

# **Dolomitization and Reservoirs Characteristics of Chx-Fxg Formation in Sichuan Basin (SW China)\***

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## **Abstract**

The upper Permian Changxing (Chx) Formation reef complexes and the lower Triassic Feixianguan (Fxx) Formation oolitic shoal carbonates in the subsurface of Sichuan Basin are significant reservoir rocks of several gas fields, and have been the focus of numerous studies on dolomitization in recent years.

The deep-burial Chx-Fxx carbonate reservoirs in Longgang area of Sichuan Basin occur at present day depth of more than 5000m. High-quality carbonate reservoirs are restricted to dolomitized strata and they are generally distributed along the platform margin, reflecting facies and diagenetic (i.e. dolomitization) control on reservoir quality. Nearly all the discovered gas pools in Longgang area are distributed in these dolomites. Understanding the mechanisms of dolomitization in these deep gas reservoirs is of vital importance for efficient hydrocarbon exploration.

Petrography, stable isotope, fluid inclusion and trace element analysis are conducted to shed light on the origin of dolomitization. A burial dolomitizing model was proposed based on the following evidences: Replacement dolomites often distribute along or overlap stylolites, suggesting formation after considerable burial; Isotopic values of dolomites range from 1.74 to 3.57‰PDB for  $\delta^{13}\text{C}$  and -4.63 to -7.33‰PDB for  $\delta^{18}\text{O}$ ; Negative oxygen isotopic values and positive carbon isotopic values indicate high precipitation temperatures and scarcely any influence from freshwater; Homogenization temperatures (range from 85 to 115 degree Centigrade) of primary fluid inclusions in dolomites suggest their deep-burial origin; High concentration of Sr and Fe in dolomites indicates a closed system and anoxic diagenetic environment.

A preliminary dolomitizing process was put forward. During sedimentation of Chx and Fxg carbonate, meteoric leaching was taken place due to periodic sea-level change. Meteoric leaching resulted in mold and/or intragranular porosity in the precursor carbonate, providing the space for subsequent dolomitizing fluids. After considerable burial, dolomitizing fluids were compelled out of the underlying shales and/or the basinal shales in Kaijiang-Liangping Trough. Dolomitizing fluids migrated upward along faults and fractures and entered the porous and permeable Chx-Fxg carbonate altered by meteoric leaching, and dolomitization occurred.

### References

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- Ma, Y., T. Guo, X. Zhao, and X. Cai, 2008, The formation mechanism of high-quality dolomite reservoir in the deep of Puguang Gas Field: *Science in China Series D: Earth Sciences*, v. 51, Suppl. 1, p. 53-64. doi: 10.1007/s11430-008-5008-y
- Wang, E., B.C. Burchfiel, L.H. Royden, L. Chen, J. Chen, W. Li, and Z. Chen, 1998, Late Cenozoic Xianshuihe-Xiaojiang, Red River, and Dali fault systems of southwestern Sichuan and central Yunnan, China: *GSA Special Paper*, v. 327, 108 p.
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# Reservoir Characteristics and Dolomitization of Chx-Fxg Carbonates in Sichuan Basin (SW China)

Liyin Pan<sup>a,b</sup>, Jianfeng Shou<sup>a,b</sup>, Jingao Zhou<sup>a</sup>



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# Outline

- **Geological setting of Sichuan basin**
- **Dolomitization control on reservoirs**
- **Dolomite petrography & geochemistry, and interpretation**
- **Conclusions**

## Objectives

- ◆ **to show the importance of dolomitization to reservoir development**
- ◆ **to discuss the dolomitization mechanism**

# Geological setting of Sichuan basin

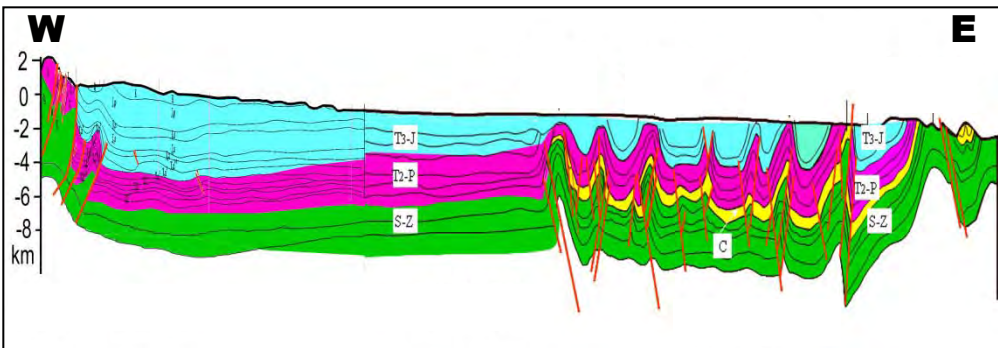
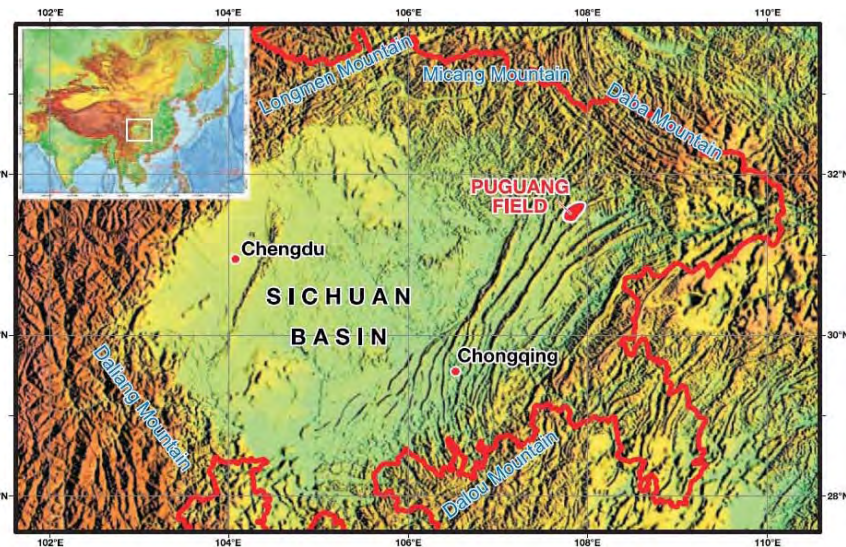
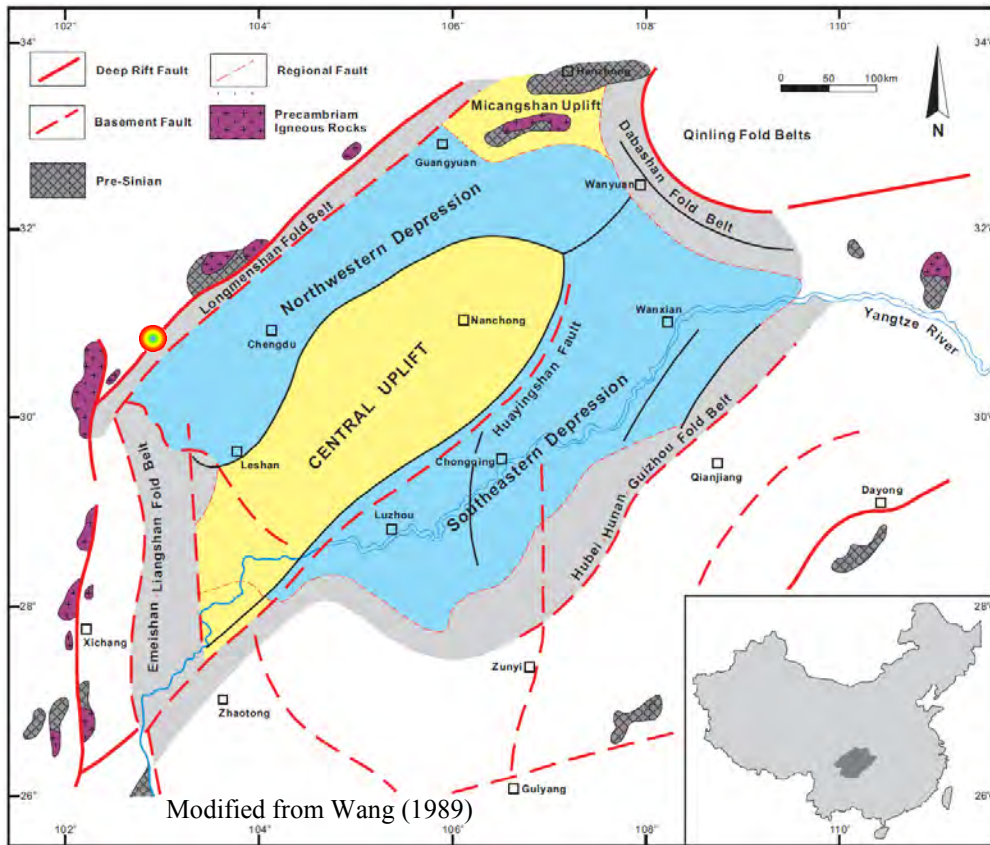
## A complicated basin

- **Craton basin (Z-T<sub>2</sub>)**

4000-9000m marine carbonate

- **Foreland basin (T<sub>3</sub>-Q)**

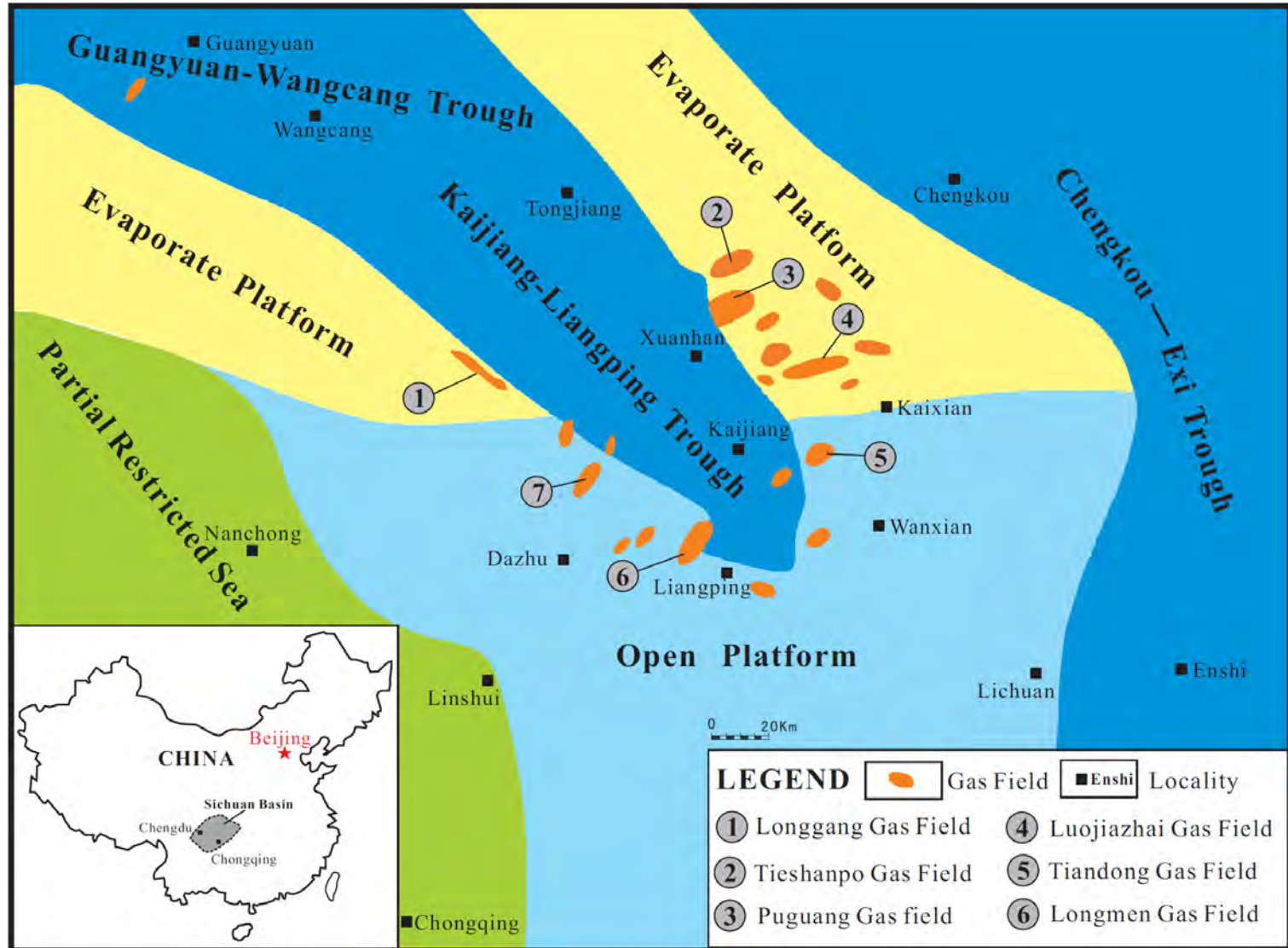
2000-6000m siliciclastics





# Changing and Feixianguan Fm.

- significant reservoir rocks for several giant gas fields
- recent focus of numerous studies on carbonate sedimentology & reservoir development



