[PS]Structurally-Controlled Hydrothermal Dolomitization: A Case Study of the Cretaceous Qamchuqa Formation, Zagros Basin, Kurdistan Iraq*

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Abstract

Structurally controlled hydrothermal dolostone hosts many hydrocarbon reservoirs worldwide and hence has been of high interest for exploration by oil companies. The Lower Cretaceous Qamchuqa Formation includes one of these major reservoirs in the Middle East. Qamchuqa Formation is divided into upper and lower units based on faunal contents. The convergence and collision between the Arabian and Eurasian plates resulted in two major folding phases at the end of Cretaceous and Pliocene times. Fracturing, dolomitization and other diagenetic processes affected the carbonates that contributed to the good porosity and development of reservoir characteristics, which make the foreland basin Qamchuqa Formation one of the main targets for oil exploration in most of the oil fields of Iraq. The role of tectonics in a foreland basin setting as related to fracturing, fluid flow and dolomitization have not been investigated in details in the region before. This study will provide an ideal example of the role of thrusting and tectonics in controlling diagenetic fluids and modifying reservoir characteristics. Integration of detailed field, petrographic and geochemical data from fractured dolostones demonstrate different phases of fluid movement during active phase (s) of tectonic cycles in the Zagros region from late Cretaceous to early Neogene time. High resolution sampling of outcrops from 16 different sections along more than 2 km and drill cores from two wells show significant relationships between zebra texture in dolomite and fracture zones, resulting from multiple pulses of hydrothermal fluid flow. These pulses also resulted in dissolution and /or precipitation of hydrothermal saddle dolomite, and later coarse crystalline calcite cement. Earlier data from stable isotopes show that saddle dolomite and host dolostones have similar stable isotopic composition. Enhanced reservoir characteristics are associated with intervals that contain large volume of hydrothermally affected zones. This present study demonstrates the linkage between fluid flux history and related diagenesis to the tectonic evolution of the Zagros Basin.

Structurally-controlled hydrothermal dolomitization in an extensional regime- a case study of the Cretaceous Qamchuqa Formation, Zagros Basin, Kurdistan Iraq

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Abstract

Structurally-controlled hydrothermal dolostone hosts many hydrocarbon reservoirs worldwide and hence have been of high interest for exploration by oil companies. The Lower Cretaceous Qamchuqa Formation includes one of these major reservoirs in the Middle East. Qamchuqa Formation is divided into Upper and Lower units based on fauna contents. The convergence and collision between the Arabian and Eurasian plates created Alpine Orogeny in Kurdistan region, Northern Iraq. As a result of this convergence Neo-Tethys Ocean closed. Then, Phanerozoic carbonate successions of the region were affected by two major folding phases at the end of Cretaceous and Pliocene times. Fracturing, dolomitization and other diagenetic processes affected these carbonates, which contributed to the good porosity and development of reservoir characteristics, which make the foreland basin Qamchuqa Formation one of the main target for oil exploration potential in most of the oil fields of Iraq. The role of tectonics in a foreland basin setting as related to fracturing, fluid flow and dolomitization have not been investigated before. This study will provides an ideal example of the role of thrusting and tectonics in controlling diagenetic fluids and modifying reservoir characteristics. Integration of detailed field, petrographic and geochemical data from fractured dolostones could demonstrate different phases of fluid movement during active phase (s) of tectonic cycles in the Zagros region from late Cretaceous to early Neogene time High resolution sampling of outcrops from 16 different sections along more than 2 km and drill cores from two wells show significant relationships between zebra texture in dolomite and fracture zones resulted from multiple pulses of hydrothermal fluid flow. These pulses also resulted in dissolution and /or precipitation hydrothermal saddle dolomite, and later coarse crystalline calcite cement. Earlier data from stable isotopes show that saddle dolomite and host dolostones have similar stable isotopic composition. Enhanced reservoir characteristics is associated with intervals that contain large volume of hydrothermally affected zones. This present study demonstrates that linkage between fluid flux history and related diagenesis to the tectonic evolution of Zagros Basin.

Objective

(1) Characterization the various types/generations of saddle dolomite and zebra textures as related to fault, fracture and host rock lithology and fabric

(2) Quantification of diagenetic processes as related to dolomitization, fracturing and fluid flow.

(3) Construction of conceptual model elucidating and predicting the fluid flow and spatial distribution of hydrothermal dolomites.

