterally through basal sandstones and ascended into the network of faults and fractures and precipitated fracture-related dolomite. The abundance of fracture-related dolomite in the periphery of Michigan Basin in southwestern Ontario suggests that dolomitizing fluids originated from the Michigan Basin rather than Appalachian Basin.

1. Introduction

Middle Ordovician Trenton and Black River carbonates in southwestern Ontario and neighboring regions form one of the most important hydrocarbon exploration targets and oil reservoirs in Lower Palaeozoic strata of North America (e.g., Davies and Smith, 2006). Laterally equivalent carbonates in New York, Ohio, Indiana, and Wisconsin have also produced large amounts of hydrocarbons and some are host to lead-zinc-fluorite mineralization.

Hydrocarbons are produced where these carbonates have been fractured and dolomitized and laterally sealed by tight, undolomitized limestone (e.g., Smith, 2006; Yoo et al., 2000; Coniglio et al., 1994; Middleton et al., 1993; Hurley and Budros, 1990; Prouty, 1988; Taylor and Sibley, 1986). Numerous studies have focused on diagenetic aspects of these carbonates as well as hydrothermal dolomites in the Lower Palaeozoic rocks of eastern Canada and the United States (e.g., Conliffe et al., 2010; Luczaj, 2006; Smith, 2006; Yoo et al., 2000; Coniglio et al., 1994; Hurley and Budros, 1990).

Some of these studies suggested that patchy dolomitization in the vicinity of fractures formed from hydrothermal fluids that

* Corresponding author. Tel.: +1 519 2533000x2494; fax: +1 519 9737081.
E-mail addresses: omidhaeri@gmail.com (O. Haeri-Ardakani), alaasm@uwindsor.ca (I. Al-Aasm), coniglio@uwaterloo.ca (M. Coniglio).
[1] Tel.: +1 519 2533000x2494; fax: +1 519 9737081.
[2] Tel.: +1 519 8884567x32066.

0264-8172/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpetgeo.2012.12.006

flowed up through basement-rooted faults and associated fractures (Smith, 2006; Coniglio et al., 1994; Taylor and Sibley, 1986). Faults and associated fractures appear to have also acted as conduits for migration of hydrocarbons and mineralizing fluids (Carter et al., 1996; Sanford et al., 1985). Therefore, an understanding of the origin and the mechanisms of precipitation of the dolomite have important implications for hydrocarbon and lead-zinc-fluorite exploration and exploitation in the region.

The purpose of the present work is to critically review and refine the current fluid flow models to document the diagenetic processes, in particular dolomitization of Trenton carbonates, by detailed petrography, stable isotope and strontium isotope analysis, fluid inclusion microthermometry and rare earth elements (REE) geochemistry. The objectives of this work are to determine: 1) the spatial distribution of dolomite, 2) the nature of the fluid(s) responsible for dolomitization, and 3) the fluid(s) migration pathways.

2. Geologic setting

The study area is located between the Michigan and Appalachian basins. These two differentially subsiding basins – the Michigan Basin in the west and the Appalachian Basin to the southeast (Fig. 1) – were separated by the Algonquin and Findlay arches which formed a broad platform. The arches formed in the Late Precambrian and remained intermittently active throughout the Palaeozoic, controlling patterns of sedimentation (Sanford et al., 1985).

The NE-SW trending Algonquin Arch extends from the southeastern part of the Canadian Shield and terminates to the southwest near the city of Chatham. This structural high continues near Windsor, where it is called the Findlay Arch, extending southwest into Michigan and Ohio. The structural depression between the two arch sections is the Chatham Sag (Fig. 1).

The region is underlain by an essentially undisturbed Phanerozoic sedimentary succession resting unconformably on Precambrian basement rocks. The Appalachian Basin, which is dominated by siliciclastic sediments, is an elongate foreland basin that developed as a result of collisional tectonics along the eastern margin of North American continent during the Palaeozoic. The Michigan Basin is an intracratonic basin dominated by carbonates and evaporites (Armstrong and Carter, 2006). The sedimentary units thicken toward the depocenter of the Michigan Basin.