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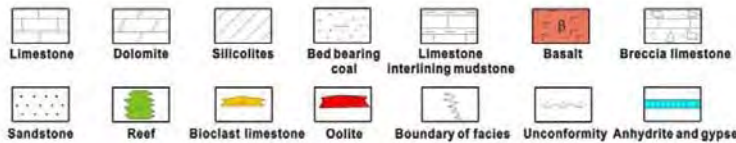
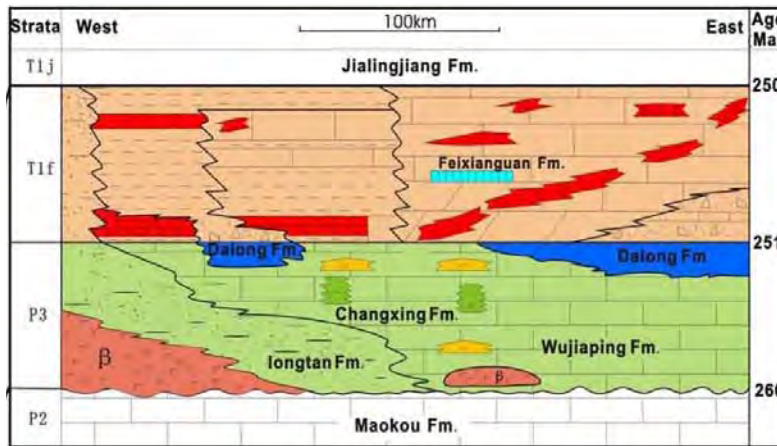
# Sedimentology of Chx & Fxg carbonate

## Changxing Fm.

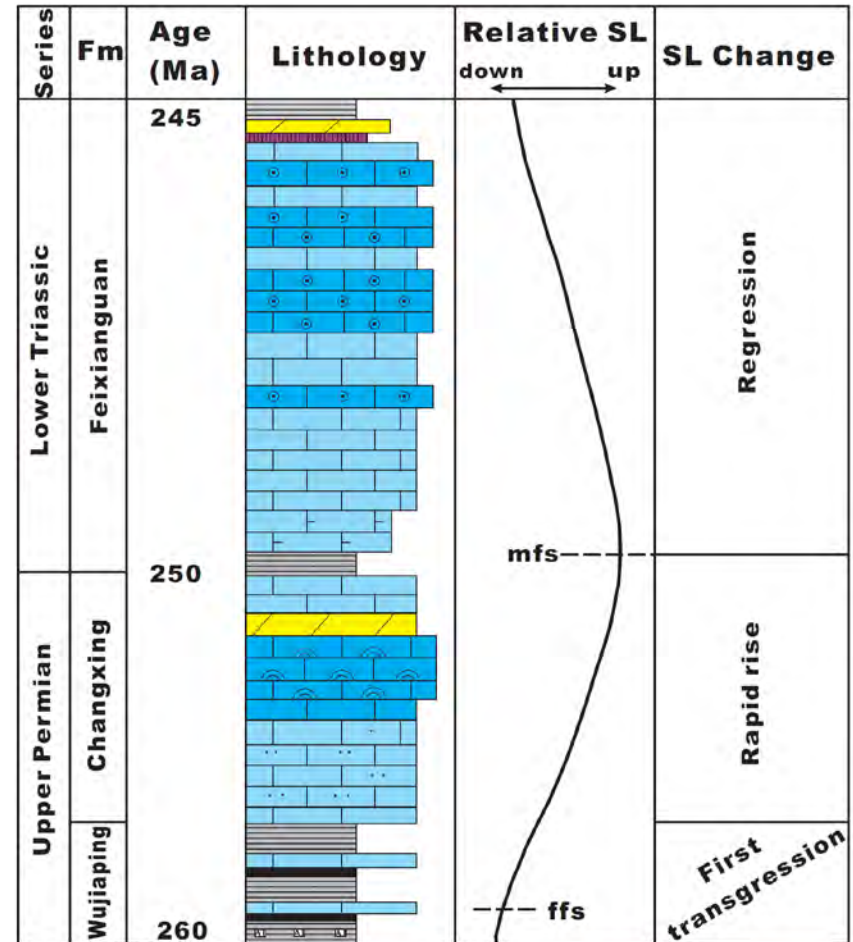
Reef complex developed in TST

## Feixianguan Fm.

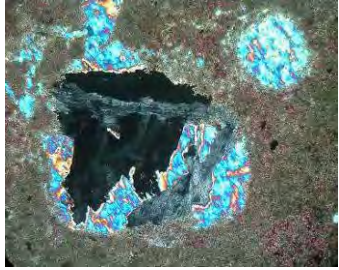
Oolitic shoals developed in HST



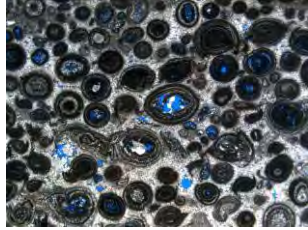
after Wang et al (1998)