Methodology

(1) Field investigations included facies relationships, structural analysis relationship, zebra texture and sampling from surface and subsurface sections.

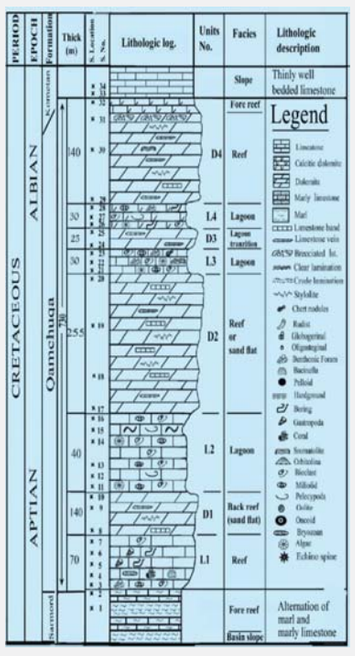
(2) Petrographic investigation, which include normal light microscopy, cathodoluminescence.

(3) Stable isotope analysis (C and O isotopes)of diagenetic components as well for different type dolomite host rock and cements.

Geological Setting and Stratigraphic Framework.

Qamchuqa Formation (Aptian- Albian) consists of thick- bedded limestone, dolomitic limestone and dolostones successions. The lower part of this formation is thin bedded and gradually become thicker and harder upward, which makes steep slopes and cliffs at many outcrops in high folded and thrust zone (north-north east- study area) of Iraq.

Depositional environment of the formation is shallow-water deposited in a wide carbonate platform including several environments such as tidal flat, lagoon, shoal, patch reef and fore-slope to ramp environments. These environments are repeated several times through the whole sequence of the formation, with wide spread outcrop distribution in North-Northeast Iraq and the subsurface of the Foothill zone toward southern Iraq. Vertical and lateral facies variations in the formation have resulted in a variety of names that have been compounded further by varying terminology developed by the operating oil companies.



Stratigraphic column and lithofacies section of Qamchuqa Formation (Ameen, 2008)

Structural Frame work

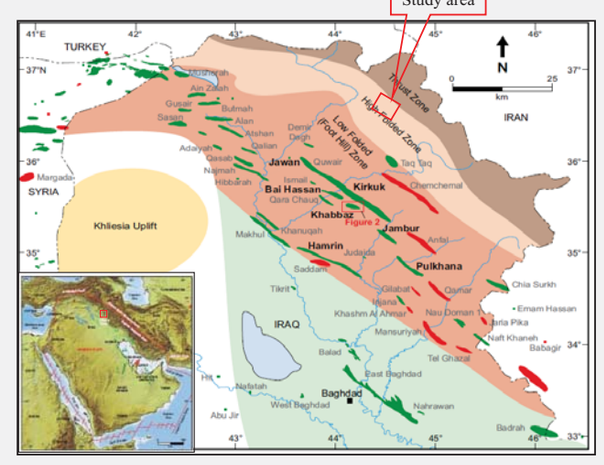
The study area is located in the Western Zagros Fold-Thrust Belt, directly to the southwest of the main Zagros Suture Zone. Structurally, the area is located within the High Folded Zones underwent intense deformations with repetition of faulted and highly fractured zones, which subjected to high stress from the Iranian Plate. The intensity of these folds increases toward the Zagros thrust zone. The fractures in this area have always vertical orientation with trace of movement.

The Zagros Orogenic Belt is part of the Alpine-Himalayan Mountain Chain and has NW-trend, as a result of convergence between the Iranian and the Arabian Plate. This belt resulted during late Cretaceous and Cenozoic, and part of this belt is in the mountains of Kurdistan region- Northern Iraq.

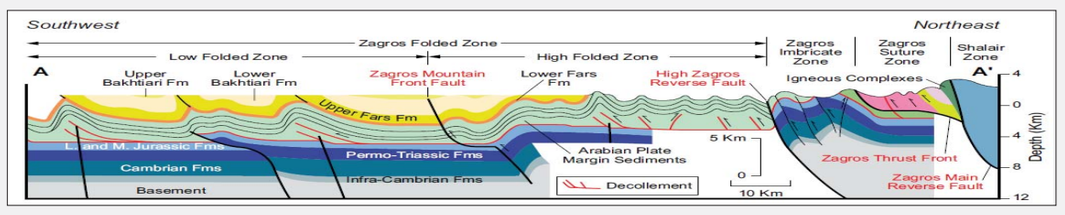
Convergence and collision between the Arabian and Eurasia plates caused final closure of Neo-Tethys and created Zagros Orogenic Belt. This continental-continental collision occurred during late Cretaceous to Miocene-Pliocene, with this collision and related uplift there was a volcanic activity in imbricate and thrust zones involving Qulqula radiolarite, Mawat Ophiolite Complex, Mesozoic and Cenozoic sedimentary and Walash volcanic rocks.

