Does Aragonite-Dolomite Sea Exist? Widespread Marine Dolomite Precipitation in Ediacaran Period in China*

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Abstract

The extraordinary abundance of dolomite in the Ediacaran Period challenges our understanding of Precambrian marine environments. Here we show that synsedimentary marine dolomite precipitation was pervasive within Sinian carbonates from the Sichuan Basin, Southwest China. The Dengying Formation of Ediacaran was divided to four members. All the rocks are dolostone except the thin clastic rocks because of short regression in Member 3. The dolostone types include stromatolititic dolostone, micritic dolostone, algal dolostone, fenestral dolostone, laminar dolostone, oolitic dolostone, oncolitic dolostone, dolostone with botryoidal structure, non-stromatolite ecologic system cyanobacteria dolostone, siliceous dolostone. Although these carbonates are composed of dolomite, textural evidence indicates an originally aragonitic mineralogy for depositional components, in common with many other Neoproterozoic carbonates. We described several new forms of fibrous marine dolomite cement from the masses that have a length-slow optical character. These fascicular slow, radial slow, and rhombic dolomite cements have finely preserved cathodoluminescent growth zones, and optical characteristics that indicate they originally precipitated as dolomite, rather than replacing calcite or aragonite cements. The low positive carbon isotope and low negative oxygen isotope data (1.59~4.52‰, -2.82~-4.82‰) show marine carbonate characteristics. The ordering degree is 0.645-0.832, which is lower than recrystallized dolostone. Calculated paleo-seawater temperature of Dengying Stage, Ediacaran Period is about 40.8°C. Previous mimetic dolomitization cannot explain the widespread huge thick dolostone. Abundant early marine dolomite precipitation implies radically different seawater chemistry for the Ediacaran. In late Ediacaran Period, there was high seawater salinity, high CO_2 partial pressure, anoxic and hot, evaporative condition in South China. Perhaps these aragonite-dolomite seas are associated with extreme Neoproterozoic glacial events and/or ocean anoxia.

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Does Aragonite-Dolomite Sea Exist?

Widespread Marine Dolomite Precipitation in Ediacaran Period in China

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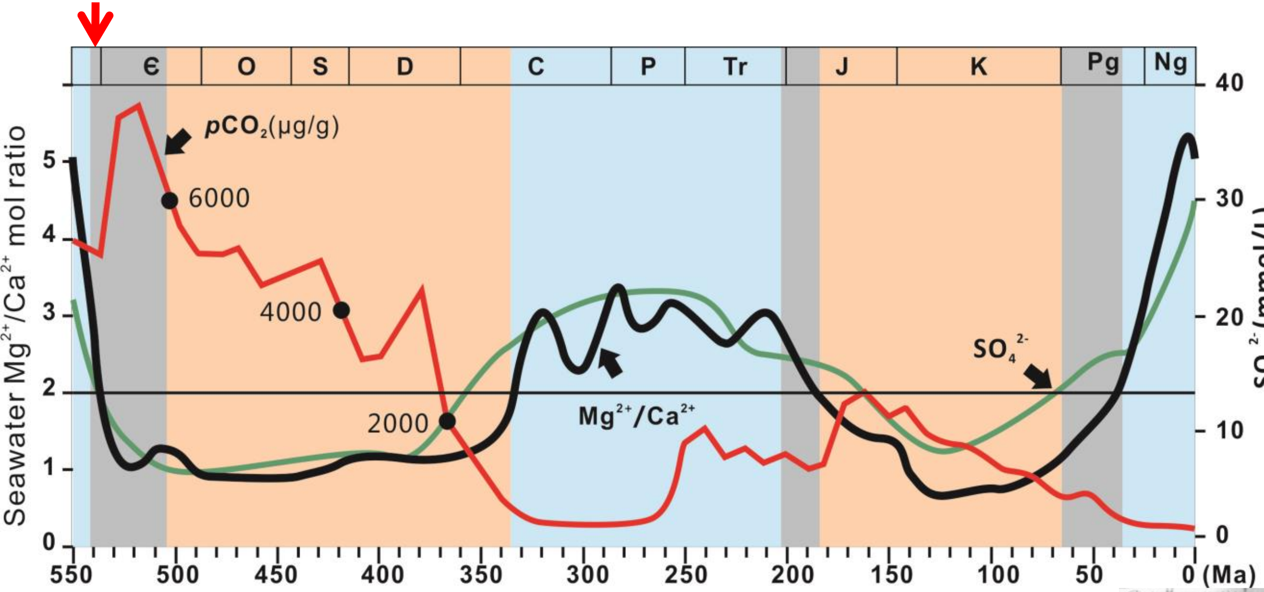
Outline

1. Introduction
2. Stratigraphy of Ediacaran in Sichuan Basin, China
3. Does Aragonite-Dolomite Sea Exist in Ediacaran Period?

1. Introduction

Aragonite-dolomite sea?



Hardie L A, 1996; Sandberg P A, 1983; Lowerstein T K, 2003; Berner R A, 2001; Li F, 2015

1. Mg^{2+}/Ca^{2+} ratio

2. SO_4^{2-}

3. pCO_2

Calcite Sea: Mg^{2+}/Ca^{2+} <2 (blue, Calcite)

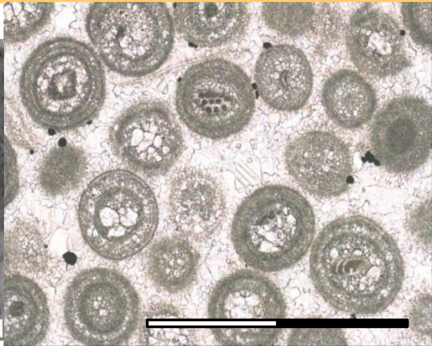
Aragonite Sea: Mg^{2+}/Ca^{2+} >2 (orange, aragonite and high-magnesium calcite)

Uncertain: no evidence/mixed (grey)

Other factors: seafloor spreading rates, volcanism, global sea level, and the primary mineralogies of marine limestones and evaporites

Ediacaran period:
Extreme high pCO_2 , Mg^{2+}/Ca^{2+} ratio=1-3, SO_4^{2-}=10-15 mmol/L

Kovalevich V M., et al., 1998



Neoproterozoic aragonite-dolomite seas? Widespread marine dolomite precipitation in Cryogenian reef complexes

