PS Dedolomitization: Types, Mechanism and Its Relationship to Carbonate Reservoir Properties*

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Abstract

The dedolomitization is very common in the strata in China and abroad (Figure 1). But it is still in dispute about its formation environment, influencing factors, mechanisms, and the role in reservoir study and so on. We analyzed the recognition marks (Figure 2), and gave detailed classification on the dedolomitization from whether or not retaining the original rhomb shape, attitude and forming environment, and representation during different diagenetic stages. The dedolomitizaition of the sedimentary carbonate sequences are generally considered as the consequence under subaerial condition. But recent researches reveal that the dedolomitization can take place in different diagenetic conditions (Figure 3). The factors influencing the dedolomitization mainly are: the dolomites' physical properties, degree of order, fluid characters (concentration of SO_4^{2-}, Ca/Mg ratio, temperature, pH, and partial pressure of CO_2) and Fe content (Figure 4). We thoroughly analyzed the dedolomitization mechanism in different environments by cathodeluminescence and stable isotope data. The dedolomitization are obviously affected by the original dolomite texture, and the dedolomitization process can be divided into two steps: (1) dissolution of dolomite; and (2) the precipitation of calcite. Maybe only the first step occurs to form the rhomb-moldic pore. Maybe the two steps take place at the same time. Maybe firstly (1) occur and then (2). The dedolomitization mostly begin from the core of the dolomite or the interface between the core and the rim, which is because there are deficits during the growth process and have high Ca content. Some soluble inclusions promote the dedolomitization. The dedolomitization can be considered as a kind of process that the Mg^{2+} is gradually released. As an opposite process of dolomitization, the studies of formation condition of dedolomitization and calcite-dolomite-solution system can help to analyze the origin of dolomitization. The near-surface dedolomitization is generally relevant to the dissolution of gypsum and the meteoric water of vadose zone and phreatic zone. Prerequisites are a solution with high calcium and low magnesium content, low CO_2 partial pressure, and temperatures < 50°C. It is confirmed that the laterally continuous distribution of dedolomitization can indicate unconformity.

The dedolomitization can reconstruct the pores. In Ordos Basin of China, it is very common that the leaching of dedolomitized calcite can increase porosity near the unconformity of the uppermost of Lower Ordovician (Figure 5). In the Huanglong Formation of Upper Carboniferous in Sichuan Basin of China, the dedolomitization is very universal. But the secondary limestones after dedolomitization have very low porosity (porosity of dolomite = 3.3-6%; porosity of dedolomitized limestone = 1-2%). The main reservoirs of Huanglong Formation are dolomite and calcareous dolomite (Figures 6, 7, 8). The dedolomitization not only resulted in the calcite replacing the dolomite, but also lead to the precipitation of calcite in the primary pores. So the porosity decreased after the dedolomitization. Generally speaking, the dedolomitization can enlarge the modic pore and inter-crystal pore. But there is close relationship between the increasing porosity of dedolomitization and latter eluviation. Without the latter leaching, maybe the dedolomitization relevant to calcite precipitation will destroy the primary pores.

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Dedolomitization: Types, Mechanism and Its Relationship to Carbonate Reservoir Properties

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In the carbonate strata in China and abroad, especially in the place where gypsum/anhydrite is dissolved, the dedolomitization is very common (Fig. 1). Switzerland geologist A. von Morlot first put forward the word "dedolomitized calcite" in 1947. He thought that the groundwater rich in Ca, S leaching the anhydrite evaporite can result in the calcitization of early stage dolomite.
Dedolomite –The product of diagenetic conversion of dolomite to another mineral (typically calcite), a process that occurs most commonly during the dissolution of associated calcium sulfates or at high temperatures. Because the term does not specify the end product of conversion, it is less definitive than terms such as "calcitized dolomite". -***Peter A. Scholle*, *2003***
The calcitization (dedolomitizaition) of the sedimentary carbonate sequences are generally considered as the consequence under subaerial condition. But recent researches reveal that the **dedolomitization can take place in different diagenetic conditions**.