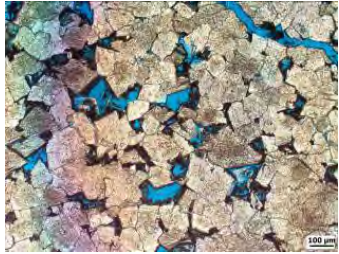
# Lithology



**Evaporite** →



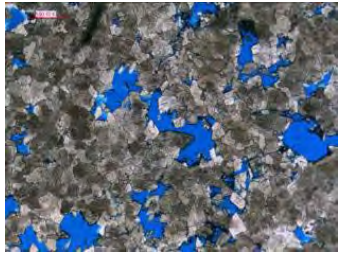
**Oolite** →



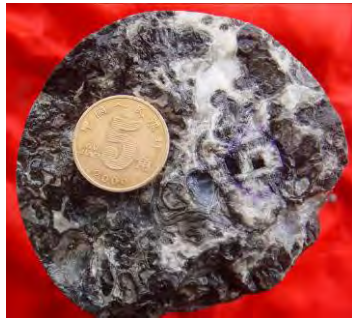
**Dolomite** →



**Micrite** →



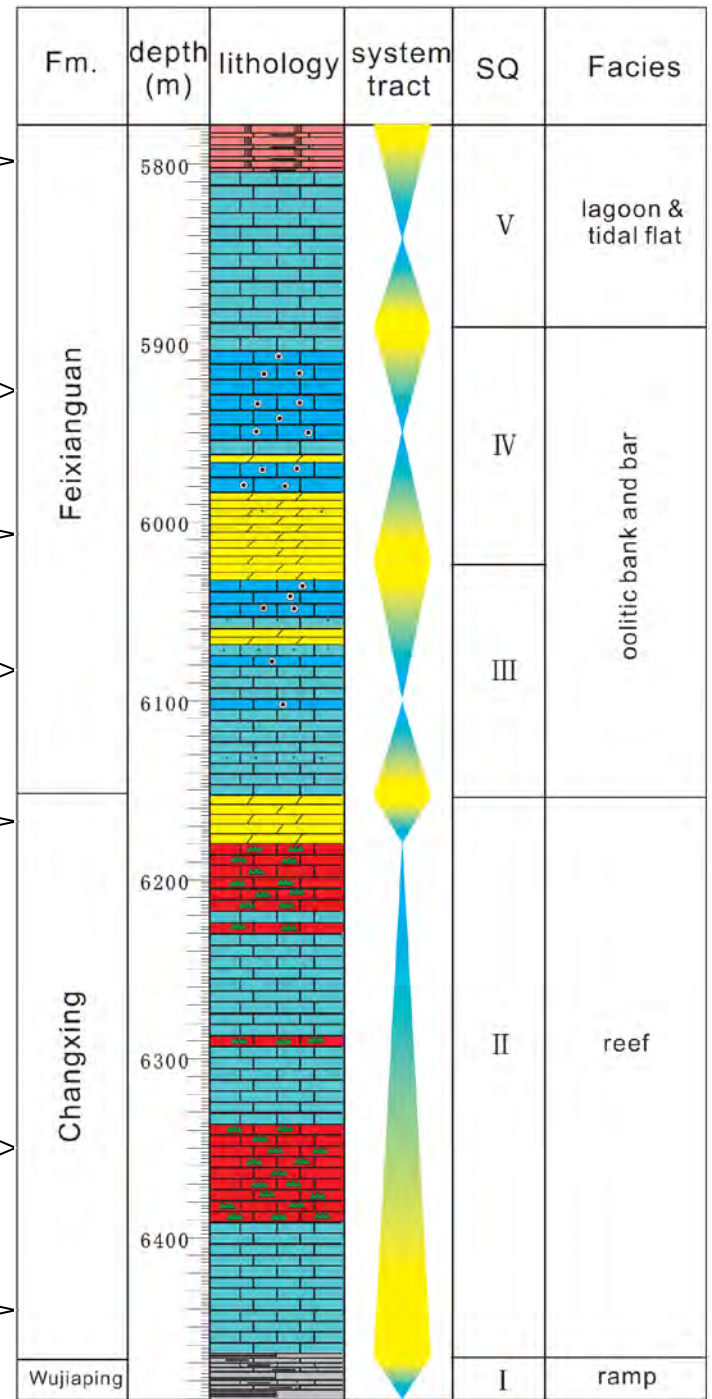
**Dolomite** →



**reef limestone** →

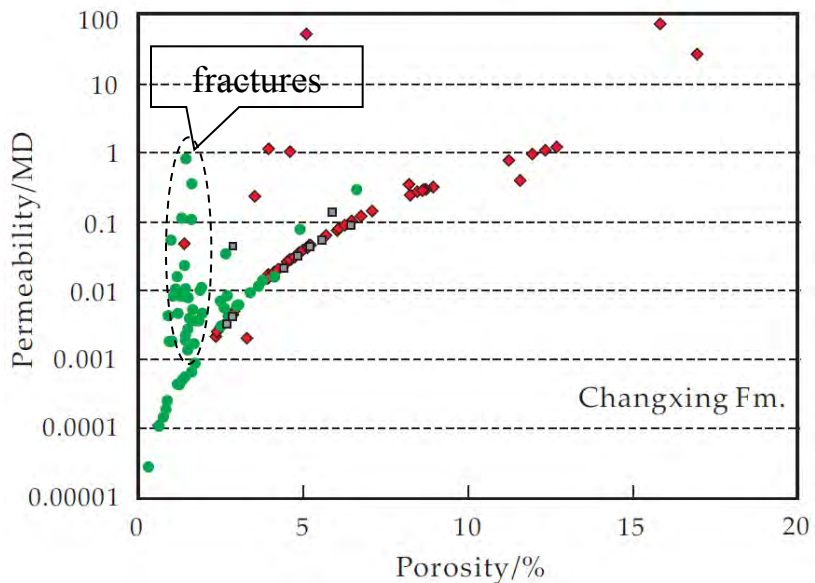
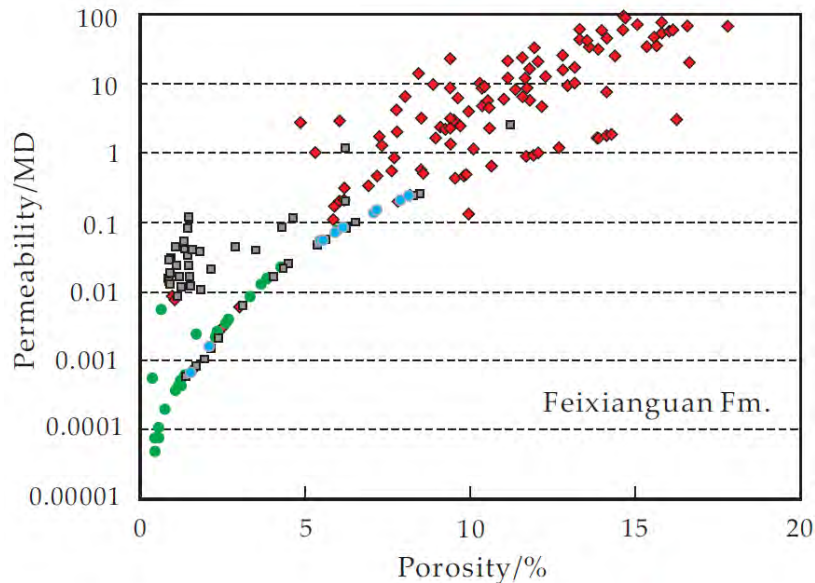
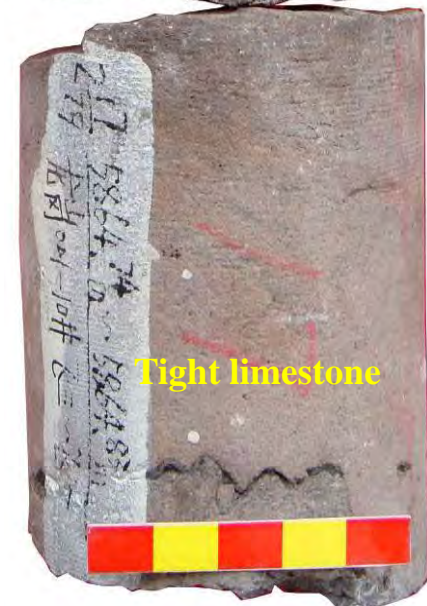
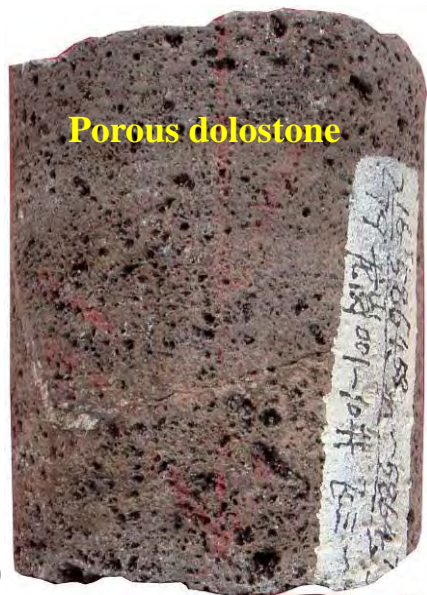


**Micrite** →



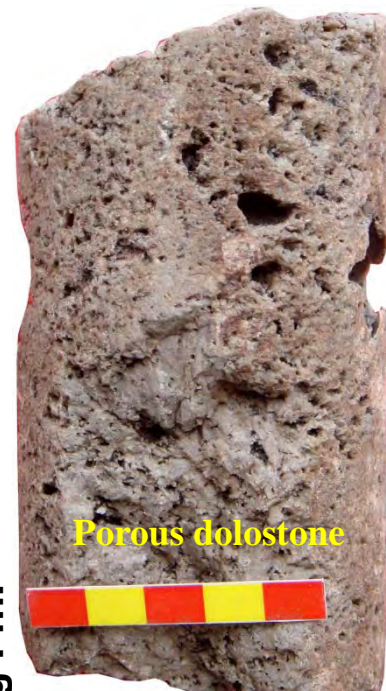
# Importance of dolomitization

Feixianguan Fm.



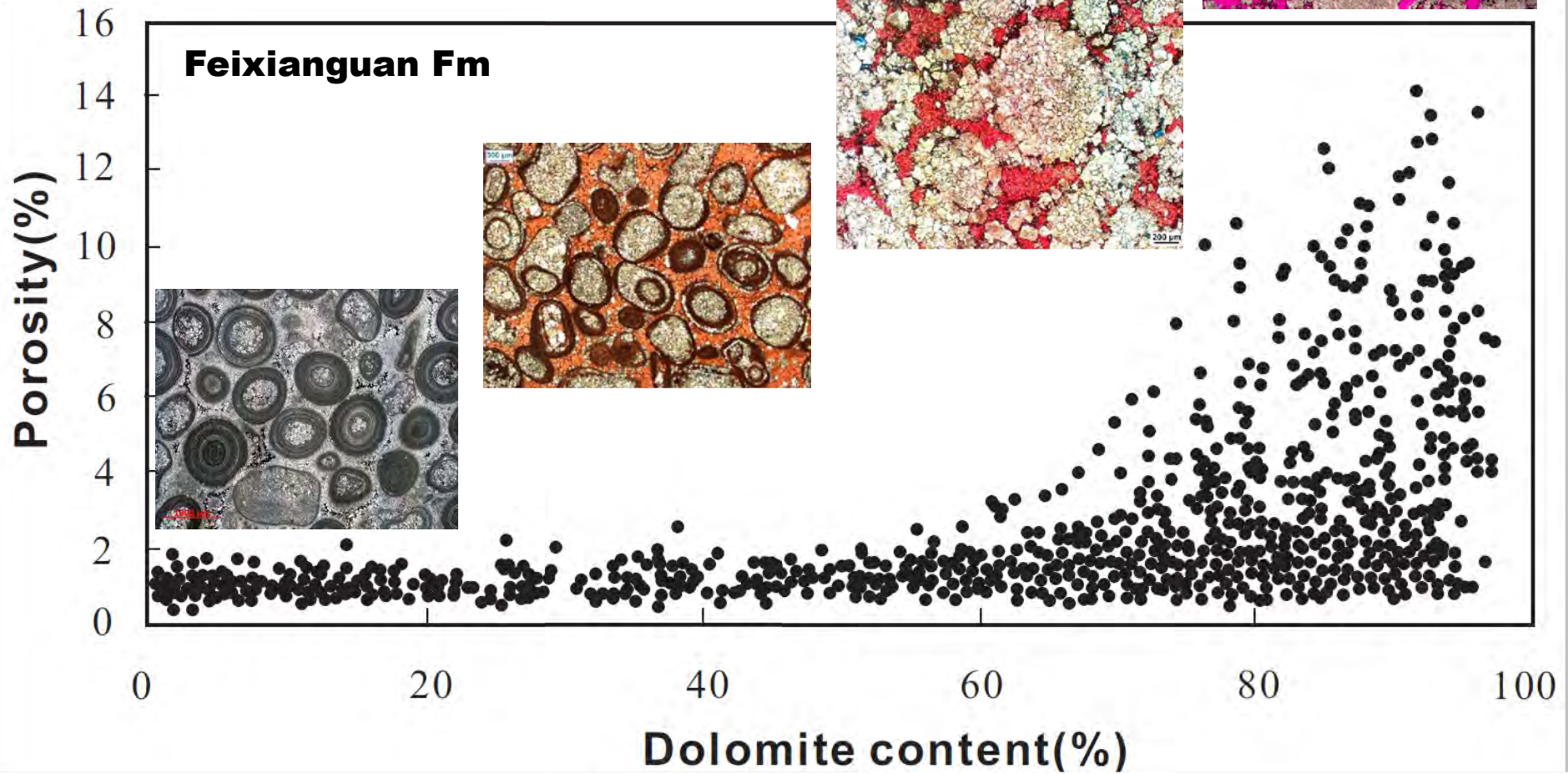
- Limestone
- ◆ Dolostone
- Limestone with mold porosity
- Calcareous dolostone and/or dolimitic Limestone

Changxing Fm.