Ashleigh v.S. Hood[1], Malcolm W. Wallace[1], and Russell N. Drysdale[2]
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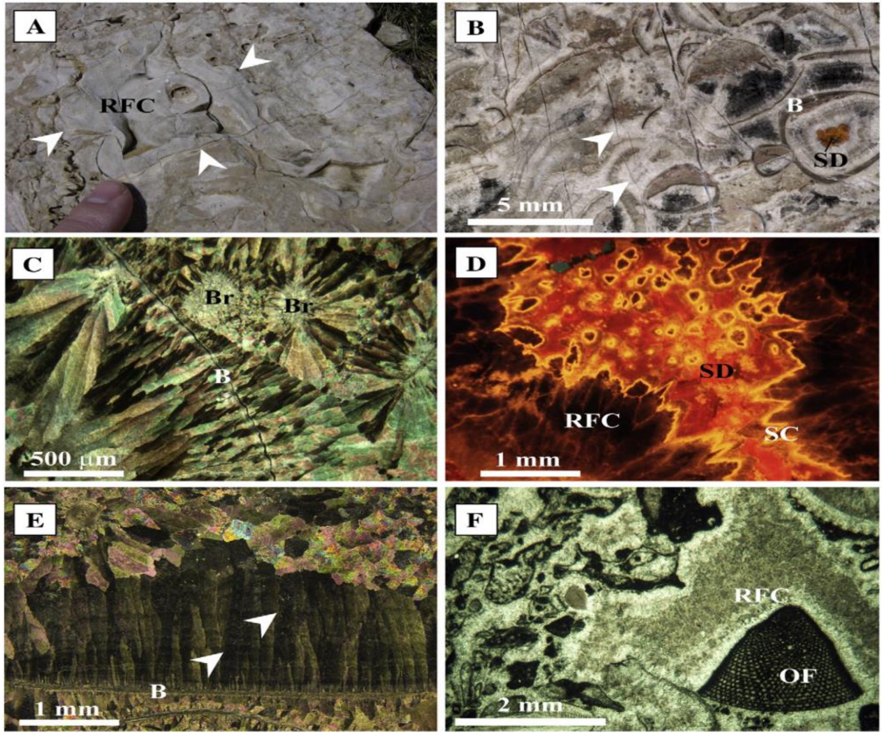
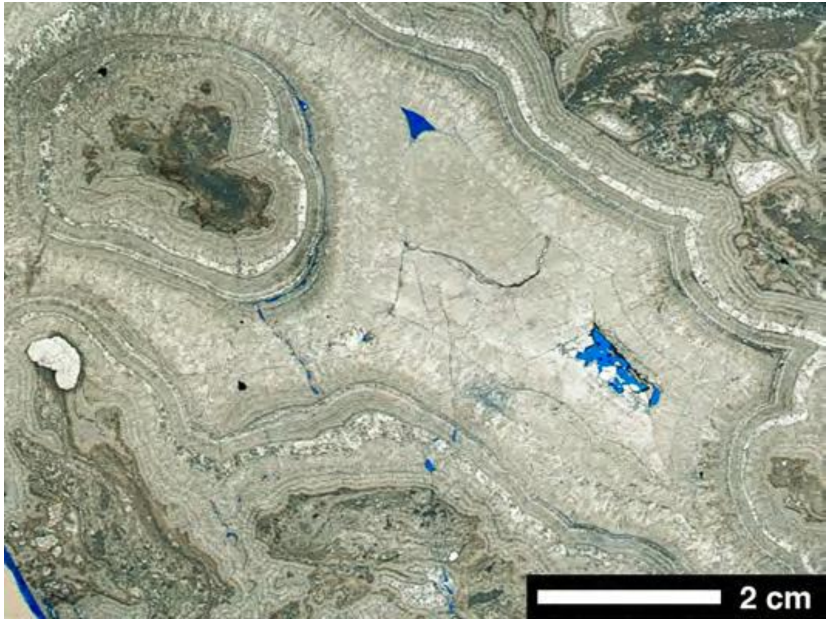
[2]Department of Resource Management and Geography, University of Melbourne, Parkville, Victoria 3010, Australia

Hood et al., 2011



Marine radiaxial and fascicular-optic calcites



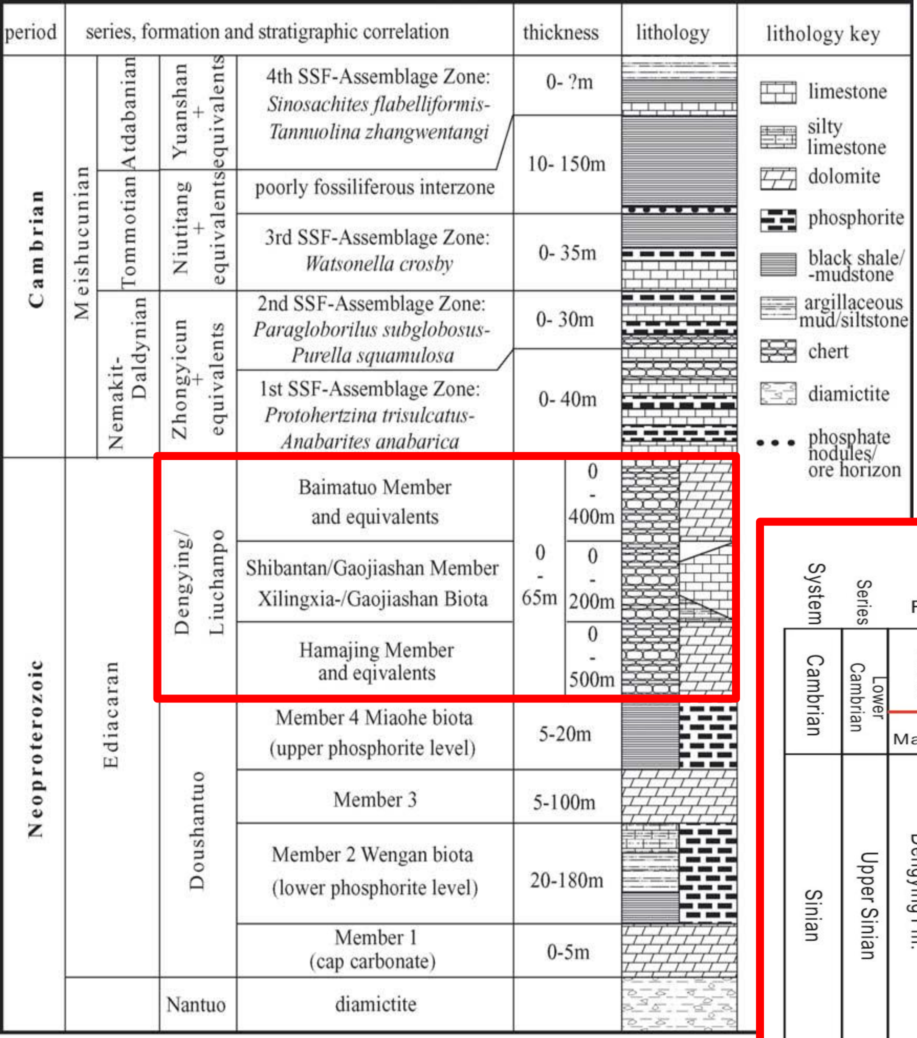
Dolostone reservoir in Ediacaran stage in Sichuan Basin, China