$$CaMg(CO_3)_2+Ca^{2+}+SO_4^{2-}=Mg^{2+}+SO_4^{2-}+2CaCO_3\downarrow \quad \cdots\cdots\cdots\cdots(1)$$

Dolomite — Gypsum dissolution — Taken away by water — Calcitization

Textural Criteria for Recognizing Dedolomitization

The dedolomitization has two meanings:
a) The dissolution of dolomite, forming **rhombic crystal moldic pore**;
b) Partially or whole **calcitization** of dolomite (Fig. 2b).
For the 2nd dedolomitization, staining with **Alizarine Red S** shows the distribution of calcite and dolomite within the dolomite rhombs.
Besides, there are some other symbols:
a. Brown and reddish rock colors: Liberation of Fe^{2+} from Fe-rich dolomite may form hematite occurring as thin coatings on the crystals or ferric iron precipitates (Fig. 2a).
b. Weathering along crystal faces of a calcitized dolomite may produce **loose sandy sediment (Fig. 2a)**.
c. Calcite pseudomorphs after sucrosic xenomorphic, nonplanar dolomite (Fig. 2c).
d. Syntaxial calcite rims bordering rhombohedral crystals (Fig. 1).
e. Relicts of dissolved dolomites preserved inside the pseudomorphs or at their boundaries (Fig. 2b).
f. Association of dedolomite with evaporite minerals.

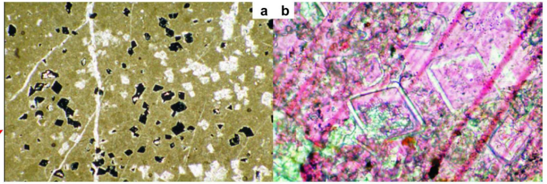
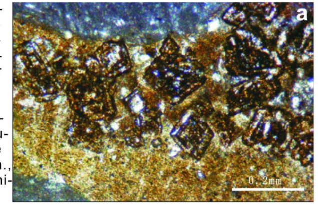
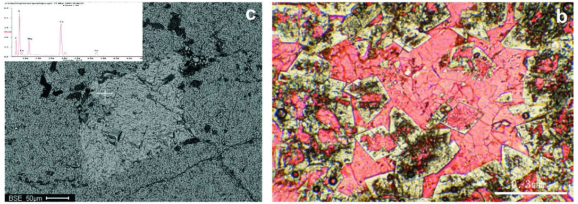


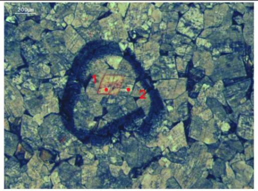
Fig. 1 Overseas dedolomitization examples (from Peter A. Scholler et al., 2003)
a. An example of selective leaching of some dolomite crystals in a partially dolomitized limestone. Dolomite leaching or dissolution is seen here, but dolomite calcitization is equally common and is also referred to as dedolomitization. Jurassic Ronda unit (Subbetic), near Ronda, Spain. XPL, HA = 3.6 mm; **b** Dedolomitization (calcitization of dolomite) is demonstrated in this example by a combination of staining and observation of internal collapse fabrics. The cores and/or certain zones of the crystals are inferred to have been poorly ordered dolomite that was susceptible to dissolution. The residual zones of less soluble dolomite collapsed and formed geopetal mounds at the bottom of rhombic voids still rimmed by thin dolomite rinds. The void spaces from dolomite dissolution and collapse were cemented by calcite at a later stage. Mississippian (Visean) Arroyo Peñasco Gp., Terrero Fm., Taos Co., New Mexico. PPL, AS, HA = ~0.4 mm

Fig. 2 a. Weathering and dolomite alteration can accentuate zonal variations in the iron contents of dolomites through the formation of hematite or limonite alteration zones. O_3 Ellenburger Ls., Llano area, Texas; **b**. A stained example showing euhedral dolomite crystals in which the cloudy, inclusion-rich cores were dissolved and the resultant pore spaces were filled by calcite cement (red). Oligocene Gambier Fm., coastal South Australia; **c**. EPMA of microspar calcarenite, O_3l, Tarim basin.