The convergence and collision between the two Arabian and Eurasian plates created Alpine Orogeny in Kurdistan region-Northern Iraq. As a result of this convergence Neo-Tethys Ocean closed. Then, Phanerozoic successions of the region were affected by two major folding phases at the end of Cretaceous and Pliocene times. In the extreme northeastern of Arabian plate (Kurdistan Region), this activity helped to build the thrust zone (Zagros thrust), and resulted in the formation of subductional tectonic facies and ophiolites together with igneous and metamorphic rocks.

The presence of an unconformity between the upper part of Qamchuqa with Dokan formations and intense tectonic activity of various parts of the basin, are the main two factors affected to porosity in the Qamchuqa formation. The first factor, the exposure of the upper part of formation to extensive dissolution by meteoric water with wide variation in both textures, extended laterally and vertically. The second factor, the intrusions of Qulqula and Mawat during volcanic activity after deposition of Qamchuqa Formation may have caused the formation of hydrothermal dolomitization.

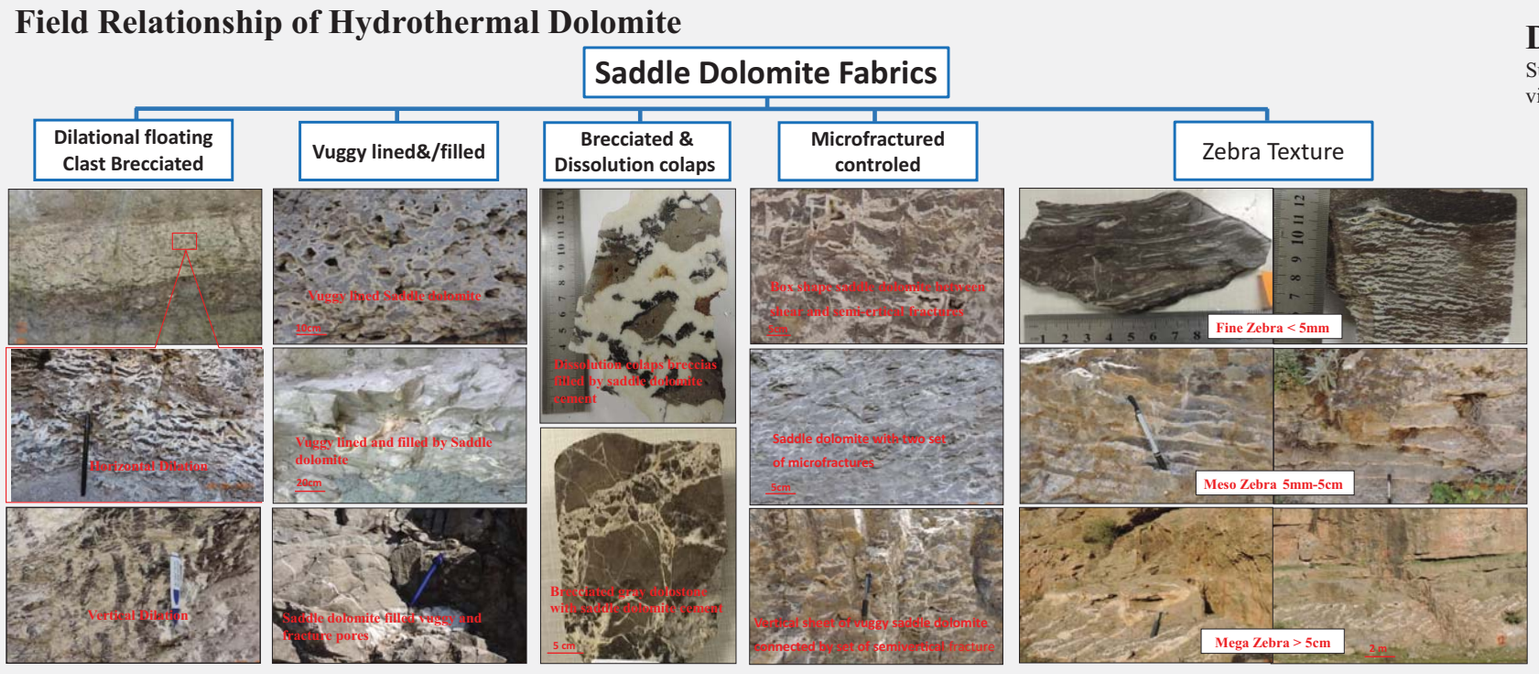


General location map showing area of study.



