Controls on Hydrothermal Dolomites and Their Reservoir Properties*

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Abstract

Hydrothermal dolomites occur in Precambrian to Cenozoic strata, with many models for hydrothermal dolomite emphasizing proximity to faults. Although some hydrothermal dolomites occur adjacent to significant faults, many do not. In this presentation, hydrothermal dolomite is described in three intervals and locations – Wabamun Group (Upper Devonian) in western Canada, Swan Hills Formation (Middle Devonian) in western Canada, and the upper Pennsylvanian at Reinecke Field in west Texas. In all three areas, petrographic and stable isotope data indicate dolomitization at high temperatures after moderate to deep burial.

Porous dolomites are surrounded by impermeable Wabamun limestones creating stratigraphic traps that are scattered across the southern Peace River Arch in western Alberta. Many hydrothermal dolomites in the Wabamun follow depositional facies and early dolomitization. Some oil fields are adjacent to mappable faults, but many are not. Many of the Wabamun fields were discovered by 3D seismic data targeting anomalies away from faults.

Porous hydrothermal dolomites in and around Rosevear Field in western Alberta occur in grainstones and grain-rich stromatoporoid boundstones. Adjacent micrite-rich facies are generally not dolomitized and not porous, creating the stratigraphic traps at Rosevear Field. Hydrothermal brines apparently moved up into platform-margin grainstones and then moved long distances along the permeable platform margin and connected embayments.

At Reinecke Field in west Texas, hydrothermal dolomites occur in an upper Pennsylvanian limestone buildup. The hydrothermal dolomites created high-permeability horizontal and vertical “raceways” within the largely limestone reservoir. Those “raceways” fundamentally affected oil production during primary, secondary, and CO₂ recovery at Reinecke Field.

Hydrothermal dolomites are important hydrocarbon reservoirs in many parts of the world. They have excellent reservoir characteristic because of their large crystal sizes, vugs, and fractures. Many factors other than faults can control their distribution, including depositional facies, early
dolomite, highly saline brines in the basin, and convective flow. Careful petrography, collection of stable isotope data, and a good understanding of the basin history can help predict these types of reservoirs in the subsurface.

References Cited


Controls on hydrothermal dolomites and their reservoir properties

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Although a volumetrically minor part of the rock record, hydrothermal dolomites are important oil reservoirs & associated with many ore deposits.

Although some hydrothermal dolomites occur adjacent to faults, many do not.
Understanding the controls on hydrothermal dolomite is important for predicting their distribution.

HYDROTHERMAL DOLOMITES

- Introduction
- Wabamun, subsurface Canada
- Swan Hills – Rosevear Field, Canada
- Reinecke Field, west Texas
- Summary & Models (facies and early diagenesis are commonly critical)
Wabamun Dolomites, south Peace River Arch

- Porous reservoir dolomites are surrounded by non-porous limestone creating stratigraphic traps
- 2 generations of dolomite,
  - Early replacive
    - Dull green fluorescence
    - Petrographically early (before fracturing)
    - High $\delta^{18}$O (low temperature)
  - Late, hydrothermal replacive & pore-lining cement
    - Black & yellow fluorescence
    - Petrographically late (before and after fracturing)
    - Low $\delta^{18}$O (high temperature)
  - Most samples are a mixture
- Hydrothermal dolomite occurs with early dolomite and mud mounds
- Substantial dissolution was associated with hydrothermal dolomite causing vugs, fractures, collapse, and geopetal structures
- Some hydrothermal dolomite bodies are near faults, many are not
- Can be found using 3D seismic-
  - differential compaction sometimes created highs at top Wabamun,
  - collapse created lows at top Wabamun
  - irregular dissolution caused disrupted seismic in the middle
Dolomite occurs as isolated patches within Wabamun limestone. Some dolomites are adjacent to faults. Most are not.

Modified from Saller and Yaremko, 1994
Understanding where hydrothermal dolomite isn’t, is critical to predicting where it is.
We need to Understand Depositional Facies & Structural Setting

Certain facies are preferentially dolomitized & others remain limestone

Modified from Saller and Yaremko, 1994
Wabamun Limestones are commonly fossiliferous wackestone & packstone, & intraclastic packstone-grainstone

Modified from Saller and Yaremko, 1994
Wabamun dolomites are generally sparsely fossiliferous wackestones & mudstone.