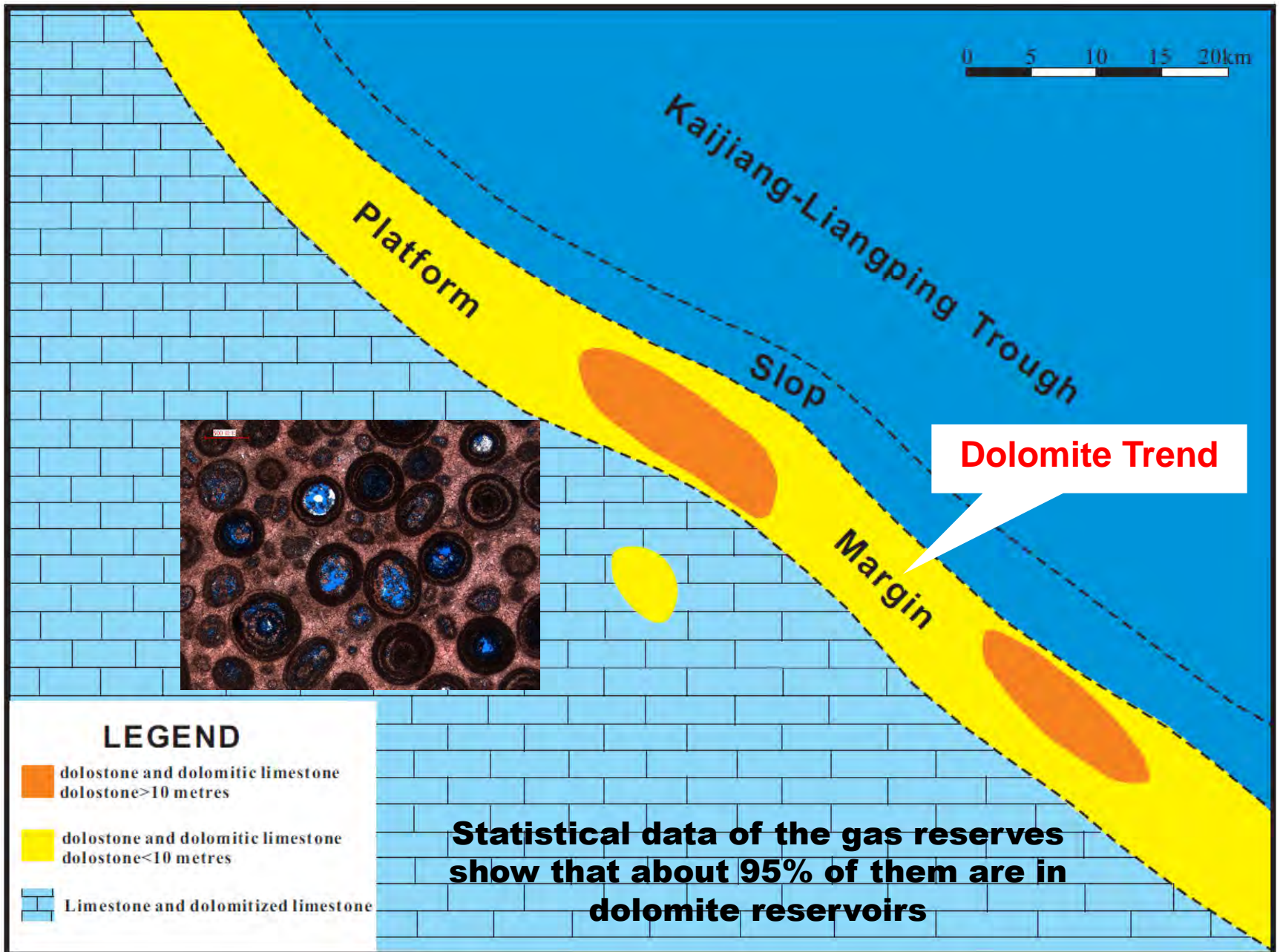


# Importance of dolomitization

Increasing porosity with increasing dolomite



# Distribution of dolomite reservoirs



# Outline

- **Geological setting of Sichuan basin**
- **Dolomitization control on reservoirs**
- **Dolomite petrography & geochemistry, and interpretations**
- **Conclusions**

# Origin of Dolomite

## Previous study

- Dolomicrite- unanimously formed by evaporative pumping model
- Other dolomites- full of debate

Fm.	Penecontemporaneous	Seepage Reflux	Mixing-zone	Burial	references
Fyg	<input type="checkbox"/>			<input type="checkbox"/>	Cai et al(2005)
	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>	Mu et al(1994)
		<input type="checkbox"/>	<input type="checkbox"/>		Zeng et al(2007)
		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Yang et al(2006)
		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Yang et al(2002)
		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Chen et al(2005)
		<input type="checkbox"/>			Luo et al(2006)
			<input type="checkbox"/>	<input type="checkbox"/>	Ma(2007)
			<input type="checkbox"/>		Xu et al(2004)
			<input type="checkbox"/>		Zhu et al(2004)
			<input type="checkbox"/>	<input type="checkbox"/>	Wang et al(1993)
			<input type="checkbox"/>	<input type="checkbox"/>	He et al(2007)
		<input type="checkbox"/>		<input type="checkbox"/>	Huang et al(2010)
		<input type="checkbox"/>		<input type="checkbox"/>	Wang et al(2006)
Chx	<input type="checkbox"/>		<input type="checkbox"/>		Wang et al(2006)
	<input type="checkbox"/>			<input type="checkbox"/>	Ma et al(2006)
	<input type="checkbox"/>			<input type="checkbox"/>	Qiang et al(1992)
	<input type="checkbox"/>			<input type="checkbox"/>	Lei et al(1994)
		<input type="checkbox"/>			Li(1989)
			<input type="checkbox"/>	<input type="checkbox"/>	Wu et al(1990)

Notes by Presenter: Dolomicrite is unanimously considered to be formed by evaporative pumping dolomitization. Formation mechanism of those porous dolomites for the gas reservoirs is still a matter of debate.

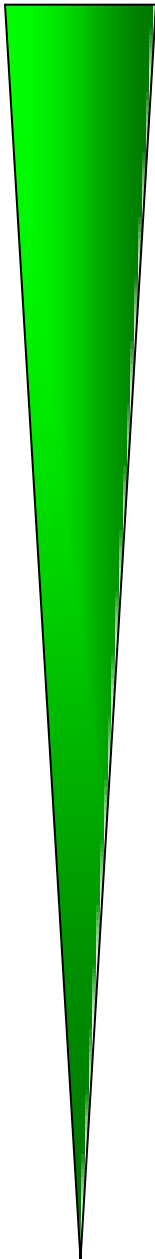
## **This study**

- **Changxing dolomites were formed primarily in burial environment**
- **Feixianguan dolomites were mostly early-formed, but experienced significant burial alteration**

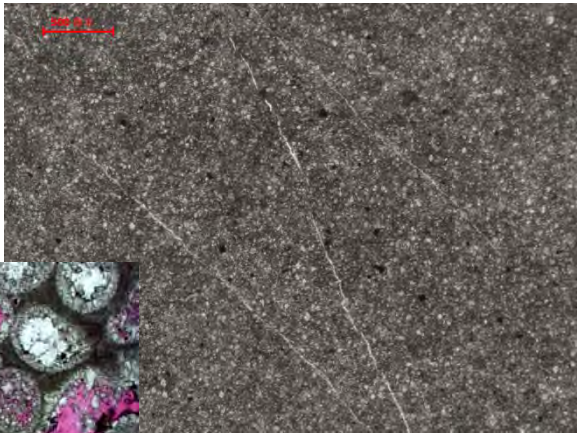


# Dolomite Petrography

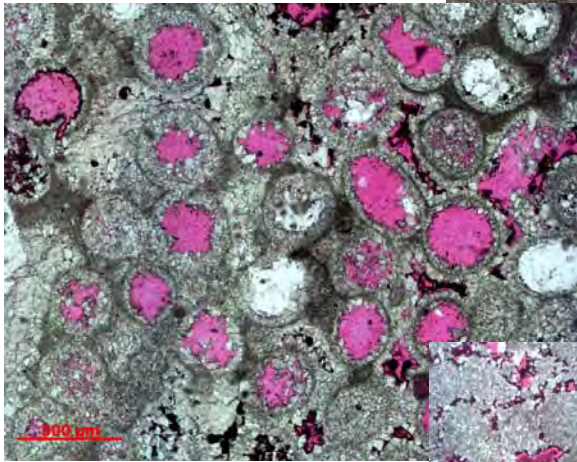
## Feixianguan Fm.



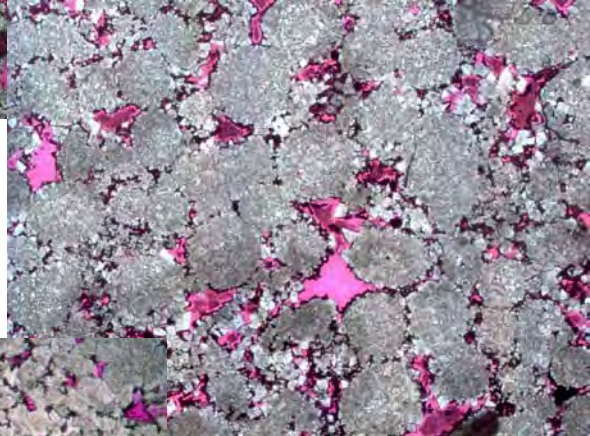
dolomicrite



oomoldic

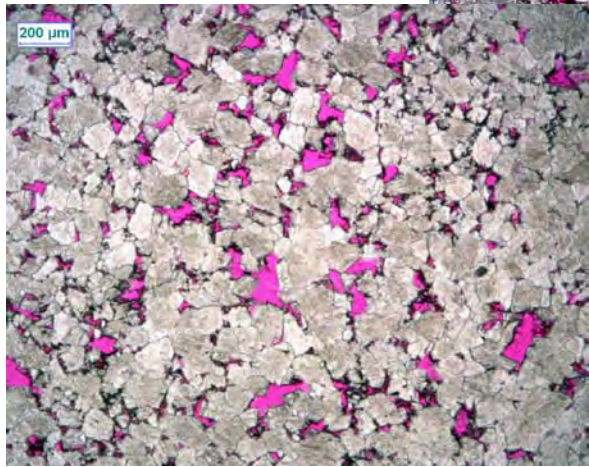


peloid



◆ Four types of dolomite textures

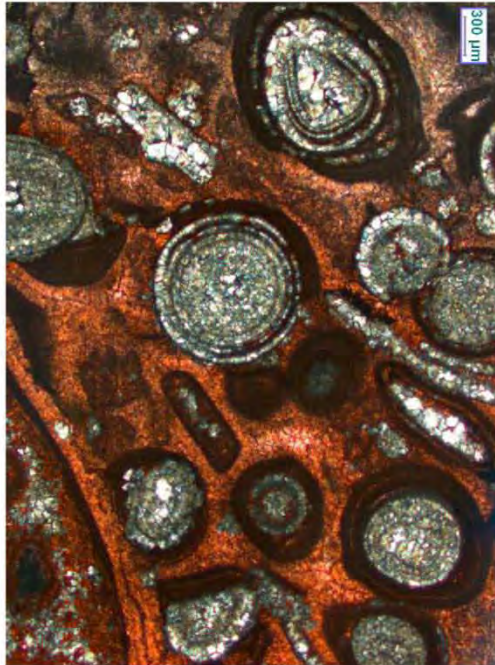
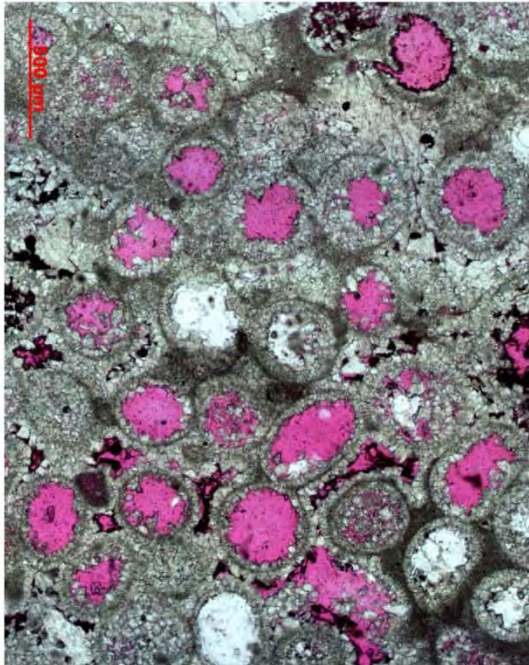
◆ Different dolomite occurred in different position within a shallowing-upward circle



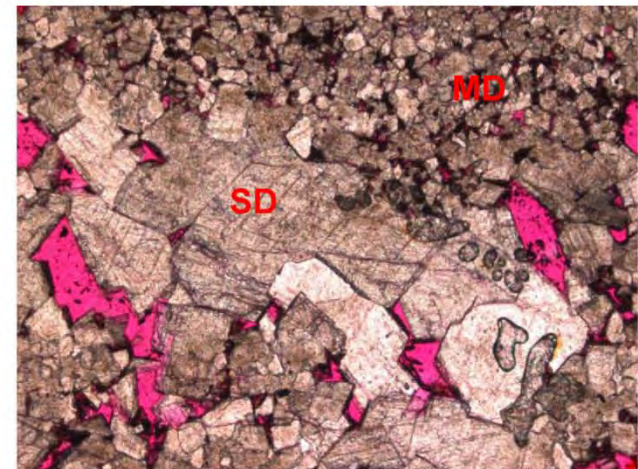
crystalline

# Dolomite Petrography

- preservation of uncompact fabrics
- fabric-selective dolomitization
- multistage dolomitization