Outline

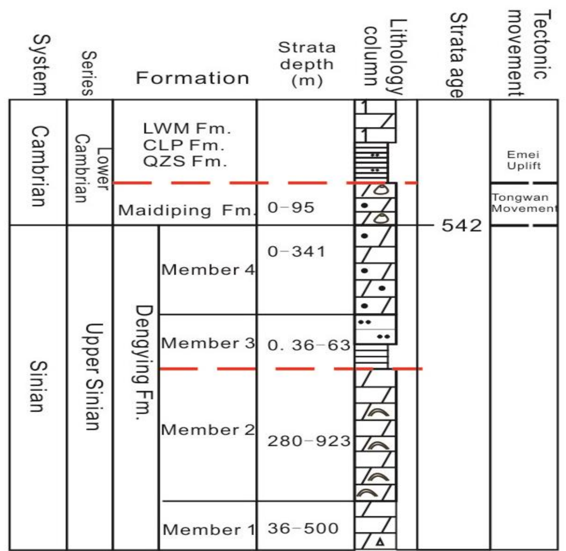
1. Introduction
2. Stratigraphy of Ediacaran in Sichuan Basin, China
3. Does Aragonite-Dolomite Sea Exist in Ediacaran Period?

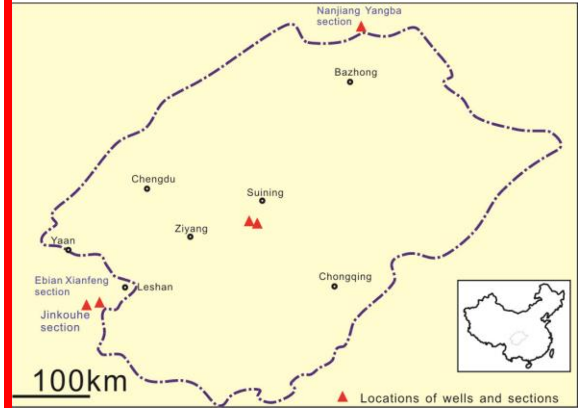
Stratigraphy

- **The huge thick (up to 1km) Dengying Formation of Ediacaran Period was divided to 4 members.**
- **All the rocks are dolostone except the clastic rocks in Member 3.**



Tatiana Goldberg, et al., 2005





Dolostone types of Dengying Fm.

(1) Stromatolite dolostone

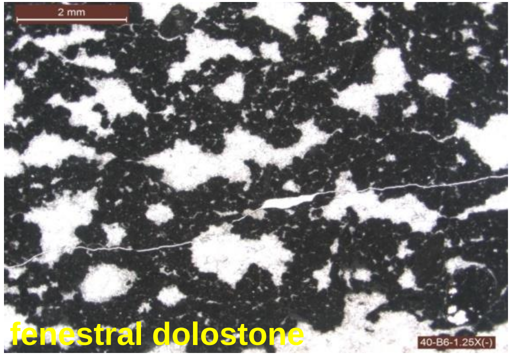
(2) Non-stromatolite ecologic system cyanobacteria dolostone

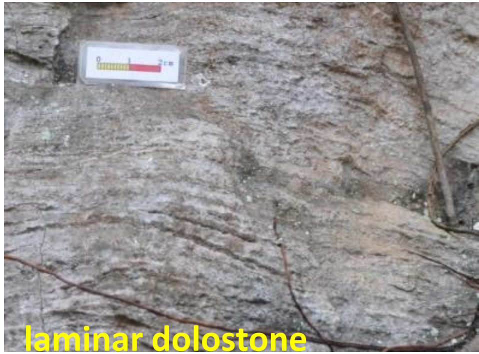
(3) Grain dolostone (oolitic dolostone, dolocalcarenite etc.)

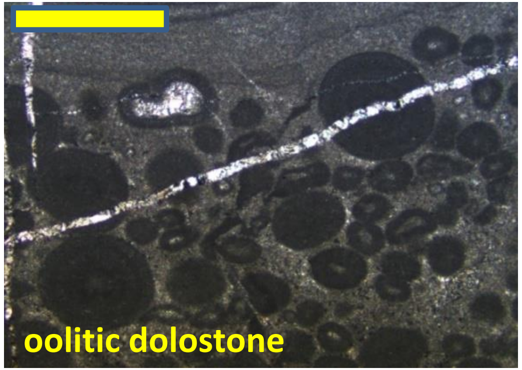
(4) Dolomudstone

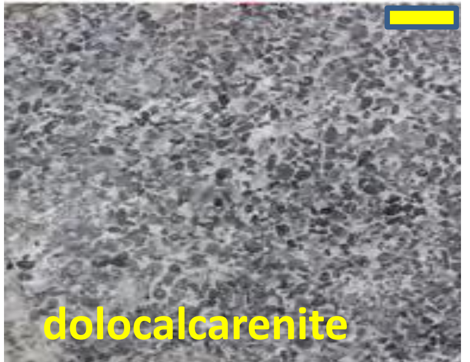
(5) Siliceous dolostone

(6) Botryoidal structure in dolostone









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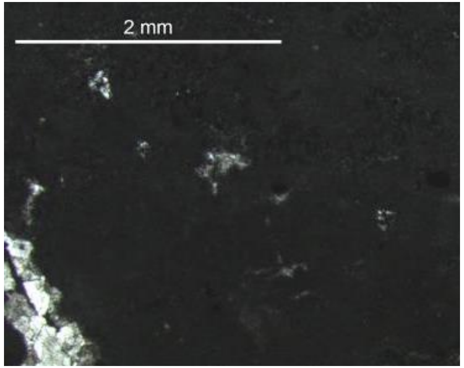

