Petrography, Geochemistry and Reservoir Characterization of Dolomicrites in the Upper Member of the Dalan Formation, Persian Gulf, Iran

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Abstract
The upper member of the Dalan Formation with the age of Middle to Upper Permian is one of most important gas reservoir in the Persian Gulf region and folded Zagros Belt. This member consists of carbonates with intercalation of evaporites. Sedimentological investigation has revealed that dolomitization has had a considerable affect on carbonate layers of this member in different stages of diagenetic histories resulted in creation of different types of dolomites. This research concentrates on dolomicrite, from the point of view of its spatial distribution and reservoir zonation.
The main objective of this investigation is petrographic study and defining textural specifications of dolomicrite and isotopic analysis of oxygen to determine the formation temperature of dolomite for documentation of the dolomitization model and measure porosity and permeability of core plugs in order to determine reservoir characterization.
Based on petrographic study very fine to fine (5-16µ) unimodal, anhedral crystals of dolomite, dolomicrite can be distinguished. This texture is equivalent to Xenotopic A and Nonplanar A. Some features like fenestral fabrics, microbial filaments, evaporitic cast, anhydrite nodules and mud cracks are also observed. This kind of dolomite is related to fenestral dolomitic mudstone facies which is deposited in supratidal to arid upper intertidal.
The result of isotopic analysis on oxygen ($\delta\ ^{18}O$) shows that the amount of $\delta\ ^{18}O$ ranges from -1.47 to +0.99 PDB. To determine the formation temperature, Land equation (1985) has been used. The calculated temperature is between 20.36° C to 46.6° C which is in agreement with sabkha environments. So, sabkha dolomitization model was suggested for this kind of dolomite.
Porosity and permeability analysis of the core plugs revealed that reservoir characterization generally is facies dependent and in mud-dominated facies like dolomitic mudstone including dolomicrite general reservoir quality is poor to fair unless this part is influenced by subsequent diagenetic processes.

Key words: *Upper member of the Dalan Formation, Reservoir Characterization, Isotopic Study, dolomicrite, Persian Gulf.*

INTRODUCTION
There are numerous hydrocarbon reserves in the subsurface strata of the Permian of the Persian Gulf region. In this area fractured oolitic, detrital and dolomitic limestones of the Dalan were discovered to contain gas which is under considerable pressure (Edgell, 1977). Important volumes of the Permian gas in Iran are now being produced in the Dalan and Kangan Formations in the coastal Fars and Boushehr area, largely at Kangan (Ghazban, 2007). The upper member of the Dalan Formation is the main reservoir of the Dalan Formation, so this investigation focuses on this member. This interval generally consists of

both mud-dominated and grain-dominated facies. Grain-dominated facies include ooid grainstone with oomoldic porosity generally have high porosity and permeability and high reservoir quality (Parham, 2006). This grain-dominated facies which show the best reservoir intervals has intercalation with mud-dominated facies. This microfacies intensively affected by dolomitization create different types of dolomite. Dolomicrite is the main type of dolomite in mud-dominated microfacies so because of their importance in reservoir zonation, and rather high distribution of this type of dolomite it is attempted to investigate a complete research about this type of dolomite include petrographic and isotopic characterization, microfacies, depositional environment, porosity, permeability and reservoir characterization of dolomicrites.

STRATIGRAGHY OF THE DALAN FORMATION

This formation named after the Dalan Anticline situated 110 kilometers S-SW of Shiraz with a total thickness of about 630 meters. The upper contact with the Kangan Formation is unconformable and the basal contact with Faraghan Formation is gradational (Motiei, 1995). Based on lithology the Dalan Formation subdivided into three primary members including the Lower Carbonate member; 2) Nar member; and 3) the Upper Carbonate member (Edgell, 1977). The Dalan (and also Kangan) reservoirs are sealed by the Triassic age Dashtak evaporitic sequence.