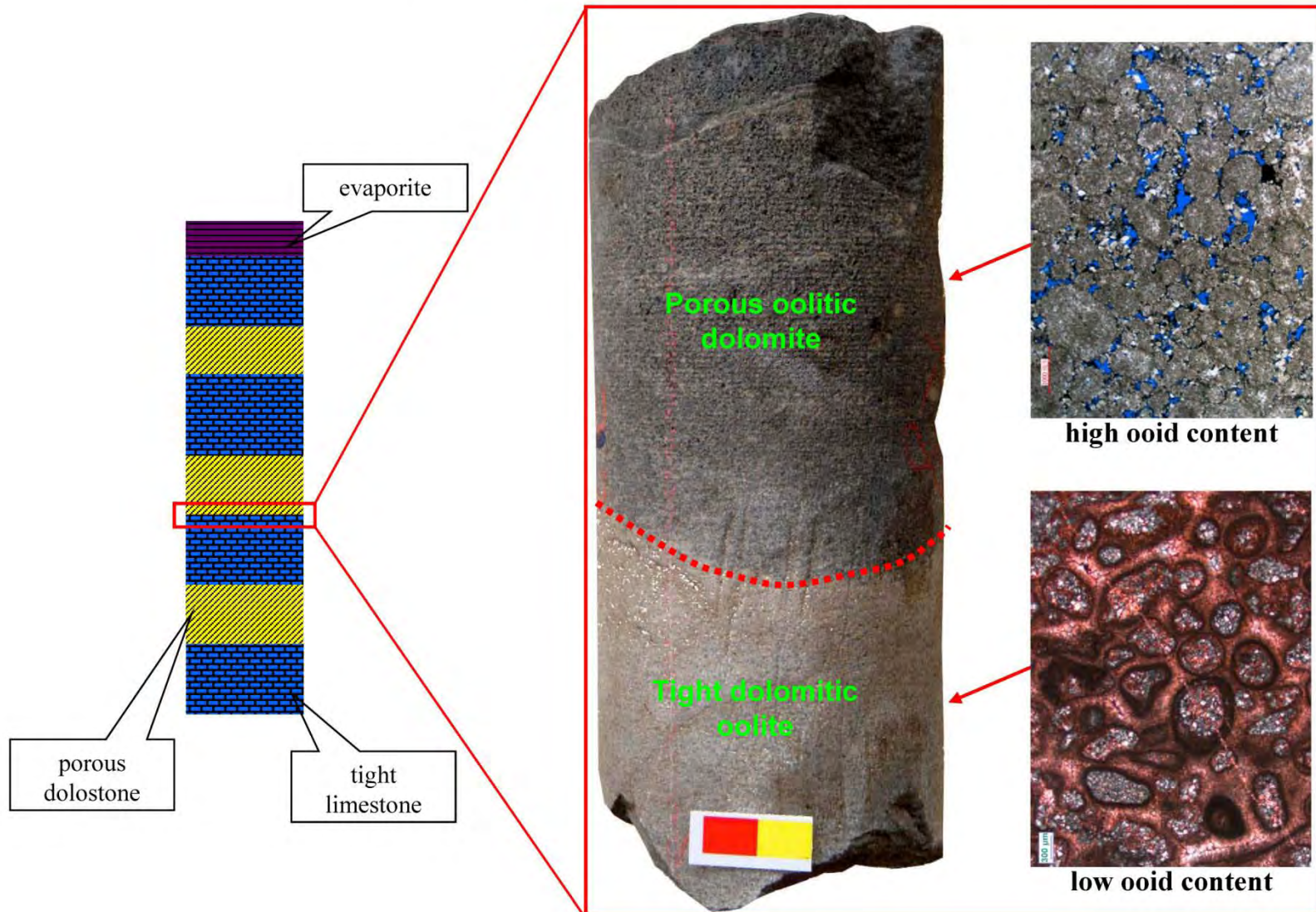


## Feixianguan Fm.



Notes by Presenter: Preservation of uncompact fabrics, which therefore requires very early consolidation.

## ● Presence of undolomitized/dolomitized intervals

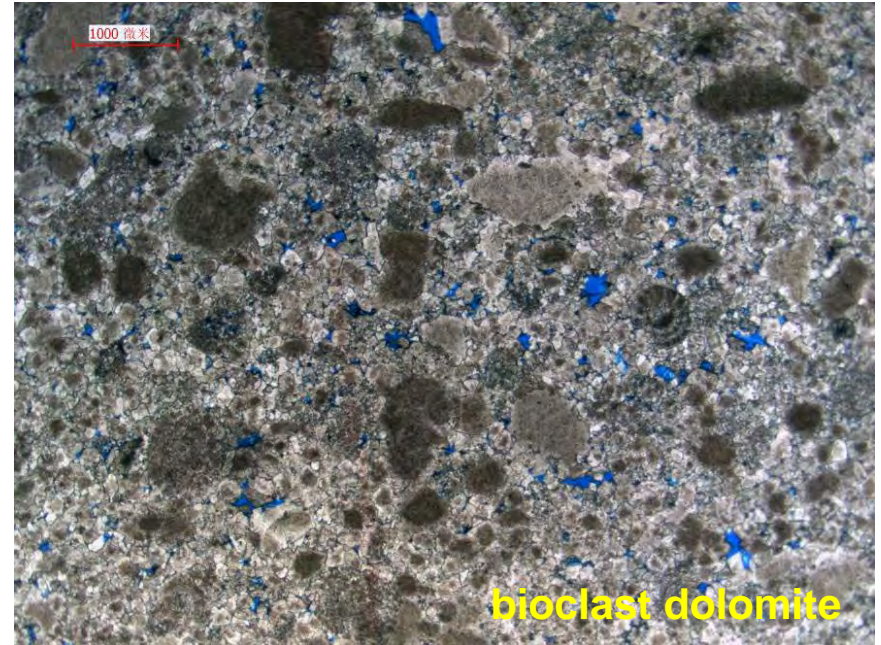


Notes by Presenter: Presence of undolomitized/dolomitized intervals - "fingers" - edge of dolomitization front/periodic reflux.

# Dolomite Petrography

## Changing Fm.

- bioclast limestone on the top of reef complex was preferentially dolomitized
- organic framework reef was not or just slightly dolomitized

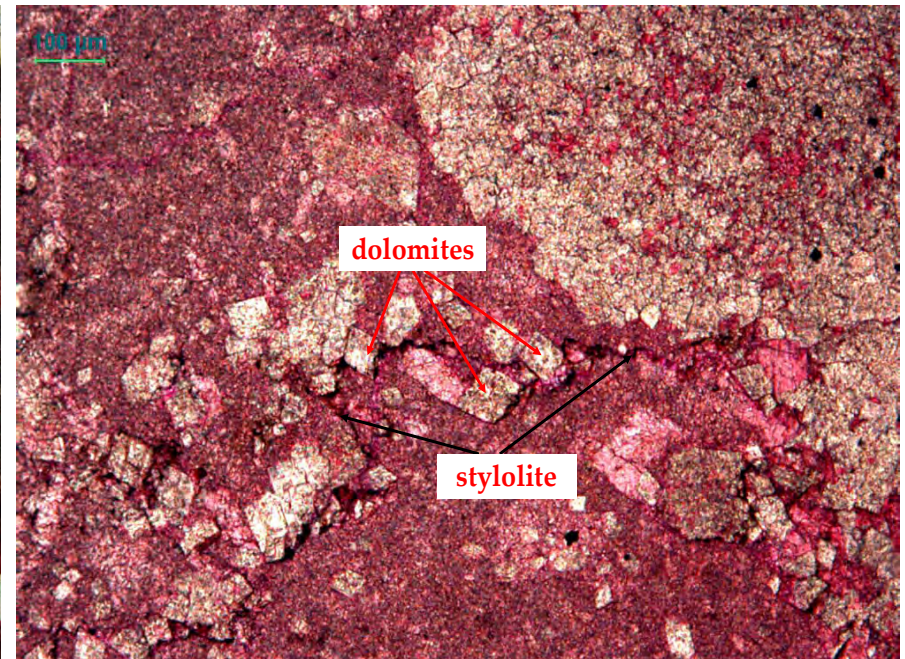


# Dolomite Petrography

Changing Fm.



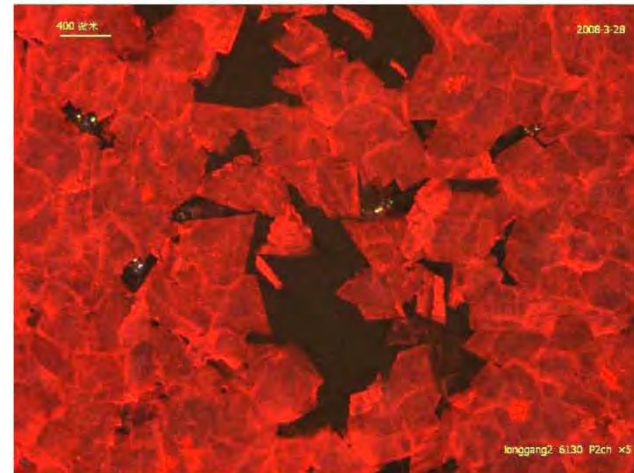
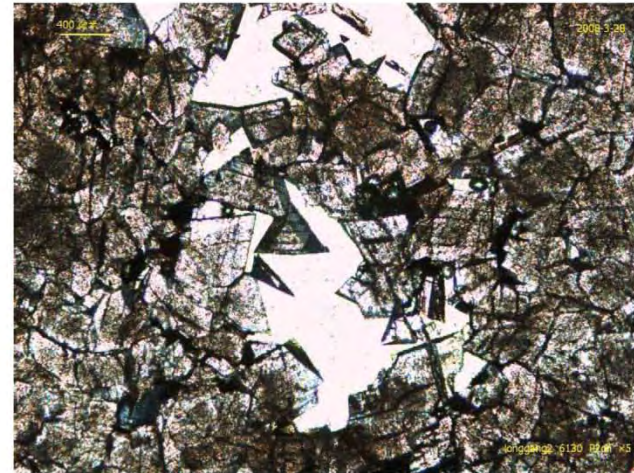
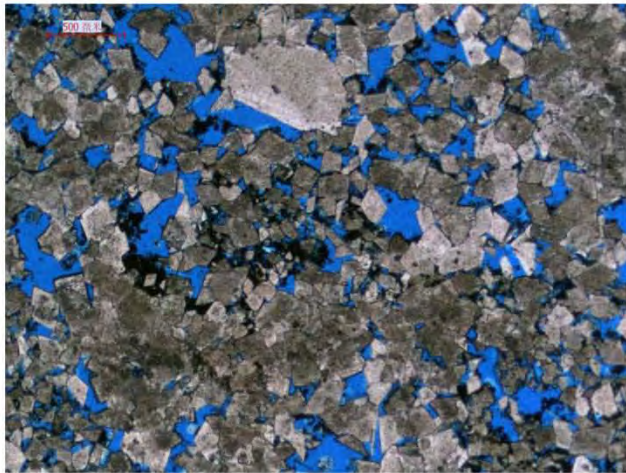
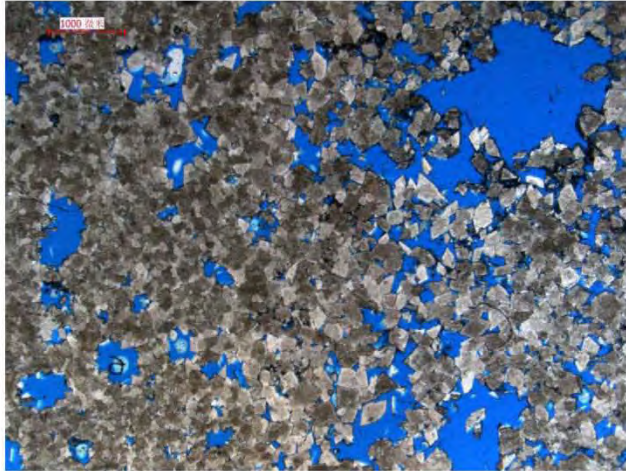
- postdated radiaxial fibrous or isopachous calcite cements
- usually occurred along fractures and dissolution seams



# Dolomite Petrography

## Changing Fm.

- Dolomites are typically medium-to-coarse crystalline, sucrosic, and of bright red luminescence



Notes by Presenter: The dissolution features in the coarsely crystalline dolomite appear to have been caused by the dissolution of relict limestones during dolomitization, as suggested by the lack of such dissolution features in the adjacent limestones.