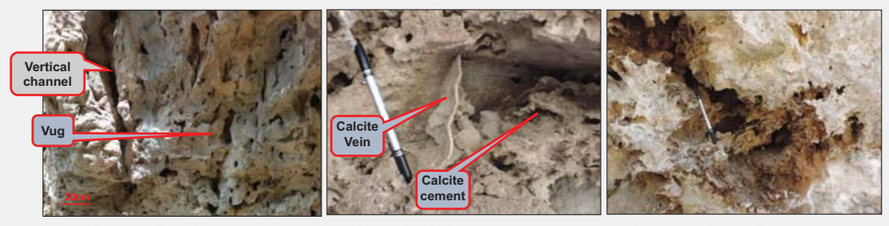
Regional geologic cross-section across northeast Iraq showing major tectonic divisions and major tectonic boundaries. (Ibrahim, 2009).

Field Relationship of Hydrothermal Dolomite



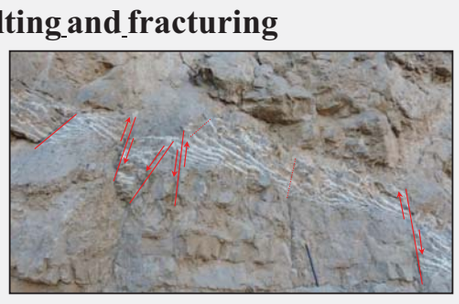
Disolution (Leaching & karstification)

Subaerial exposure with extensive erosional and karstification increase overall porosity. Porosity development via karting, caves and large vuggy pores represents an important characteristic of Qamchuqa Formation.

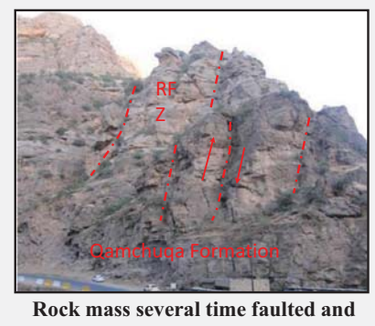


Karstification at an outcrop from Balakian gorge- Suran City -northern Iraq.

Faulting and fracturing



Two set of normal faults fractures (set of horst and graben) cross cutting zebra texture.



Rock mass several time faulted and fractured.

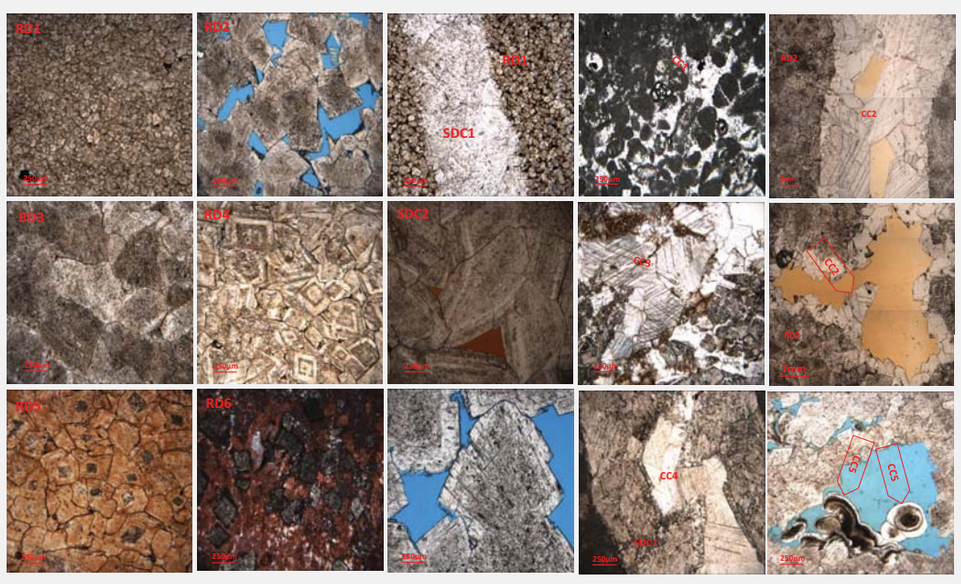
Petrographic analysis

Dolomite matrix and cement types.