METHODS OF STUDY

In order to study the sedimentological and reservoir properties of the upper member of the Dalan Formation about 150 meters of cores from the well have been studied. For thin section study about 450 samples were collected from every 30 cm of the cored intervals. Thin section was treated with Alizarin Red-S following Dickson (1966); microfacies were described using the Danhum (1962) terminology; 6 dolomitic samples were selected for SEM photograph. In order to measure the formation temperature of dolomicrites, 8 samples were collected. The selected samples were pure and without contamination and with no or the least alteration. Samples were drilled with dental drill and have sent to Liverpool university of England for Isotopic analysis. To estimate reservoir porosity and permeability, 166 horizontal core plugs were analyzed. For compartmentalization of the interval into different zones with different reservoir potential, the cross plots of porosity and permeability versus depth for each interval has been drawn.

PETEROGRAPHY

Based on petrographic investigation this kind of dolomite consists of very fine to fine, unimodal, anhedral crystals of dolomite. The size of dolomite is between 5-16 μ (fig. 1). This texture is equivalent to xenotopic-A (Gregg and Sibley, 1984) and nonplanar-A (Mazzullo, 1992). Some features like fenestral fabrics, microbial filaments, evaporitic cast, anhydrite nodules and mud cracks are also observed.

GEOCHEMICAL STUDY

Isotopic composition of dolomites reflects the formation temperature and composition of dolomitized fluid (Tucker and Wright, 1990). Previous studies revealed that oxygen isotopic composition of the carbonate sediment has changed during the geologic history. The value of oxygen isotope of recent dolomite varies from -1 to -8 ‰ PDB which is more than the amount of recent tropical carbonate. The concentration of $\delta\ ^{18}O$ in dolomicrites of the upper member of the Dalan Formation varies from -0.46‰ to + 0.99‰ PDB with the average of +0.105‰ (Table 1). In order to estimate the condition and the formation temperature of the dolomite it is possible to analogous the chemical composition of the dolomite to chemical and isotopic composition of calcite mineral and unaltered shells of the formation with similar age (Allen and Wigging, 1993). Because their chemical composition indicate the chemical composition of marine water of that age, so by use of isotopic composition of marine water it is possible to estimate the water temperature. In fig. 2 isotopic composition of the dolomicrite of the Dalan Formation is compared with the chemical and isotopic composition of calcite mineral and unaltered shells of the age of Permian (Allen and Wigging, 1993). According to Allen (Allen and Wigging, 1993) the isotopic composition of calcite mineral and unaltered shells of the age of Permian varies from -2.8‰ to +2.2‰ PDB. In order to analog of the results of isotopic analysis of dolomicrites with the isotopic composition of Permian, isotopic composition of dolomicrite plotted in the graph (fig.2). As the graph demonstrates, isotopic composition of the dolomicrites is in the range of chemical composition of unaltered shells of the Permian. It can be concluded that the formation temperature of the dolomicrites is similar to the water temperature of the marine water with the age of Permian. So the samples show the least alteration and as a result it is possible to use the result of this analysis to estimate the formation temperature of the dolomicrites by the use of Land equation.

DETERMINATION OF FORMATION TEMPERATURE OF DOLOMICRITES

The least-altered samples, was used to calculate the formation temperature of dolomite, using the equation of Land, 1985:

$$T^{O}C = 16.4 - 4.3\ ([\delta\ ^{18}O_{dol} - 3.8]\ -\delta\ _{Water} + 0.14([\delta\ ^{18}O_{dol} - 3.8]\ -\ \delta\ _{Water})^{2}$$

where *T* is temperature (in ºC), $\delta\ ^{18}O_{dol}$ is the oxygen isotope value in studied samples (in PDB), δ_{Water} is the oxygen isotope value of marine water in the Permian (in SMOW), e.g. -2.8 and 2.2 ‰ SMOW (Given and Lohmann, 1986; Allen and Wiggins, 1993). The calculation gives the minimum and maximum temperature between 20.26º and 46.6ºC. These temperatures indicate that the dolomites formed with a warm fluid in an evaporitic condition.