# Dolomite Geochemistry

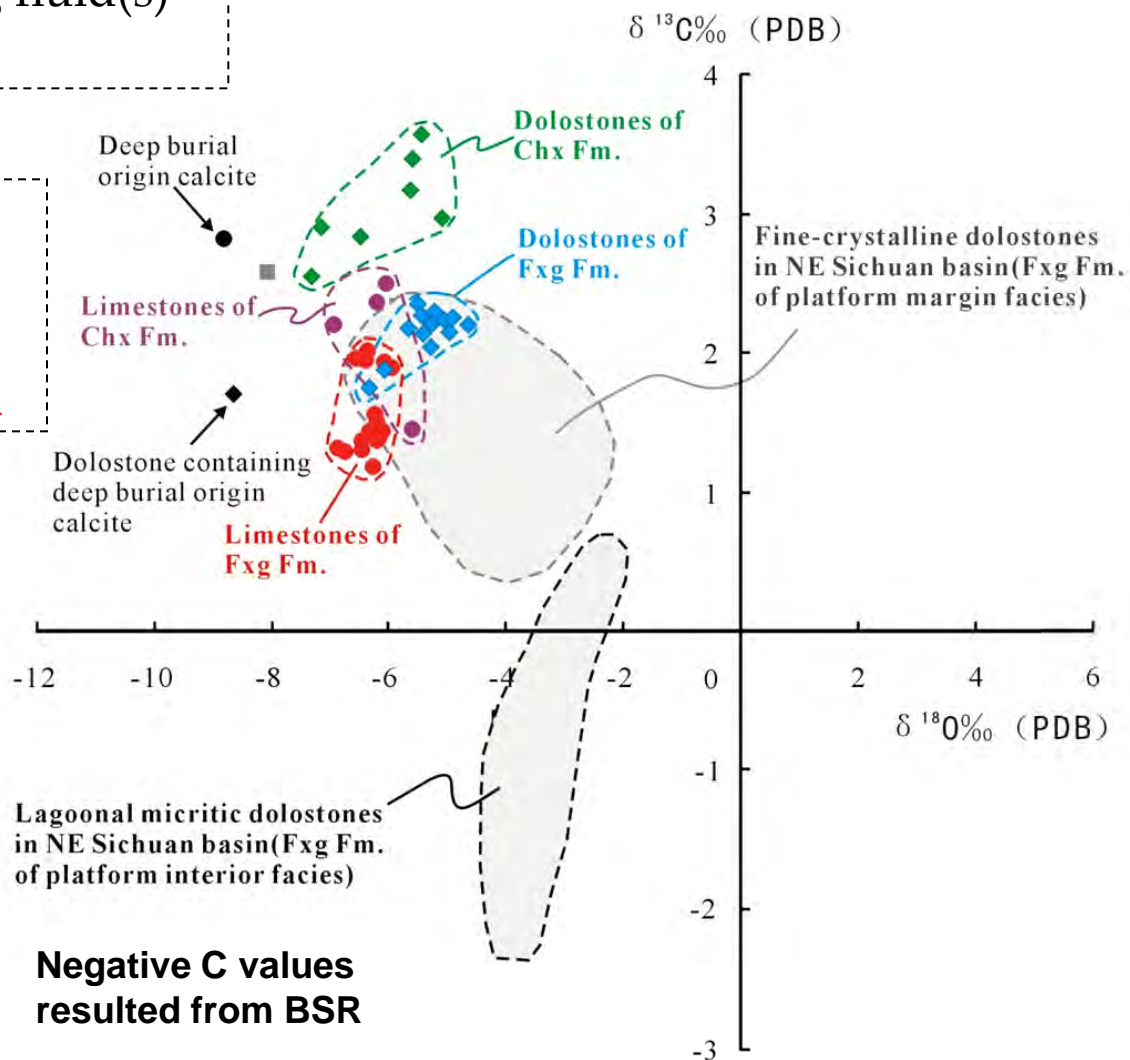
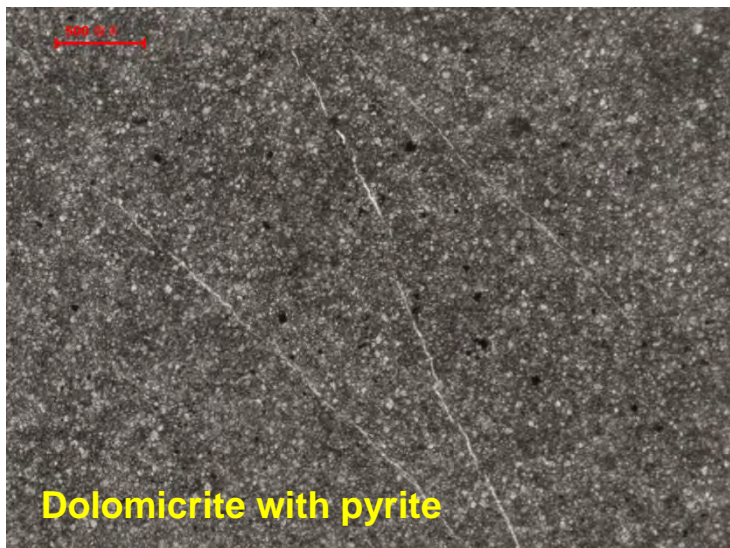
## Carbon and oxygen isotope

### Positive C values

- marine origin of dolomitizing fluid(s)
- rare or no freshwater influence

### Negative O values

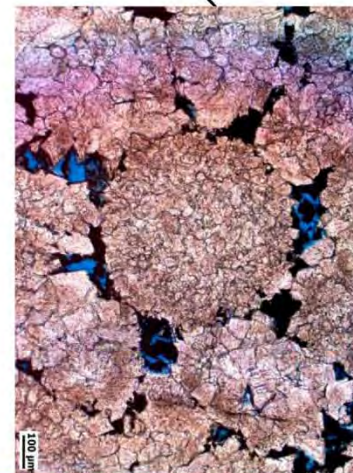
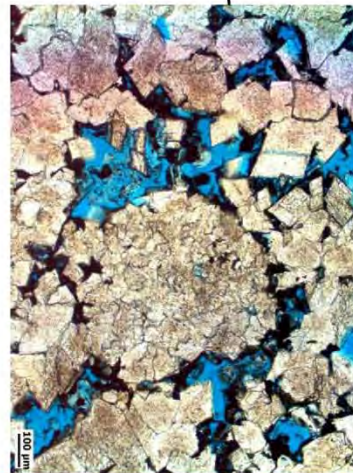
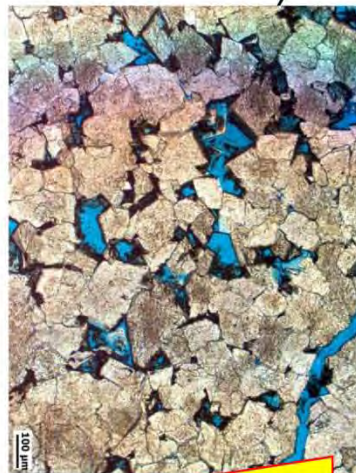
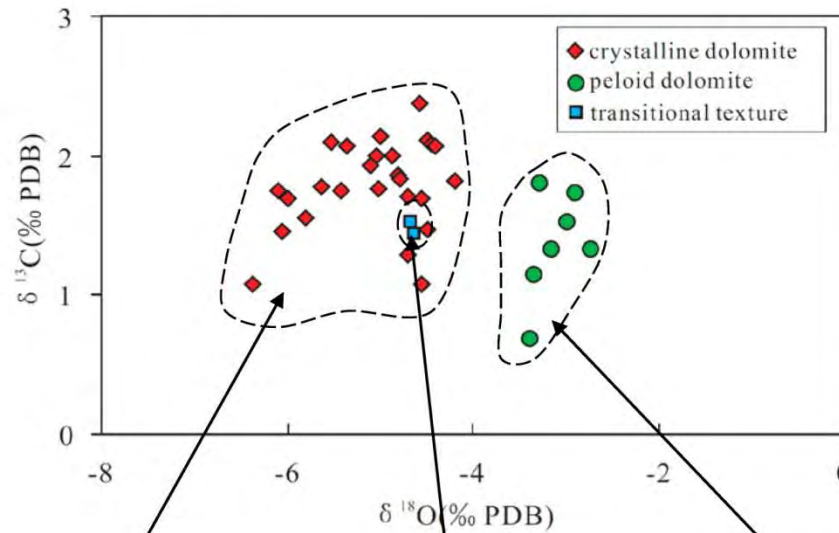
- freshwater influence? **NO**
- high temperature? **Changxing**
- recrystallization? **Feixianguan**



# Dolomite Geochemistry

# Carbon and oxygen isotope

Feixianguan Fm.



**← Increasing burial alteration**

Notes by Presenter: Transitional dolomite textures from peloid dolomite to crystalline dolomite and corresponding increasingly depleted  $^{18}\text{O}$ .