(1) RD1- Fine crystalline. planer-s (subhedral) to nonplanar-a (anhedral) gray dolomite. (< 50 µm)
(2)RD2- Medium to coarse crystalline euhedral to subhedral gray dolomite (50– >150 µm)
(3) RD3- Coarse crystalline zoned Nonplanar-a (anhedral) gray dolomite (>250 µm)
(4)RD4- Euhedral medium to coarse-crystalline gray dolomite (100 – >250 µm)
(5) RD5- Medium to coarse zoned crystalline subhedral to anhedral (brown) black dolomite (75 - > 250 µm)
(6) RD6- Fine to medium crystalline euhedral planer dolomite.
(7) Selective dolomitization & associated with stylolite.
(9) SDC1- Fine crystalline saddle dolomite (<500µm)
(10) SDC2- Medium crystalline saddle dolomuite (>500µm – 2mm)
(11)SDC3- Coarse crystalline saddle dolomite (>2mm)

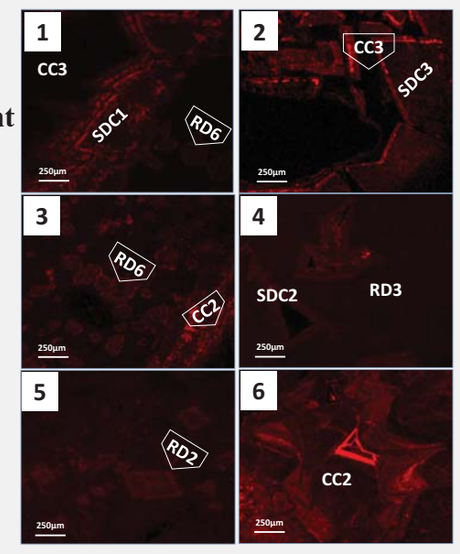
Calcite cement types.

(1) CC1- Equent cement filling interpartical & moldic pore (Early).
(2) CC2- Spary calcite filling fractures and vuggy molds
(3) CC3- Blocky calcite partially filling karstification
(4) CC4- Equent cement filling fractures and vuggs after saddle dollomite
(5) CC5- Acicular fibrous and marine phreatic environment (Late)



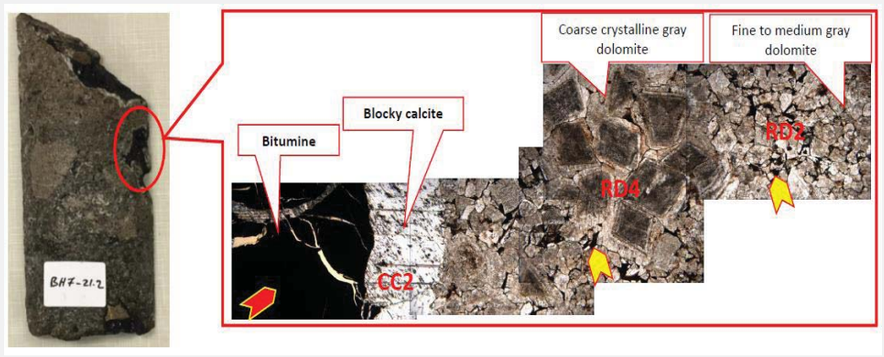
Cathodoluminescence Petrography of different type of hydrothermal dolomite and calcite cement

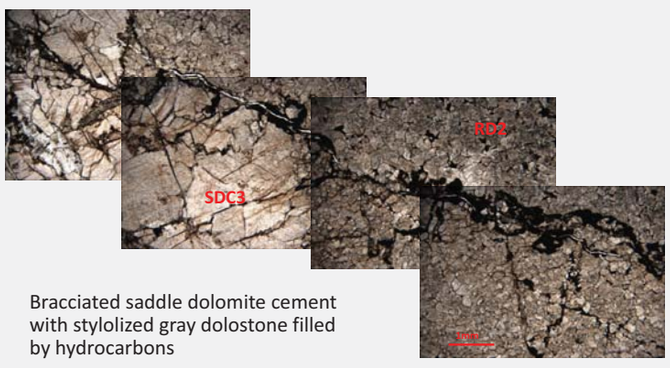
(1)- Saddle dolomite cement (SDC1)build on the two side of fracture followed by sparry calcite cement (CC2)
(2) Sparry calcite cement (CC3) filling brecciated and dissolved saddle dolomite cement (kartisification).
(3) Selective dolomitization floating dolomite in micritic matrix of limestone
(4) Zoning of saddle dolomite filling micro vugg in gray dolostone.
(5) Trace of overgrowth gray dolostone (RD2)
(6) Blocky calcite cement filling vuggy pores (CC2).