DISCUSSION AND DOLOMITIZATION MODEL

Based on petrographic studies such as very fine to fine, unimodal, anhedral crystals of dolomite and features like fenestral fabrics, microbial filaments, evaporitic casts, anhydrite nodules and mud cracks, it can be concluded that this kind of dolomite is related to fenestral dolomitic mudstone facies which is deposited in supratidal to arid upper intertidal. This kind of dolomite replaced the precursor limestone. According to formation temperature of dolomicrites, using isotopic data, it can be concluded that dolomicrites formed in arid condition, so based on these indicators sabkha dolomitization model suggested for this kind of dolomite.

RESERVOIR CHARACTRIZATION OF DOLOMICRITES AND RESERVOIR ZONATION

In order to evaluate reservoir properties of dolomicrites, helium porosity and air permeability of about 166 core plugs have been measured. Porosity and permeability has been cross plotted versus depth. These cross plots revealed that the studied interval does not show homogeneous reservoir quality, so it can be compartmentalized into different zones with different reservoir quality. These zones named A, B, C, D, E and F (Table 2). In this zonation, zone B, C, D and E are grain-supported and zone A and F consist of mud-supported facies, which are described below: in fig.3 cross plot of lower and upper dolomitic unit has been demonstrated. In the upper dolomitic unit can be divided into two zones A and B. and in lower dolomitic unit divided into zone E and F. Zone A and E which contain dolomicrite describe below.

Zone A- The average porosity is 8.4% mD and the average permeability is 2.84 mD. This part consists of dolomudstone and stromatolite dolobunstone facies. In dolomicrites of this part porosity in the form of fenestral observed but chicken wire anhydrite cement decreased or occluded the porosity. Although as a result of replacement of lime mud to dolomicrite, intercrystalline and matrix porosity created, but it could not generate high reservoir potential.

Zone F- the average porosity is 4.34% and the average permeability is 0.099 mD. This zone consists of dolomudstone with various amount of chicken wire anhydrite. The amount of anhydrite increase in the lower parts.

This analysis revealed that reservoir characterization generally is facies-dependent and in mud-dominated facies like dolomitic mudstone including dolomicrite general reservoir quality is poor to fair (North, 1985, cited in Ahr 2008) unless this part is influenced by subsequent diagenetic processes. Different processes which locally enhanced reservoir quality of dolomicrites including recrystallization by increasing crystal size and therefore increasing intercrystalline porosity, 2) pervasive dissolution as a result of meteoric diagenesis when it makes well developed vuggy porosity and 3) fracturing by connecting the old porosity and improving permeability. Although poikilotopic anhydrite cement as a late stage diagenetic cement occluded or decreased some of the precursor porosity and has negative effect on reservoir quality.

CONCLUSION

1-Based on petrographic evidences this type of dolomite is related to fenestral dolomitic mudstone facies which is deposited in supratidal to arid upper intertidal.

2-Calculated formation temperature of dolomicrites is between 20.26º and 46.6ºC. These temperatures indicate that the dolomites formed with a warm fluid in an evaporitic condition.

3-Based on integrated petrographic and geochemical studies, besides microfacies and depositional environmental investigation, sabkha dolomitization model has been suggested for this kind of dolomite.

3-Reservoir characterization of this formation is facies-dependent and mud-dominated facies include mudstone has different reservoir quality from grain-dominated facies.

4-Dolomicrites has low porosity and permeability and therefore poor reservoir quality.

5-General reservoir quality of dolomicrite is poor to fair unless this part is influenced by subsequent diagenetic processes.

6-Recrystallization, dissolution and fracturing are different processes locally enhanced reservoir quality of dolomicrites

7-Poikilotopic anhydrite cement as a late stage diagenetic cement occluded or decreased some of the precursor porosity and has negative effect on reservoir quality.