# Dolomite Geochemistry

# Strontium isotope

## Feixianguan dolomite

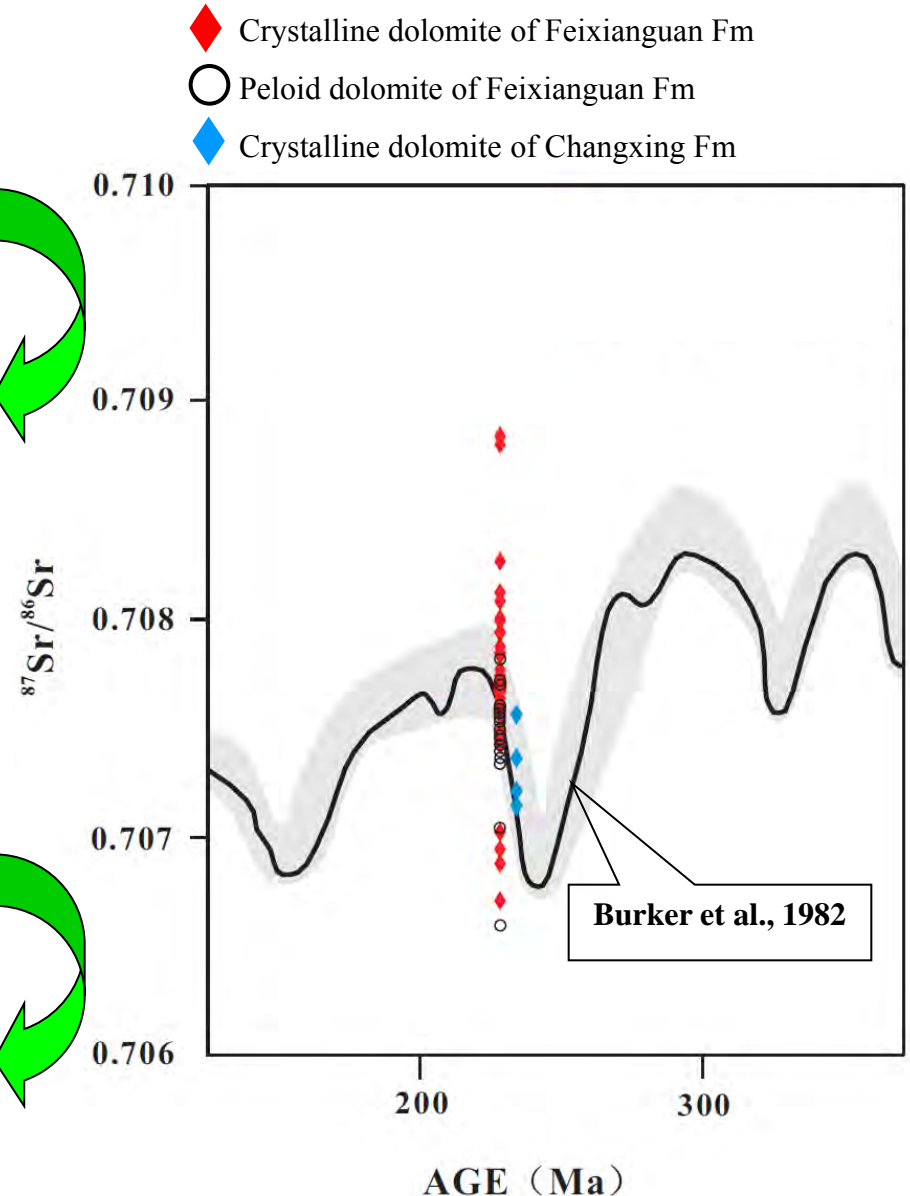
cover and beyond the range of early Triassic seawater

Alteration of early-formed dolomite

## Changing dolomite

within the range of late Permian seawater

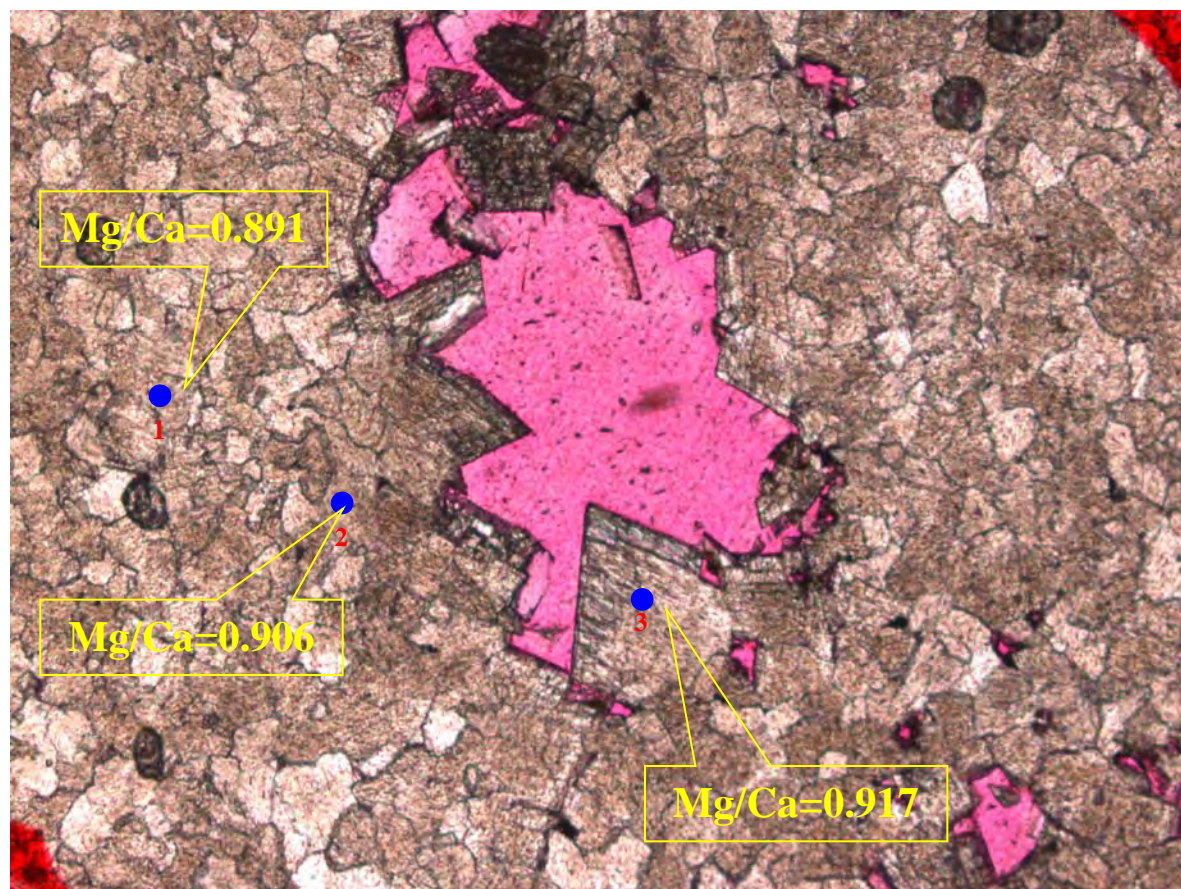
Dolomitizing fluids were probably the late Permian seawater



# Dolomite Geochemistry

## Major and trace element

**Feixianguan dolomites Ca&Na-rich, Sr-poor, indicating early, rapid nucleation in saline water of an open system**

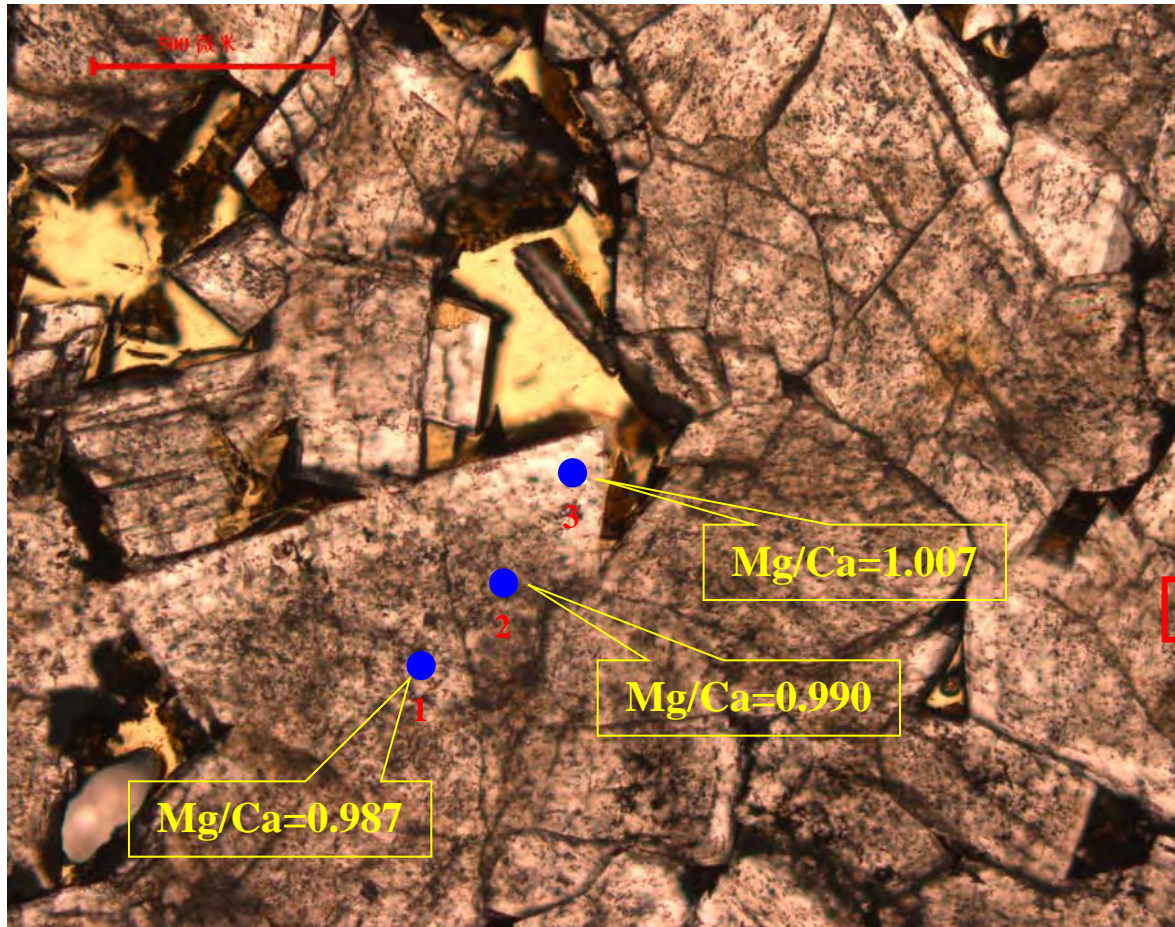


Point	1	2	3
Na	586	608	704
Sr	bdl	bdl	279
Mn	132	751	201
Fe	389	350	350

# Dolomite Geochemistry

## Major and trace element

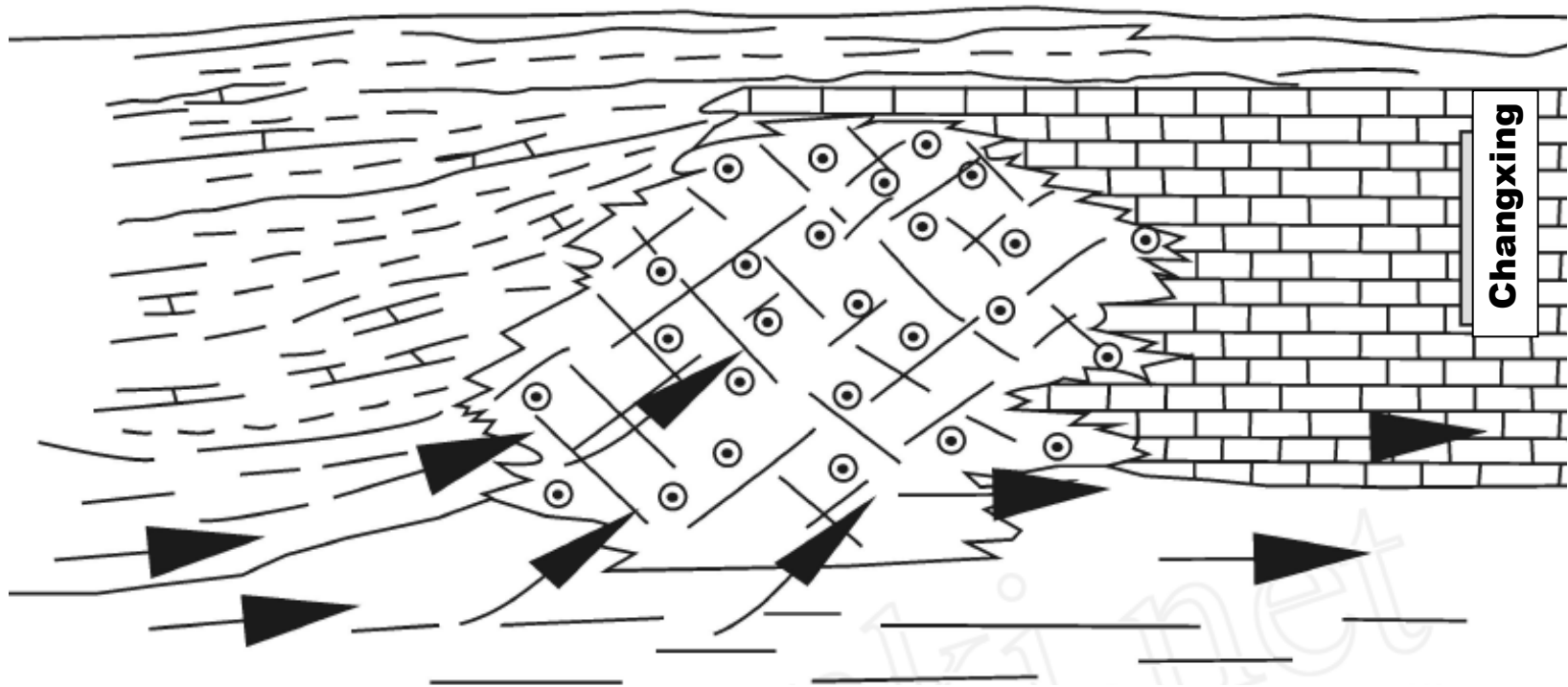
**Changxing dolomites** Near stoichiometry and low-Na reflecting slow growth from dilute solutions, possibly aided by elevated temperatures



Point	1	2	3
Na	67	59	bdl
Sr	bdl	254	1193
Mn	147	bdl	bdl
Fe	bdl	bdl	241

# CHANGXING DOLOMITES WERE FORMED PRIMARILY IN BURIAL ENVIRONMENT

coarse crystalline, relationship to fractures & dissolution seams,  
depleted  $^{18}\text{O}$  but normal  $^{87}\text{Sr}/^{86}\text{Sr}$ , near stoichiometry.....