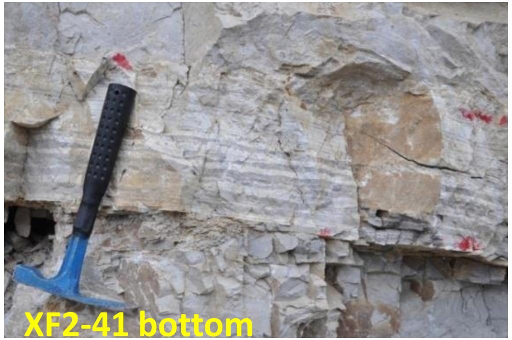

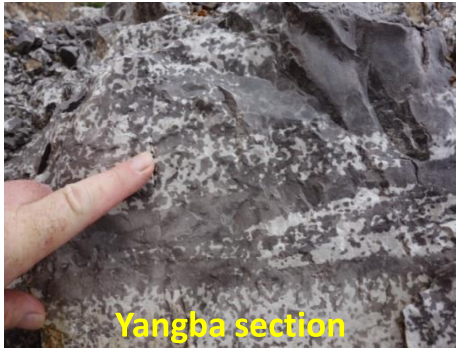

Outline

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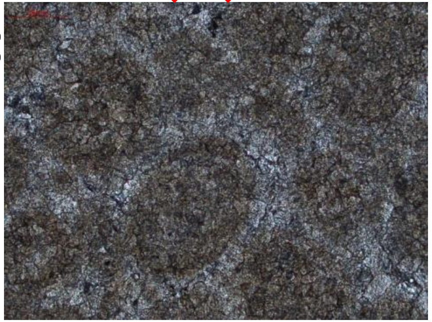
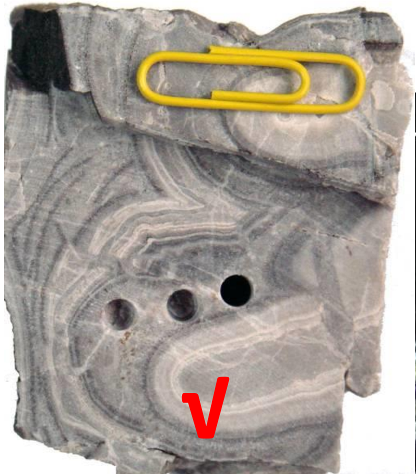
3.1 Sample selction and micro-fabric analysis

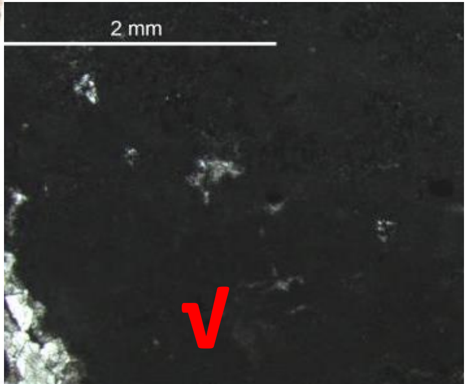
- No/little diagenetic reconstruction:
- Dolomudstone/Algal dolostone
- Fibrous dolomite cement fans

