The Influence of Fault-Controlled Dolomitisation on Porosity Modification in the Western Canada Sedimentary Basin

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Search and Discovery Article #11136 (2018)**
Posted October 15, 2018

*Adapted from poster presentation given at AAPG 2018 Annual Convention & Exhibition, Salt Lake City, Utah, United States, May 20-23, 2018
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Abstract

The differentially dolomitised Devonian carbonates of the Western Canada Sedimentary Basin (WCSB) have been extensively studied due to their importance as hydrocarbon reservoirs. Multiple phases of dolomitisation are known to have occurred, including so-called hydrothermal dolomitisation, along major faults within the WCSB. Middle Cambrian aged fault-controlled dolostone bodies exposed in the Rocky Mountains exhibit comparable textures to the Devonian; in particular, they are non-strata bound and highly fractured and brecciated. In outcrop, strata bound dolostone bodies are texturally more homogenous, and are found distal to faults, suggesting that dolostone texture is at least in part controlled by distance from fault. To test this hypothesis in the subsurface, variably dolomitised cored intervals of Devonian Swan Hills and Leduc Formations and Wabamun Group were described, based on their proximity to mapped platform margin faults and/or regional Precambrian shear zones. Two contrasting types of dolomitisation were identified:

1. Fabric-retentive textures were found in the Swan Hills Fm. Partial dissolution of stromatoporoids created minor mouldic porosity, but most mouldic pores and fractures were occluded by saddle dolomite cements.

2. Fabric-destructive textures were found in cores from the Swan Hills and Leduc Formations, with a higher frequency of biomouldic pores than in fabric-retentive dolostone. Vuggy porosity is common, and lined with coarsely crystalline dolomite cement. Fractures are abundant and often cross-cut stylolites, indicating formation after burial.

Initial subsurface observations appear to support the outcrop based dolomitisation model proposed, with fabric-destructive dolomite forming proximal to faults, producing abundant secondary porosity and dense fracture networks. Fabric-retentive dolomite represents a more distal expression of fault-controlled dolomitisation, with minor dissolution and porosity generation. The presence of contrasting types of dolomitisation within individual formations indicates that lithological variation may not be the only controlling factor on dolostone texture. As such, this study will provide insights into how porosity may be distributed within other fault-controlled dolostone reservoirs within the WCSB and globally.
1. INTRODUCTION

- Dolostones comprise some of the largest and most important hydrocarbon reservoirs across the globe. However, their formation mechanism remains uncertain, particularly those thought to have formed through fault-controlled hydrothermal dolomitisation (HTD).
- This project considers the basin-scale controls on fault-controlled hydrothermal dolomitisation within the Western Canada Sedimentary Basin (WCSB), a mature petroleum province in which dolomitized limestone is one of the most important reservoir types.
- The differentially dolomitised Devonian carbonates of the WCSB have been extensively studied due to their importance as hydrocarbon reservoirs, with multiple phases of HTD known to occur along faults.
- Recent research (Schultz et al., 2016) indicates induced seismic events are closely associated with Devonian reefs, suggesting that reef nucleation and later diagenesis is controlled by faults. This has implications for hydrocarbon exploration, as understanding the distribution of dolomite bodies along faults may lead to new discoveries in the WCSB and other mature basins.

2. MOTIVATIONS

- Middle Cambrian aged fault-controlled dolostone bodies exposed in the Canadian Rocky Mountains exhibit comparable textures to the Devonian, and are non-stratabound, highly fractured and brecciated (Stacey et al., 2017). In outcrop, stratabound dolostone bodies are more texturally homogenous, and are found distal to faults, suggesting that dolostone texture is partly controlled by distance from fault (Stacey et al., in prep.).
- To test this hypothesis in the subsurface, variably dolomitised core intervals of the Devonian Swan Hills and Leduc Formations and Wabamun Group were described, based on proximity to mapped platform margin faults and/or regional Precambrian shear zones.

3. AIMS & OBJECTIVES

- To determine the role of faults as fluid pathways and the impact of regional-scale structural and tectonic influences on fluid flux, and how these affect basin-scale porosity modification and distribution.
- Compare the textures of dolomite from cored intervals with those observed at outcrop in the Middle Cambrian Cathedral Formation to suggest a possible model of dolomitisation and porosity development.

4. GEOLOGICAL FRAMEWORK

Fig. 4A: Location of studied wells. Fig. 4B: Position of studied wells in relation to structural features. Data provided by the Alberta Geological Survey.

Fig. 4C: Schematic cross section as shown on Fig. 4.1A (modified from Green and Mountjoy, 2005; Atchley et al., 2006).

**Legend**
- Carbonate platform/ramp
- Basinal facies
- Oil field
- Gas field
- Inferred fault
- Well location

**Structural Features of the WCSB:** Snowbird Tectonic Zone; Precambrian shear zone that potentially influenced deposition of the Cooking Lake Platform and later Leduc Formation reefs (Ross and Stephenson, 1989). Swan Hills Platform: Platform margin trends are dictated by the occurrence of deep-seated faults that potentially extend upward into Swan Hills reefs (Corlett et al., 2018). Peace River Arch: Consists of uplifted Precambrian basement with onlapping Granite Wash immature clastics. The Wabamun Group is intersected by deep-seated faults related to this structure (Packard et al., 2001; Ma et al., 2006).
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5. LIMESTONE - PLATFORM MARGIN - DISTAL TO FAULT

6. FABRIC-DESTRUCTIVE DOLOSTONE - PLATFORM MARGIN/INTERIOR - SHEAR ZONE - PROXIMAL TO FAULT

7. FABRIC-DESTRUCTIVE DOLOSTONE - PLATFORM INTERIOR - PRA - PROXIMAL TO FAULT
8. FACIES CONTROLS ON RESERVOIR PROPERTIES

A: Swan Hills Formation - 100/04-13-069-09WS/0

B: Swan Hills Formation - 100/03-10-035-05WS/0

C: Leduc Formation - 100/02-27-052-26W4/0

D: Wabamun Group - 100/13-13-078-26W5/0

9. PARAGENESIS & POROSITY EVOLUTION

A. SWAN HILLS FORMATION

B. LEDUC FORMATION

C. WABAMUN GROUP

10. OUTCROP ANALOGUE - RESERVOIR MODEL

11. CONCLUSIONS

- Porosity modification of Middle to Upper Devonian limestones began during meteoric diagenesis, with the creation of mouludic porosity.

- Replacement dolomitisation took place during shallow burial (<1000 m) associated with Antler tectonism. Later phases formed during deep burial (>1000 m), associated with hydrocarbon migration.

- Porosity was further increased by dissolution during dolomitisation, but this was partially occluded by calcite, dolomite and quartz cements, except in examples where porosity preservation occurred due to HCs.

- Regional-scale structural and tectonic features have a recognisable impact on the type and style of dolomitisation observed. This is most likely due to contrasting fluid sources (i.e. clastic vs carbonate aquifer).

- Porosity development in the Cambrian is similar to the Devonian, suggesting that porous replacement dolostone forms distal to faults.