The dedolomitization phenomenons in different diagenetic condition can be classified into 4 types:
1. **Near-surface dedolomitization**: Prerequisites for forming near-surface dedolomite is a solution with **high calcium and low magnesium, low CO_2 partial pressure, and temperatures < 50°C**. Near-surface dedolomitization is often related to dissolution of gypsum and dolomite in vadose or phreatic meteoric waters.
2. **The dedolomitization relevant to fracture** have lower O isotope value (-6.3 to -9.6‰, PDB) and higher C isotope (1.0 to 2.6‰), wide range of Mn content (290-540ppm), medium Fe content (120-170ppm) and very low Sr content. It is shallow-burial origin.
3. **The dedolomitization relevant to stylolite** have close relationship with hydrocarbon, and have very low O isotope value (-7.88‰), lower C isotope value (-1.37‰), medium Fe, Mn content (Fe=450ppm, Mn=120 ppm), higher Sr content (940ppm). It is owing to deep-bury (Fig. 3).
4. **The dedolomitization of the dolomite in the gypsum nodules**.



Number	$\delta^{13}C_{PDB}$	$\delta^{18}O_{PDB}$
1	-1.37	-7.88
2	-1.09	-6.42

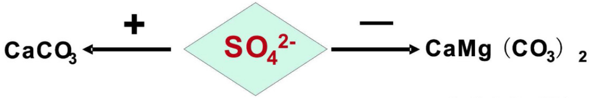
Number	Na_2O	MgO	K_2O	CaO	MnO	FeO	SrO	BaO	CO_2	Total
1	0	0.607	0.008	55.484	0.012	0.045	0.094	0.028	43.723	100
2	0	21.29	0.004	30.283	0.022	0.01	0.002	0	48.388	100

Fig. 3 The laser C&O isotope (up-right table) and EPMA spectrum (down table) result of medium-coarse crystal dolomite (up-left photo) in Penglaiba formation, Lower Ordovician (O_1p) in SW Tarim basin. The up-left photo shows the dedolomitization in the centre of the dolomite. Stained, PPL.

The dedolomitization can be considered as a kind of process that the Mg^{2+} is gradually released.
This is opposite to the dolomite forming process: firstly original dolomite precipitates, and then transforms to ideal dolomite in high Mg/Ca environment. That is to say, the ideal dolomite firstly releases the Mg^{2+} to become dolomite rich in Ca, then finally transforms to be calcite.

The factors influencing the dedolomitization mainly are:

1. **The dolomites' properties** : The dolomite with good porosity is easily dedolomitized. On the one hand, the Epsom salt ($MgSO_4$), which is the outgrowth of dedolomitization, is easily dissolved, so the rock after dedolomitization is porous with lower permeability; On the other hand, the dedolomitized calcite is more easily dissolved than the original dolomite, thus the permeability could become higher.
2. **The degree of order of dolomite:**The degree of order of dolomite has great influence on dedolomitization velocity, but this influence tends to be lessened with the temperature increase.
3. **The source of Calcium** : Gypsum can provide the source of Ca for dedolomitization, so a lot of gypsum can promote dedolomitization.
4. **The fluid properties**: The fluid with high Ca/Mg ratio easily leads to dedolomitization. If the solution has higher Ca/Mg ratio, the Mg^{2+} ions have higher releasing rate, and the dedolomitization would be faster. The Ca/Mg ratio is controlled by the calcite-dolomite equilibrium of the fluids in the pore (Fig. 4) and the degree of order of dolomite.