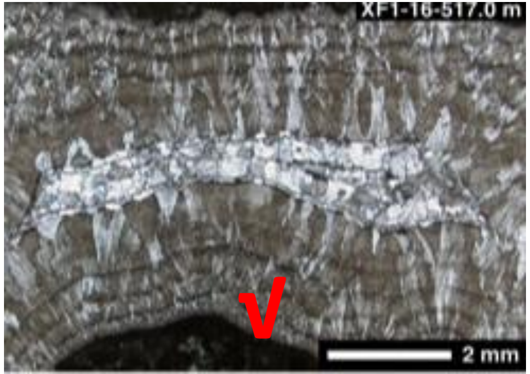


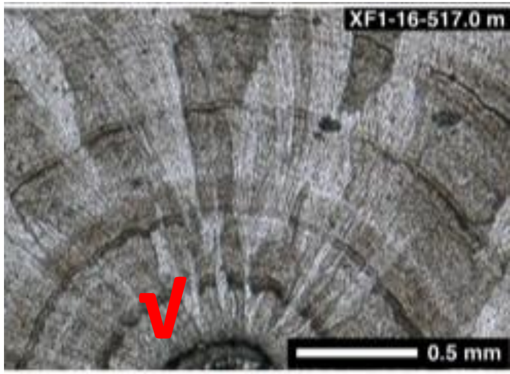
Recrystallized ooids

No evaporite but many vugs and breccias









3.2 Geochemical analysis

(1) Mg/Ca ratio

(2) Ordering degrees of host rock

(3) Microbial dolomite

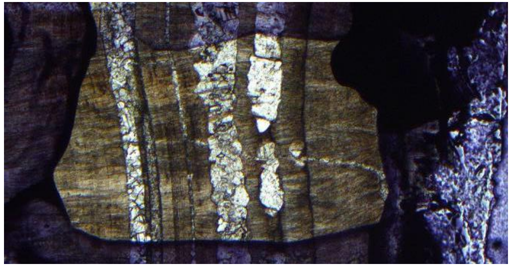
(4) Trace elements and Isotopes

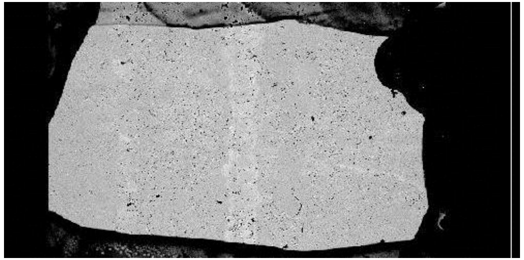
(5) Seawater characteristics

(1) Mg/Ca ratio

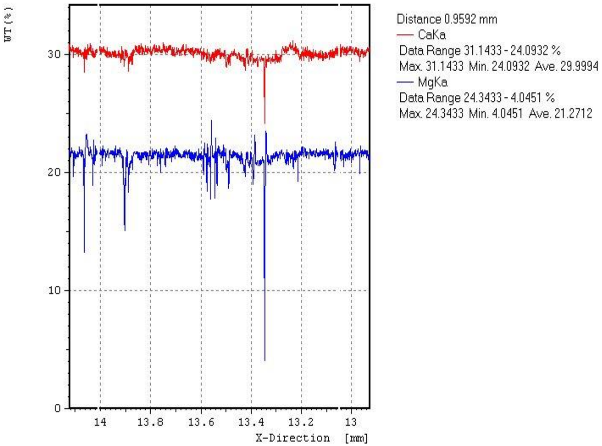
	Mg(mol%)	Ca (mol%)	
GS1-4981.9-1a11	50.8	48.5	1.047239
GS1-4981.9-1b11	52.2	47.7	1.094398
GS1-4981.9-1b13	49.8	50.0	0.996382
JKH-1-1a11	49.7	50.3	0.98785
JKH-1-1b11	49.9	50.0	0.997761
JKH-1-2a11	50.8	49.1	1.035079
JKH-1-2b11	52.4	47.5	1.103536
JKH-1-2b13	50.0	49.6	1.00828
JKH-1-2c11	50.0	49.8	1.003954
JKH-1-3a11	50.2	49.8	1.007815
JKH-1-3b11	50.2	49.6	1.011746
JKH-1-3c11	50.4	49.6	1.016461
JKH-1-3d11	49.1	50.8	0.965817
JKH-1-3e11	52.0	48.0	1.081586
JKH-2-1a11	50.9	49.1	1.036368
JKH-2-1b11	50.2	49.7	1.009166
JKH-2-1c11	51.5	48.3	1.065922
JKH-2-2a11	51.8	48.1	1.076862
JKH-2-2b11	51.1	48.9	1.04501
JKH-2-3a11	49.6	50.3	0.986207
JKH-2-3b11	50.2	49.8	1.008659
GK1-5180-1a11	50.7	49.3	1.028174

Mg/Ca ratio between 0.98-1.1



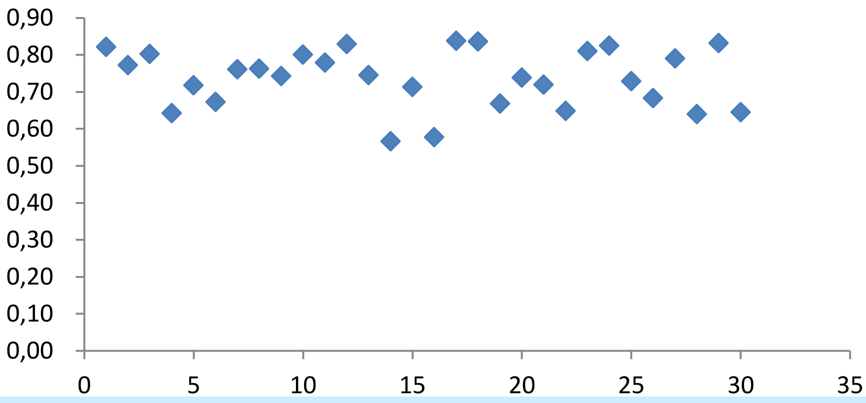


GK1-5180-2a11	51.0	49.0	1.040563
GK1-5180-2b11	50.5	49.5	1.02088
GK1-5180-3a11	50.9	49.0	1.039909
GK1-5180-3b11	50.4	49.5	1.017854
GK1-5441.80-1a11	50.8	49.1	1.034858
GK1-5441.80-1b11	49.5	50.1	0.986854
GK1-5441.80-2a11	50.2	49.7	1.010335
GK1-5441.80-2b11	50.6	49.4	1.023374
GK1-5441.80-2c11	50.6	49.3	1.026108
GK1-5441.80-2d11	51.3	48.6	1.0555
GK1-5441.80-2e11	50.9	49.1	1.036741
GK1-5441.80-3a11	50.6	49.3	1.025657
GK1-5441.80-3b11	50.3	49.7	1.010962

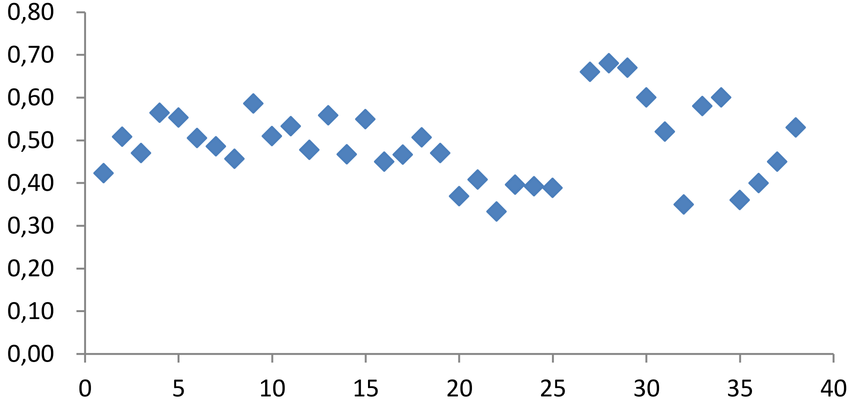


(2) Ordering degree of host rock

Ediacaran dolomite in Sichuan Basin



Seawater dolomite of Miocene in South China Sea and Cayman island

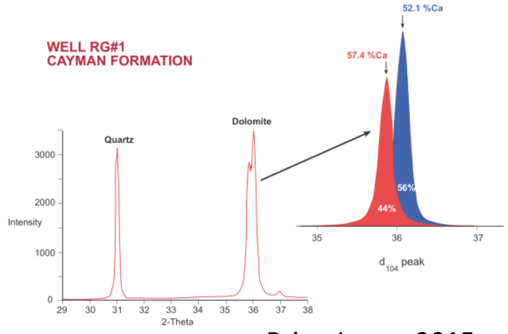


Ordering degree of Ediacaran dolomudstone 0.57-0.84; most of them< 0.8;
Seawater dolomite of Miocene: 0.33-0.68

Two hypothesis on Ediacaran dolomite:

(1) Contemporaneous seawater dolomitization?

(2) Seawater precipitation?