Bitumen Emplacement

Vuggy lined blocky calcite cement-CC2, followed hydrocarbon filling vuggy (red arrow) and intercrystalline (yellow arrows) pores.





Bracciated saddle dolomite cement with stylolized gray dolostone filled by hydrocarbons

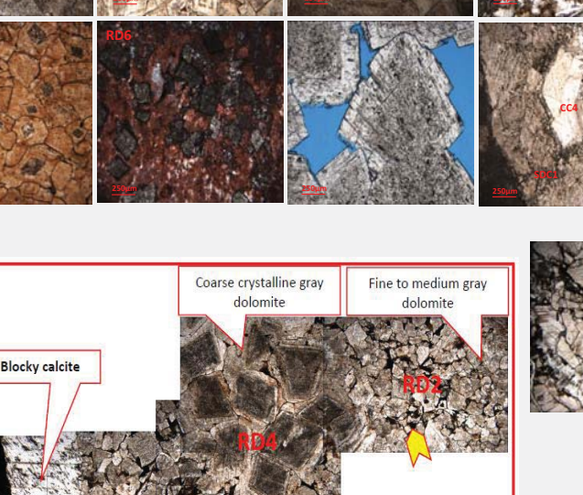
Hydrocarbon in porous zebra.

Diagenitic Features and Paragenitic Sequence of the Qamchuqa Formation

Diagenetic phases and events	Shallow burial (eogenetic)	Intermediate-Deep burial (mesogenetic)	Uplift (telogenetic)	Φ/K effect
Micritization				– –
Calcite cement (CC1)				+ +
Dissolution				+ –
Fracturing 1				+ +
Calcite cement (CC2_)				– –
Stylolization 1				– +
Replacive dolomite (RD1)				+ +
Replacive dolomite (RD2,3,4,5)				+ –
Euhedral dolomite along stylolite/dissolution seam				+ –
Fracturing 2				+ +
Saddle dolomite cement SDC1,2,3				+ +
Stylolization 2				– +
Saddle dolomite along stylolite/dissolution seam				– +
Fracturing 3 brecciation				+ +
Calcite cement (CC3,4)				– –
Bitumen replacement				
Dedolomitization& Karstification				+ +
Calcite cement (CC5)				– –

Timed events ------- probably continuous events

Stable Isotope Geochemistry



(1) Overlap the δ13C and δ18O values of the pervasive gray and black dolostone matrix with saddle dolomite cement with high depletion indicate their modification due to hydrothermal fluids circulation influence.
(2) Values of the Saddle dolomite cement show a range of depletion which indicate that affected by warm fluids circulation.
(3) Calcite cements values show extremely a wide range depletion with a trend from early (vein display) to late stage (void filling) slightly more negative than Late Cretaceous carbonate values including their modification due meteoric diagenetic environment of sub-aerial exposure.

Fluid Flow

Conceptual fluid flow model and tectonic in the study area (modified after Al Qaqim et al, 2012)

Conclusion

- Carbonates of the Qamchuqa Formation were deposited in shallow marine with wide environments of carbonate platform - tidal flat, lagoon, shoal, patch reef and fore-slope to ramp environments.
- Qamchuqa Formation was subjected to widespread diagenetic processes including early and late dolomitization and finally subaerial exposure causing extensive alteration of original facies with dissolution and karst development.
- Distinguishing wide range in fabric and texture of "zebra" with sheet of horizontal vugs enhanced porosity combine with vertical permeability of late stage extension fractures.
- Isotopic data support that the formation of all generations of matrix dolomite and saddle dolomite cement occurred at higher temperatures from hydrothermal fluids generated at depth.
- Field observation of different fabric of saddle dolomite related to fracturing system and pervasive dolostone matrix supported by isotopic data help to build conceptual model of reflux warm fluid flow vertically through fault and fracture system and laterally through porous permeable layers (pervasive dolostones).