From Cambrian to Mississippian, the region was located at tropical latitudes (Van Der Voo, 1988) and intermittently covered by inland seas. Erosional and non-depositional gaps occur within the succession mainly due to regression, resulting in an incomplete stratigraphic record (Johnson et al., 1992).

Sedimentation of Palaeozoic cover in the area commenced with transgression over the Precambrian basement. The Middle Ordovician consists of the Black River and Trenton groups, which together range up to 280 m in thickness. These strata consist of fossiliferous carbonates underlying the deeper-water shales of the Blue Mountain Formation (Armstrong and Carter, 2006).

The Trenton Group includes the Cobourg, Sherman Fall (the focus of this investigation) and Kirkfield formations, in descending order (Fig. 2). These strata represent the upper part of a widespread carbonate platform developed during the Middle Ordovician over a vast area of the North American craton (Wilson and Sengupta, 1985). The Trenton Group in the subsurface of southwestern Ontario exhibits a sharp irregular contact with overlying shales of the Blue Mountain Formation.

The Sherman Fall Formation consists of a lower shaley or argillaceous member and an upper, thinner, coarser grained, bioclastic limestone. The lower member consists of interbedded limestone and calcareous shale ranging up to 60 m thick in the outcrop area (Melchin et al., 1994). In the subsurface, the Sherman Fall Formation ranges from about 16 m thick on Manitoulin Island to 43.8 m in Lake Erie, south of Essex County. The upper member consists of bioclastic and intraclastic grainstones. This unit ranges up to 10 m thick in outcrops near Lake Simcoe, and is interpreted to represent deposition in a shallow shoal environment (Brookfield and Brett, 1988).

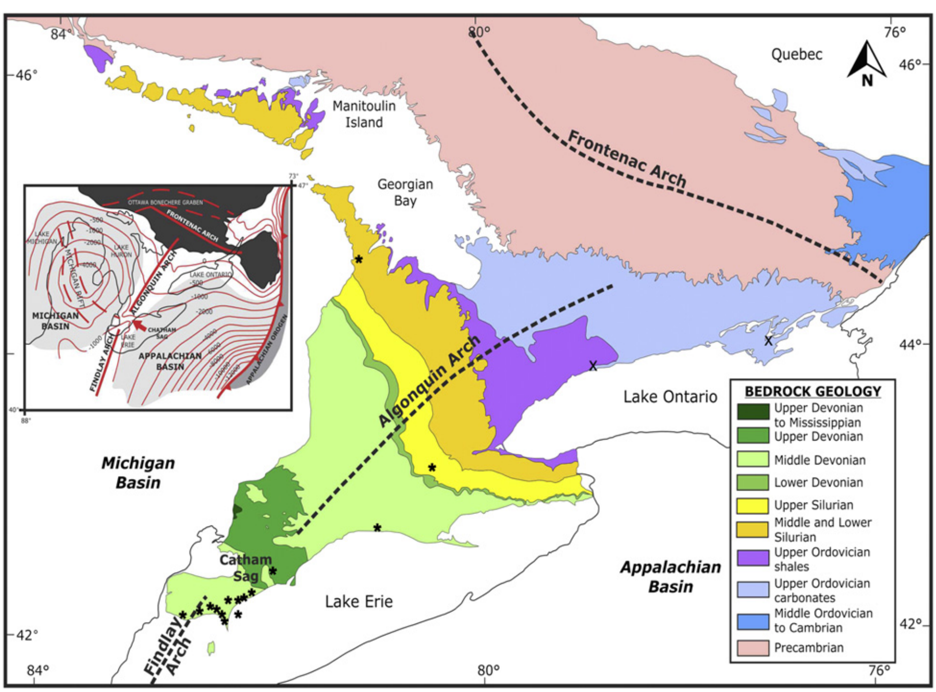


Figure 1. Generalized Palaeozoic bedrock geology map of southern Ontario (adapted from Armstrong and Carter, 2006). Inset shows generalized basement structural contours (meters above sea level datum) and location of structural arches and basins (adapted from Johnson et al., 1992). Core (*) and surface sampling locations (×) shown on the map.