Brian Jones, 2015

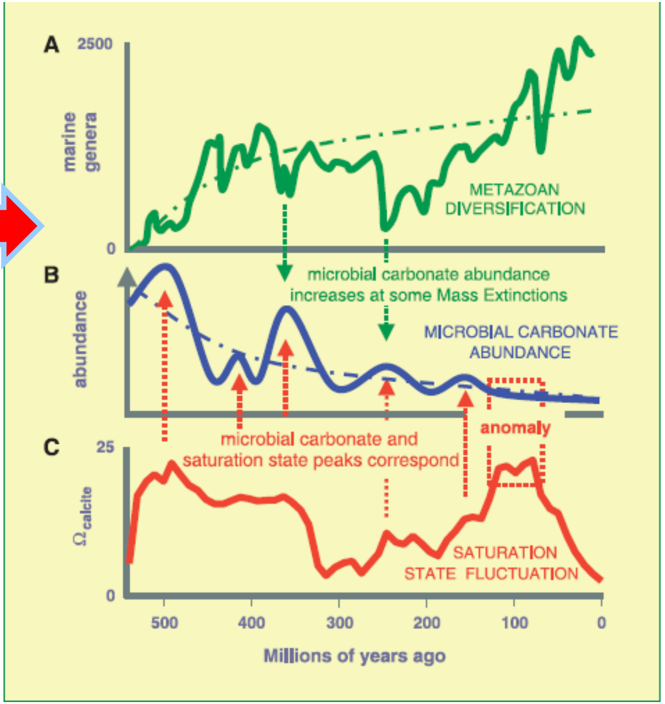
(3) Microbial dolomite

Sedimentary dolomite: a reality check

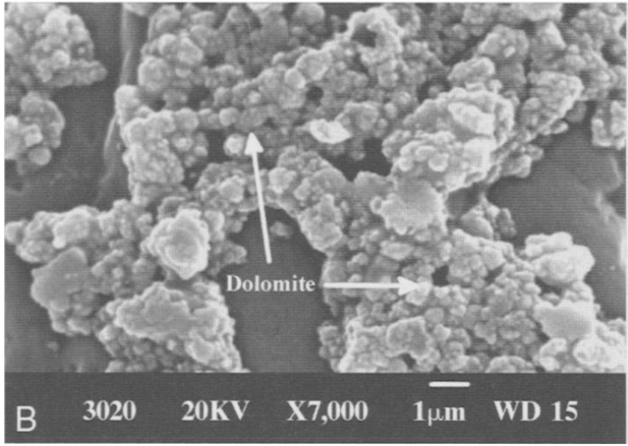
DAVID T. WRIGHT[1] & DAVID WACEY[2]

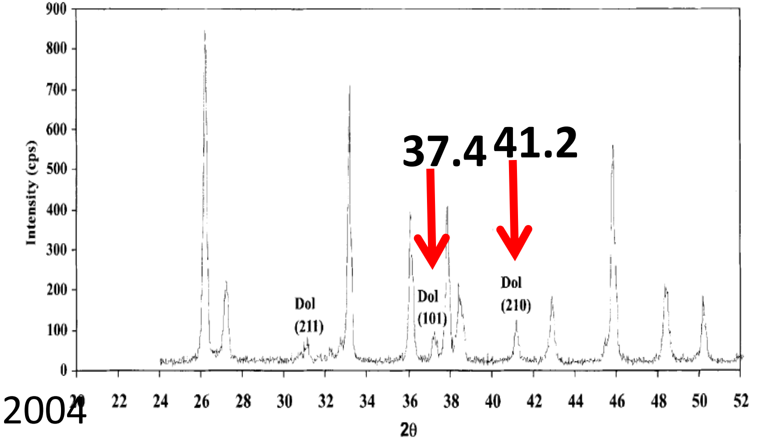
[1] *Department of Geology, University of Leicester, Leicester LE1 7RH, UK*

[2] *Department of Earth Sciences, University of Oxford, Oxford OX1 3PR, UK*



Distribution pattern of microbialite in geological history. Riding and Liang, 2005





Laboratory experiments demonstrated that bacterial sulphate reduction in the Coorong lakes modifies lake-water and pore-water chemistry so that dolomite precipitation is kinetically favoured.

Wright et al., 2004

(3) Microbial dolomite

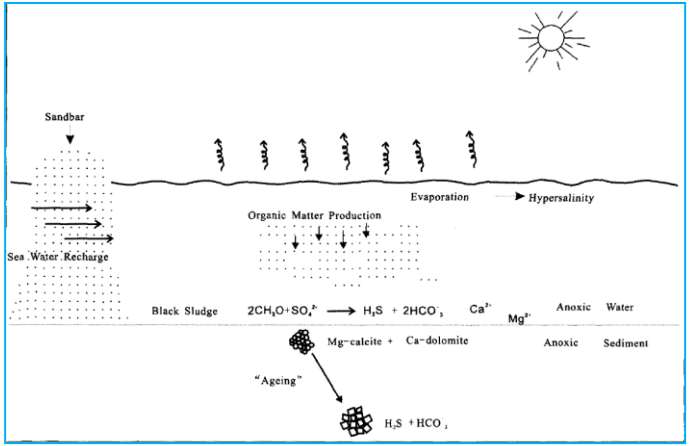
①**Anaerobic environments**

a. Sulphate-reducing bacteria: (Extracellular polymeric substances, EPS)

b. Methanogenic Archaea: oxygenation of methane

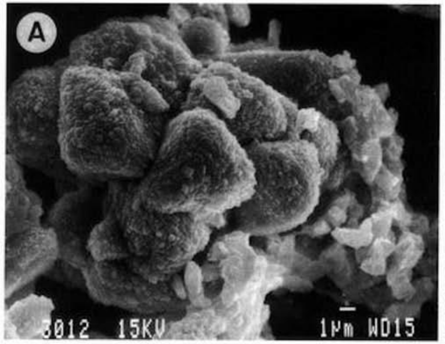
c. Halophilic aerobic bacteria

②**Aerobic environments**: Aerobic microbial dolomite (Sdnchez_Roman M， et al., 2008)

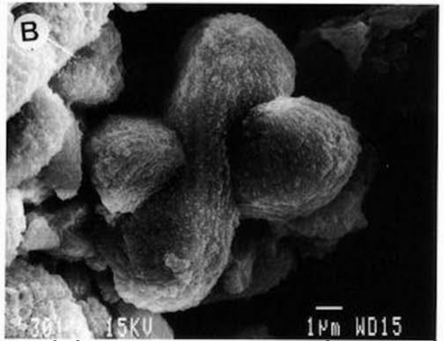


The morphological characteristics of dolomite associated with microbe including:

a. Spherical(spheroidal or voidal)morphology
b. Dumbbell morphology
c. Nanoglobule textures in initial nucleation stage