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Table 1- Carbone and Oxygen isotopic value of the upper Dalan samples.

Table 2- Reservoir quality and zonation of the upper Dalan Member.

Sample No.	D 13C PDB	D 18O PDB
P.841	3.92	-0.46
P.802	3.21	0.99
P.807	5.62	0.97
P.840	4.49	0.24
P.853	5.35	-1.47
P.814	3.48	-0.35
P.823	2.84	-0.12
P.817	1.75	-0.2

Formation	Depth (m)	Fabric	Average Porosity (%)	Permeability (mD)	Reservoir characterization	Reservoir zonation
Upper Dalan	2863-2876	Mud-Dominated	8.4	2.84	Poor	A
	2876-2883	Grain-Dominated	16.12	33.34	Good	B
	2883-2927	Grain-Dominated	23.87	41.26	Excellent	C
	2927-2958	Grain-Dominated	14	10.92	Fair	D
	2958-2988	Grain-Dominated	13.04	6.6	Fair	E
	2988-3014	Mud-Dominated	4.34	0.099	Poor	F

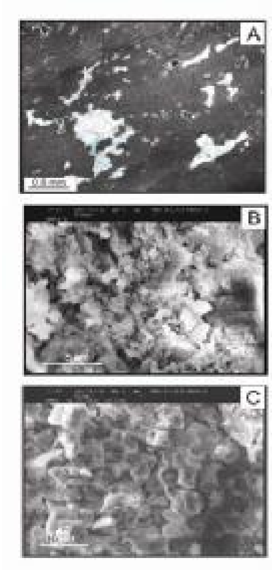

Fig 1. Dolomicrite A) Photomicrograph of dolomicrite with fenestral fabric, anhydrite cement decreased the fenestrea (xpl). B and C) SEM photograph of dolomicrite. B) anhedral form of dolomicrite. C) Very fine to fine, unimodal crystals of dolomite.

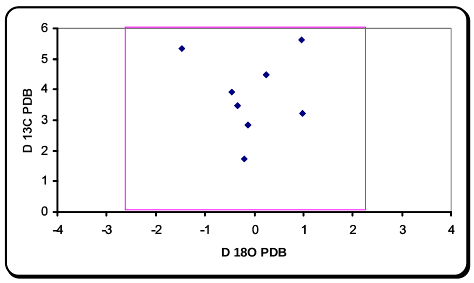

Fig 2. The analogs of isotopic composition of dolomicrites of the upper member of the Dalan Formation with the isotopic composition of calcite mineral and unaltered shells of the age of Permian (area in purple) (Allen and Wigging, 1993).

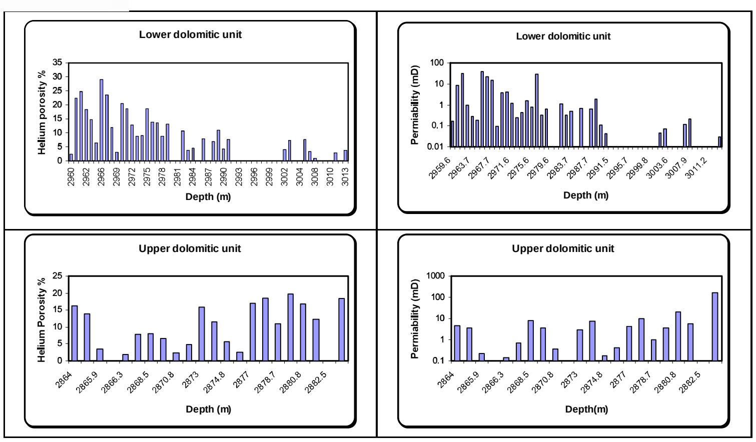

Fig.3. Variation of porosity and permeability versus depth in the lower and upper dolomitic unit.