Curtis C. D，1984

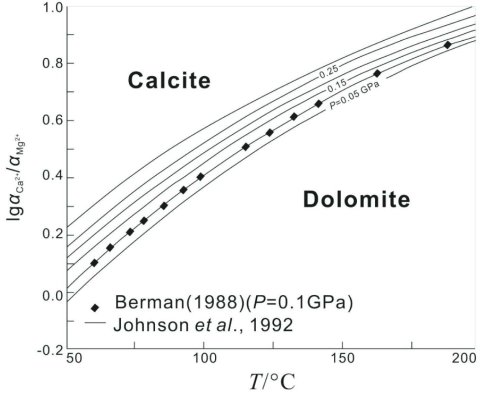
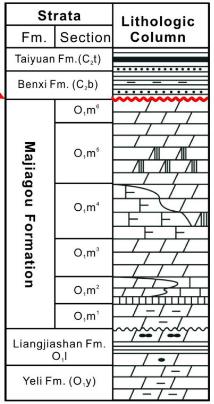


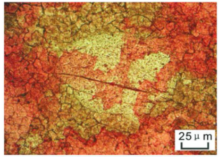
Fig. 4 Calcite-Dolomite-Water system phase diagram, the isolines mean the pressure value (after Yu et al., 2003)

In Ordos basin of China,there is an unconformity which can be correlated laterally in the uppermost of Lower Ordovician.

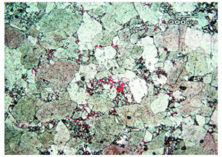
Dedolomitization developed between the unconformity surface and 100m downward, which has paragenesis relationship with dolomitized karst breccia (Fig. 5a, b, c, d).

It is very common that the leaching of dedolomitized calcite can *increase porosity near the unconformity of the uppermost of Lower Ordovician in Ordos basin* (Fig. 5b,c, d).

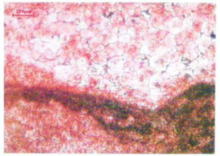




a. Dedolomitized limestone. Showing some subidiomorphic-xenomorphic dolomites have been calcitized. The crinoid was dolomitized and showed pressure-twinning. Ordos basin, well HT1, $O1m^4$, PPL, stained



b. Medium-coarse crystal dolomite with dedolomitized calcite (rosiness). There are some solution pores (red). Ordos basin, well Sh249, O_1m^5, impregnated, PPL, stained



c. Vadose silt limestone. Bottom left is fine silt limestone, bottom is mudstone, and upper is calcitized dolomite with cloudy core and bright margin. Ordos basin, well ZT1, O_1m^5, PPL, ×50, stained. Corresponding to the right core.

d. The cave was filled with brecciated limestone. Showing dedolomitization after patchy dolomitization, and cemented by calcareous mud and powder crystal calcite. Stylolites and micro-stylolites are well developed. ZT1, O_1m^5

Fig.5 Examples of O_1m dedolomitization in Ordos basin, China

Significance of dedolomitization in carbonate diagenesis:

1. The dedolomitization is very important in recognizing exposure and unconformity. It is confirmed that the **laterally continuous distribution of dedolomitization can indicate unconformity (Fig. 5c, d)**.
2. **The dedolomitization can reconstruct the pores**. The distribution of the secondary pores associated with delomitization in the hydrocarbon reservoir maybe more universal than that thought before.

Purser (1985) considered that the dedolomitization can enlarge the dissolved moldic pore and inter crystal space. After dolomite dissolved, subsequently the space is filled with latter cements, forming dolomite crystal mold. The crystal moldic pore can indicate the exposure and the effect of meteoric water.

There is this kind of pore in Silurian dolomite in Kentucky of America. The reservoirs are fine grain dolomite and intraclastic dolomite, which have poor porosity. But the porosity can reach 9% in some area. There are two kind of pores: 50μm micropore and 5mm moldic pore. The dedolomitized calcite has poikilitic texture, but it couldn't increase the porosity by itself. The leaching of dedolomitized calcite produced the majority of pores.

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But some researches indicated that the dedolomitization destroy the primary pore and resulted in the decrease of original rock.

Well Number		TS6	GU7	LE6	QL5	QL11	CH32	CH2
Dolomite	Depth (m)	26	20	10.5	17	17	4.5	6.2
	Average Porosity Φ（%）	3.37	5.82	3.87	5.0	5.21	1.99	1.83
Limestone and Secondary Limestone	Depth (m)	30	25	18	38	30	20	20
	Average Porosity Φ（%）	1.13	1.19	1.06	1.65	2.04	1.99	1.03

Table.1 The porosity correlation table of dolomite and limestone (including secondary limestone) in East Sichuan basin, China.