Ca-dolomite structure with spherical structure

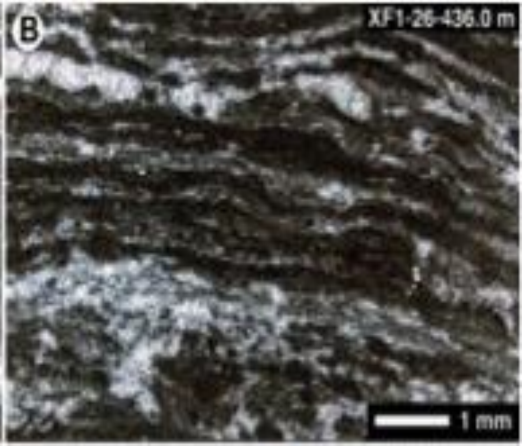


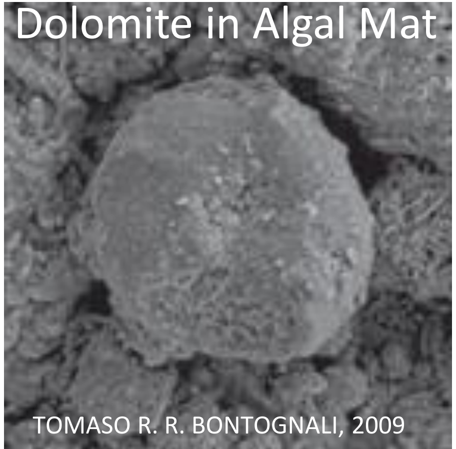
Ca-dolomite structure with twisted interlocking semi-dumbbells

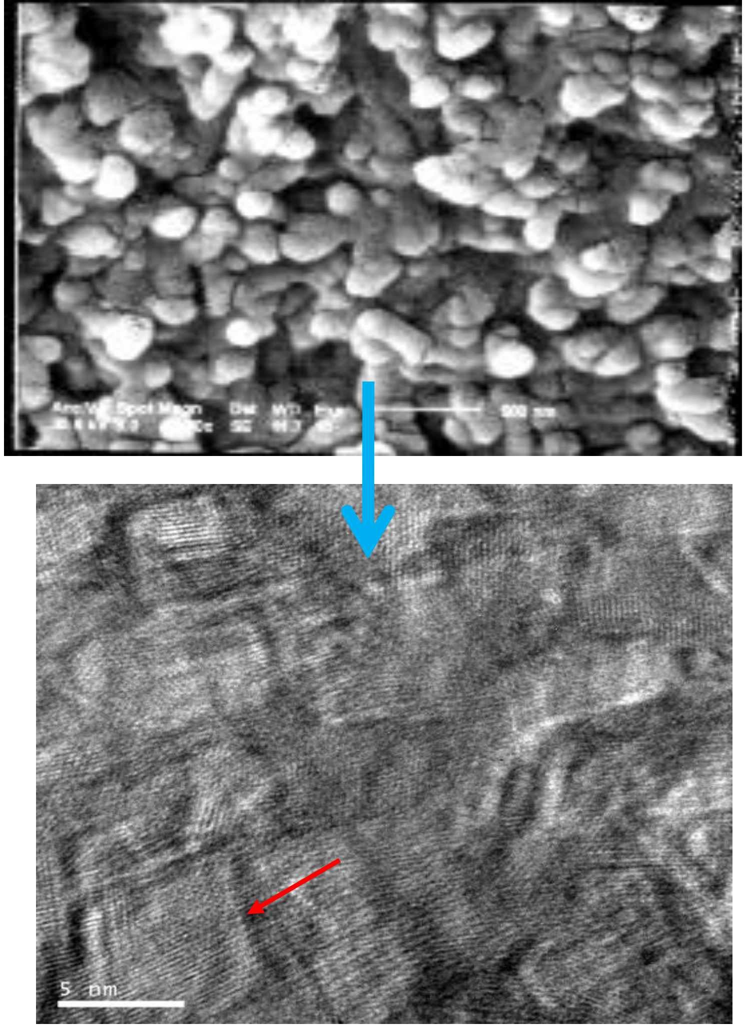
Crisogono Vasconcelos, 1995, 1997

Multiple crystal nucleus formation of dolomites

It is likely that these **biochemical processes of bacteria** were more widespread in Late PreCambrian when dolomite was found in far greater abundance than limestone.