Fractures & brecciation are common & related to dissolution during hydrothermal dolomitization.
2 generations of dolomite: most rocks are mixtures

**Early replacive**: Dull green fluorescence; Before fracturing

**Late, hydrothermal**: replacive & pore-lining cement
Black & yellow fluorescence; Before and after fracturing

Late pore lining dolomite cement (L) overgrows replacive dolomite (R). The rest of the large pore was filled by even later calcite cement (C)

Modified from Saller and Yaremko, 1994
Stable Isotope Compositions of Wabamun Limestones and Dolomite

Hitchon and Friedman, 1969, Alberta Basin Devonian waters are +3 to +7

\[ \delta^{18}O_{\text{water}} = +3\% \quad \sim 150^\circ C \]
\[ \delta^{18}O = +5\% \quad \sim 135^\circ C \]

Fluid Inclusions Wabamun Peace River Arch (Packard et al, 1989, 1992)

\[ \text{Th} = 80-150^\circ \]
\[ \text{Tf} = 23-29\% \text{ equiv NaCl} \]

Early Dolomite
\[ \delta^{13}C = 0.3\% ; \]
\[ \delta^{18}O = -3.6\% \]

Late Dolomite
\[ \delta^{13}C = 0.5\% ; \]
\[ \delta^{18}O = -7.3\% \]

Large range in \( \delta^{18}O \) with consistent \( \delta^{13}C \) suggests dolomite precipitated over a large range in temperatures or mixing of a high and low temperature end-member

Modified from Saller and Yaremko, 1994
Burrowed dolomites dominate.
- Some burrow fills are dense
- Some burrow fills have porous sucrosic dolomite
- Some of those porous burrow fills have geopetal structures suggesting dolomite crystals falling into open voids

Multiple generations of dolomite crystal fills in certain burrows

Modified from Saller and Yaremko, 1994
2 Stage Process to Create Porous Geopetal Dolomites

X2.5

- Replacive Dolomite with Intercrystalline Porosity
- Replacive Dolomite with Little Porosity
- Limestone with Dolomite Rhombs
- Porous Sucrosic Dolomite
- Open Fractures

Early Dolomitization

Late Dolomitization

Modified from Saller and Yaremko, 1994
Wabamun Dolomites have High Vertical & Horizontal Permeability

Modified from Saller and Yaremko, 1994
MODEL FOR EARLY, NEAR-SURFACE DOLOMITIZATION

MAP VIEW

CROSS SECTION

SLIGHTLY RESTRICTED (SLIGHTLY HYPERSONALINE) SEAWATER ON DEPOSITIONAL HIGHS DOLOMITIZED UNDERLYING STRATA

Modified from Saller and Yaremko, 1994
Massive dissolution & Brecciation

Winterburn Dolomite

Stage 1: Early dolomitization during shallow burial creates porous, dolomitized areas surrounded by nonporous limestone. Burial compaction preferentially fractures more lithified dolomites.

Dolomitization - dissolution - collapse zone at margins of dolomite

Stage 2: Late dolomitization and dissolution. Hot burial fluids move through permeable Winterburn dolomite into porous Wabamun dolomite. Burial fluids preferentially dissolve and/or dolomitize limestone adjacent to dolomite.

Modified from Saller and Yaremko, 1994
Hydrothermal dissolution resulted in collapse & brecciation including clasts of Banff (A) in a breccia within the Wabamun.
Wabamun dolomites have a distinct seismic signature in 3D data

1. Structural high due to differential compaction
2. Thinning of overlying Banff due to early differential compaction
3. Disrupted seismic within the Wabamun

Modified from Saller and Yaremko, 1994
Dolomite occurs as isolated patches within Wabamun limestone. Some dolomites are adjacent to faults. Most are not. Modified from Saller and Yaremko, 1994.
HYDROTHERMAL DOLOMITE

– Introduction
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– Swan Hills – Rosevear Field, Canada
– Reinecke Field, west Texas
– Summary & Models (facies and early diagenesis are commonly critical)
Porous, hydrothermal dolomites occur in grainstone facies along the margin of the shelf & Rosevear channel.
Geochemistry of Rosevear Dolomites (Kaufman et al., 1990, 1991)