**Possible model for Changxing dolomitization**

# **FEIXIANGUAN DOLOMITES WERE MOSTLY EARLY-FORMED, BUT EXPERIENCED SIGNIFICANT BURIAL ALTERATION**

## **Early dolomitization**

- **preservation of uncompact fabrics**
- **fabric-selective**
- **presence of undolomitized /dolomitized intervals**
- **Ca, Na-rich, Sr-poor dolomites**

## **Evidences for burial alteration**

- **pore filling coarse dolomite and/or saddle dolomite**
- **transitional dolomite textures from peloid dolomite to crystalline dolomite and corresponding increasingly depleted  $^{18}\text{O}$**
- **scattered  $^{87}\text{Sr}/^{86}\text{Sr}$**

# Model for FXG Dolomitization Process

## Stage 1&2 - Deposition and marine diagenesis

Micritization, marine cementation.....



Micrite envelopes, fibrous high-Mg calcite cement

## Stage 3 - Meteoric diagenesis and subsequent reflux dolomitization

Dissolution, cementation, dolomitization .....



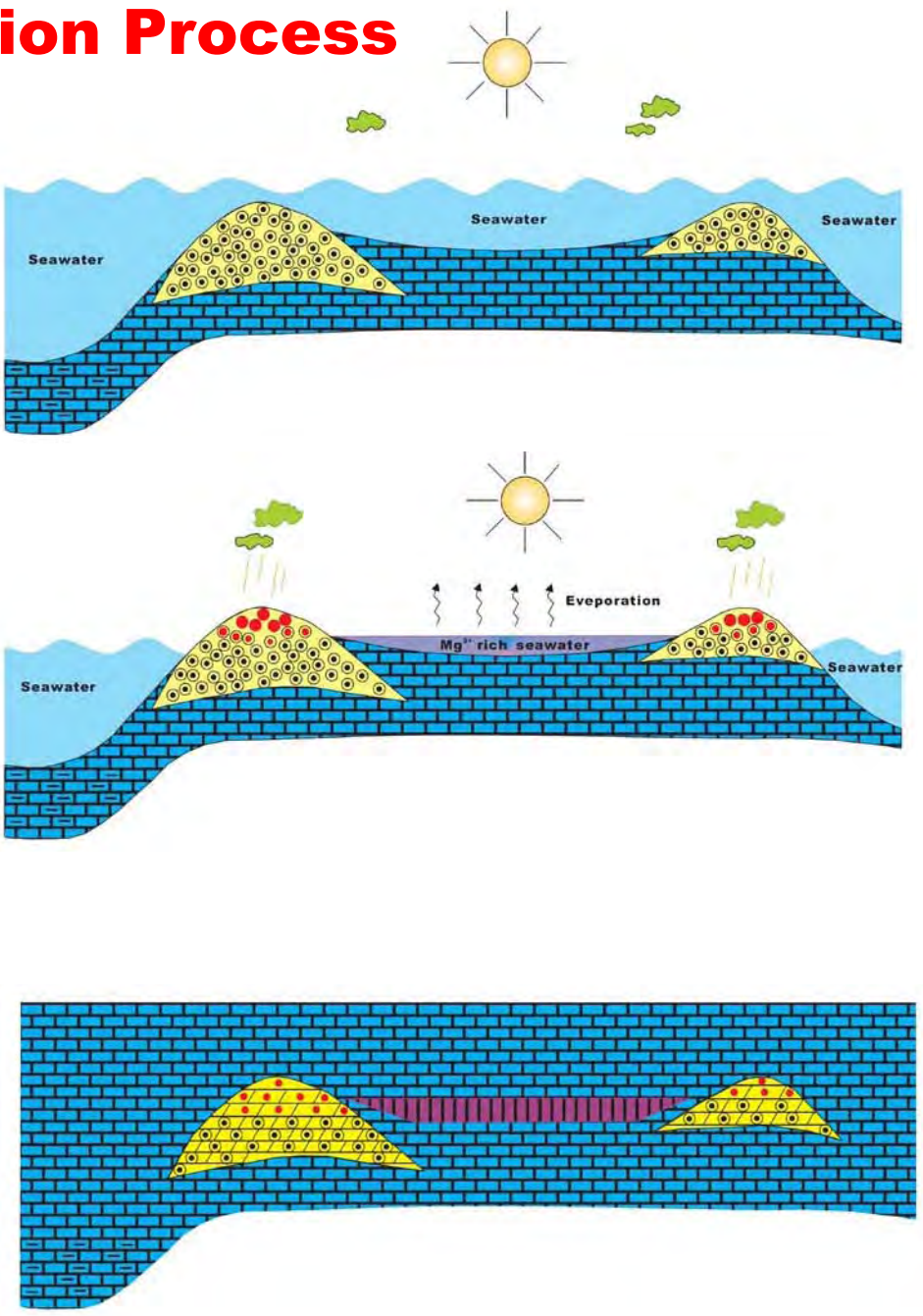
Moldic and/or intragranular porosity, equant calcite cement, oomoldic and ooid dolomite

## Stage 4 - Burial diagenesis (alteration)

Recrystallization, cementation, TSR, dissolution .....



Original fabric destruction, PF-dolomite and saddle dolomite, PF-blocky calcite, increasingly depleted  $^{18}\text{O}$ , scattered  $^{87}\text{Sr}/^{86}\text{Sr}$ , sour gas, vugs.....



# Model for FXG Dolomitization Process

## Stage 1&2 - Deposition and marine diagenesis

Micritization, marine cementation.....



Micrite envelopes, fibrous high-Mg calcite cement

## Stage 3 - Meteoric diagenesis and subsequent reflux dolomitization

Dissolution, cementation, dolomitization .....



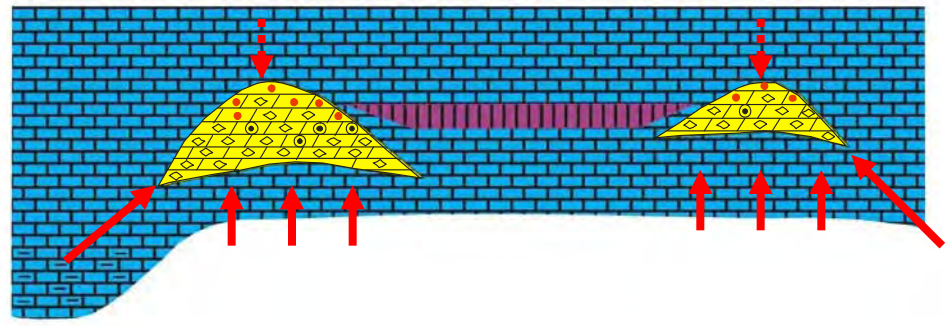
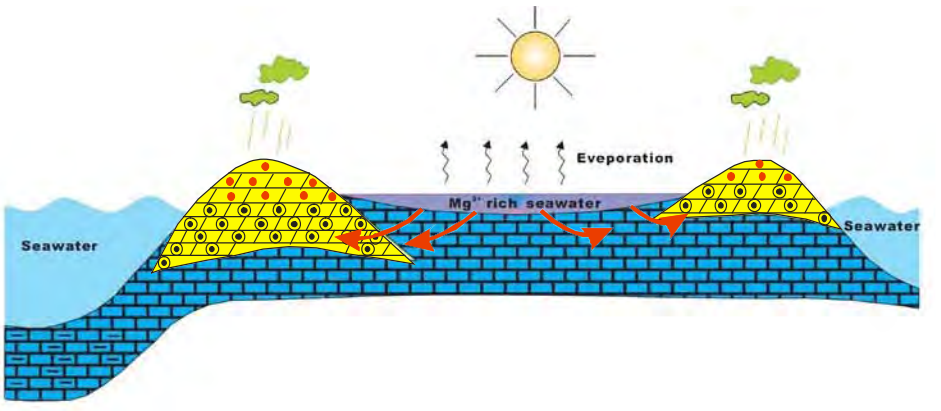
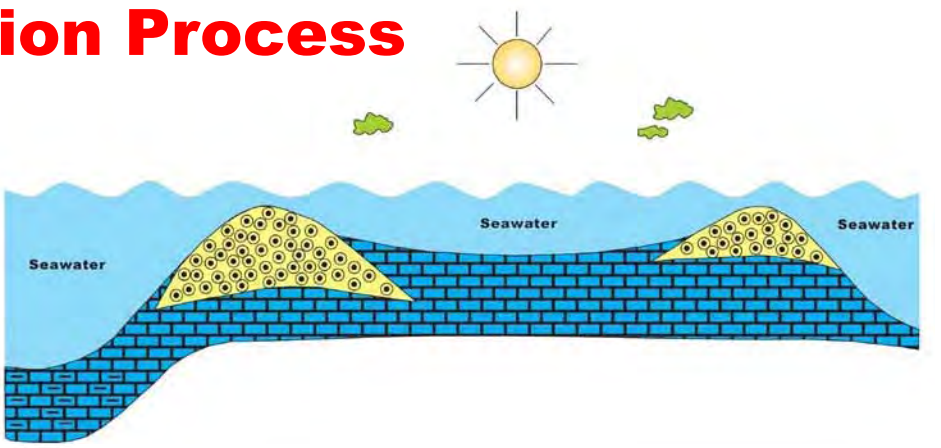
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Original fabric destruction, PF-dolomite and saddle dolomite, PF-blocky calcite, increasingly depleted  $^{18}\text{O}$ , scattered  $^{87}\text{Sr}/^{86}\text{Sr}$ , sour gas, vugs.....



# Conclusions

- **Dolomitization played a significant role in the development of Chx & Fxg carbonate reservoirs in Sichuan basin**
- **Dolomites are mainly distributed along the platform margin**
- **Based on sedimentology, petrography and geochemistry, Changxing dolomites were formed in burial environment; while Feixianguan dolomites were mostly early-formed, but experienced significant burial alteration**





***Thanks for your attention!***

**Questions?**