In the Huanglong formation of Upper Carboniferous in East Sichuan basin of China, the dedolomitization is very universal (Fig. 7a, b, c, d). But the secondary limestones after dedolomitization have very low porosity (porosity of dolomite= 3.3-6%; porosity of dedolomitized limestone=1-2%).

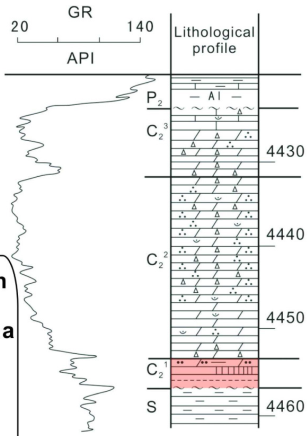
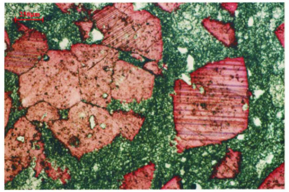
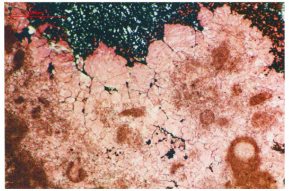


Fig.6 Lithological profile of C_2h in East Sichuan basin, China

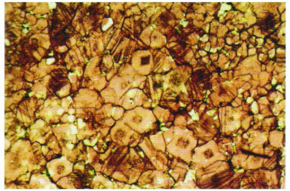
The main reservoirs of Huanglong formation are dolomite and calcareous dolomite (Fig. 8). The dedolomitization not only resulted in the calcite replacing the dolomite, but also lead to the precipitation of calcite in the primary pores. So the porosity decreased after the dedolomitization (Fig. 7a, b, c, d).



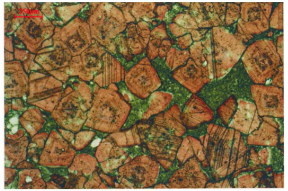
a. Dedolomitized limestone. Showing remained shape of rhombic dolomite, which have been totally calcitized. There are some solution pores in the clay cements and the dedolomitized calcite. Sichuan basin, well TS6, C_2h. PPL, stained



b. Dedolomitized limestone. Showing totally calcitized dolomite, but remain the former shape of grains and the lamina dolomite cements around the grains. Sichuan basin, well TS6, C_2h. PPL, stained



c. Fine crystal dedolomitized limestone. Showing the cloudy cores in the calcitized dolomite. Iron spread around. Sichuan basin, well QL41, C_2h. PPL, ×40, stained.



d. Medium-coarse crystal dedolomitized limestone. Automorphic-hypautomorphic dedolomitized calcites have growing rims. Well TD13, C_2h. PPL, stained

Fig.7 Examples of C_2h dedolomitization in East Sichuan basin, China

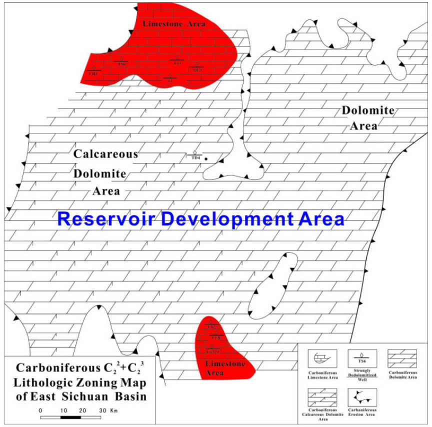


Fig.8 Sedimentary facies of C_2h in East Sichuan basin, China

<u>There is close relationship between the increasing porosity of dedolomitization and latter eluviation. Without the latter leaching, maybe the dedolomitization relevant to calcite precipitation will destroy the primary pores. Of course the dissolution after the dedolomitization can form some pores (Fig. 7a).</u>

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