- Fluid Inclusions
  - Th ~ 127-146°C
  - Tf ~ 21-24 wt% equivalent NaCl
- $\delta^{18}O$ of dolomites -6.2 to -10.3 (PDB)
- $\delta^{18}O$ values (mean=-7.5‰, PDB)
- Saline waters $\delta^{18}O$ of 3-7‰ (Hitchon and Friedman, 1969)
- $T = 135^0C$ for $\delta^{18}O$ dolomite=-7.5‰, PDB and water $\delta^{18}O= 5$‰ (SMOW)
- All data are consistent with dolomitization involving waters that precipitated halite at high temperatures

From Hitchon and Friedman, 1969
Facies - Selective Porosity, Permeability, Mineralogy

- Tidal Flat Lam. Mudst
- Lagoon Amphipora W-P
- Shoal - Oopel Grainstone
- Shoal - Grainstone w/ Amphipora
- Reef - Boundstone
- Forereef – Strom. Packst
- Slope – Strom Wackest
- Basin – Cherty Mudst

From: Saller et al., 2001
Shoal Grainstone
Basinal Chert Mdst
Tidal Flat/ Lagoon
Forereef
SWAN HILLS PLATFORM
Shoal Grainstone
Basinal Chert Mdst
Forereef
From: Saller et al., 2001
Hydrothermal Brines Moved Through & Dolomitized Shelf Margin & Embayment Margin Grainstones

Rosevear Field is ~300 BCF of Stratigraphically Trapped Gas

From: Saller et al., 2001
HYDROTHERMAL DOLOMITE

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– Reinecke Field, west Texas

– Summary & Models
  (facies and early diagenesis are commonly critical)
Vugs & coarse intercrystalline porosity cause high permeability

From Saller and Dickson, 2011
Maps showing modeled distribution of limestone (blue) and dolomite (pink) at horizons 1 & 2 (above). Dots are well control.

Reinecke South Dome has produced ~45 Million BO from ~1 sq mile

From Saller and Dickson, 2011
Reinecke Field: Porosity vs Permeability Colored by Lithology

From Saller and Dickson, 2011
Two-phase fluid inclusions (liquid and vapor) in dolomites have

1. Homogenization temperatures of 90-120° C
2. Water and hydrocarbons
3. Highly saline waters (TDS of 20-25 wt%)
Stable carbon and oxygen isotope compositions of carbonate samples from Reinecke Field indicate dolomites formed at high temperature.

If precipitated from saline Permian Basin waters ($\delta^{18}O$ values of +5 to +6 ‰, SMOW: Stueber et al., 1998), Reinecke dolomites ($\delta^{18}O$ of -3 to -5.5 ‰, PDB) precipitated at temperatures of 84-118° C (using equation in Land, 1985).

From Saller and Dickson, 2011
SEISMIC LINE OVER REINECKE FIELD
Note lack of faulting

Hydrothermal Dolomitization occurred by Convective Flow of Dense Brines associated with Halite Precipitation during the Late Permian from Saller and Dickson, 2011.
Reinecke Field

Reinecke Field is a Single Tank. During Primary & Secondary Recovery, Bottomwater Drive Effectively Pushed Oil to Wells at Top of Reservoir (Recovery of >50% OOIP)

CO₂ is Now Pushing Residual Oil Down To Be Banked & Recovered in Lower Parts of Reservoir

Crestal CO₂ Flood Produced Residual Oil but Oil Production & CO₂ was Heterogeneous

CO₂ escaped South Dome

From Saller and Dickson, 2011
Hydrothermal dolomites are important hydrocarbon reservoirs in many parts of the world.

- Many factors other than faults can control the distribution of hydrothermal dolomite including:

  1. Early Dolomite

  2. Depositional Facies
Factors other than faults controlling distribution

3. High salinity brines in the basin (associated with salt deposition)
4. Convective Flow
Hydrothermal dolomites have

• Excellent reservoir characteristics (including high horizontal & vertical permeability) because of
  – large crystal size,
  – vugs and fractures

• Careful petrography, collecting geochemical data, and a good understanding of the basin history can help predict hydrothermal dolomite reservoirs in the subsurface
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