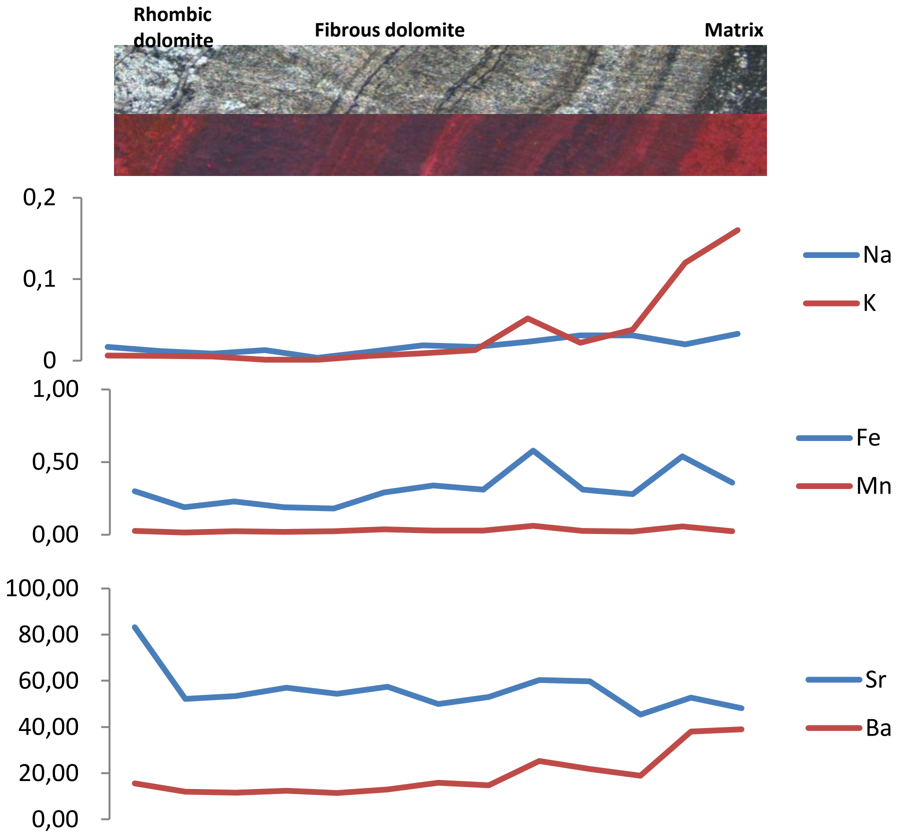


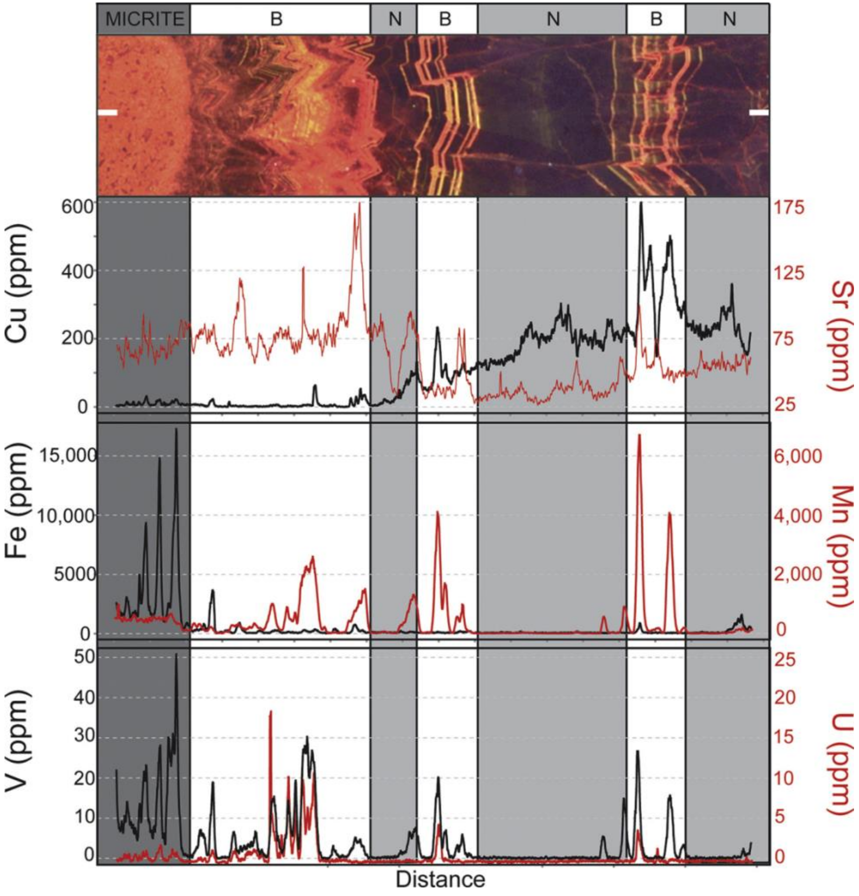
Dolomite under TEM

(4) Trace elements and isotope

Matrix (host rock): high Na and K; higher Fe; 40-60 ppm Sr; Sr/Ba>1

Fibrous dolomite cements: medium Na and K contents; Sr/Ba>1

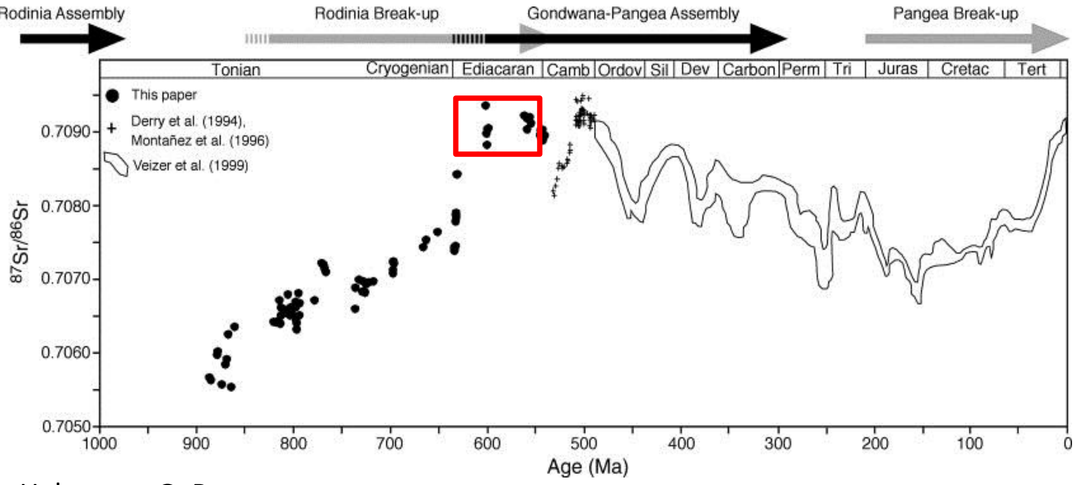




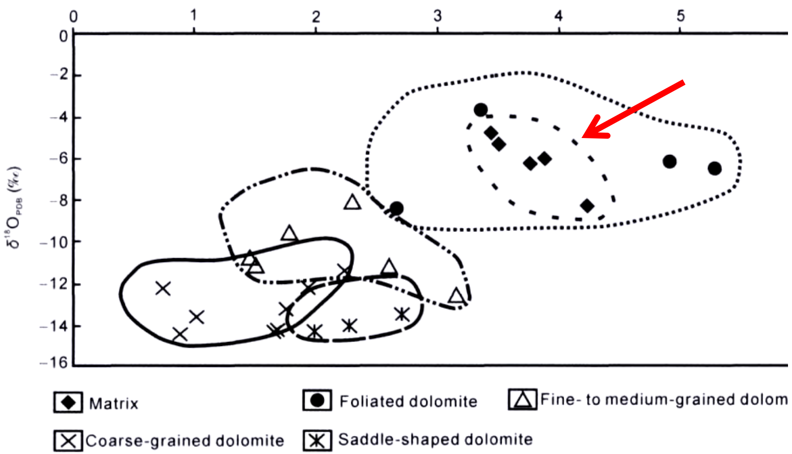
Ashleigh van Smeerdijk Hood et al., 2015

(4) Trace elements and isotope

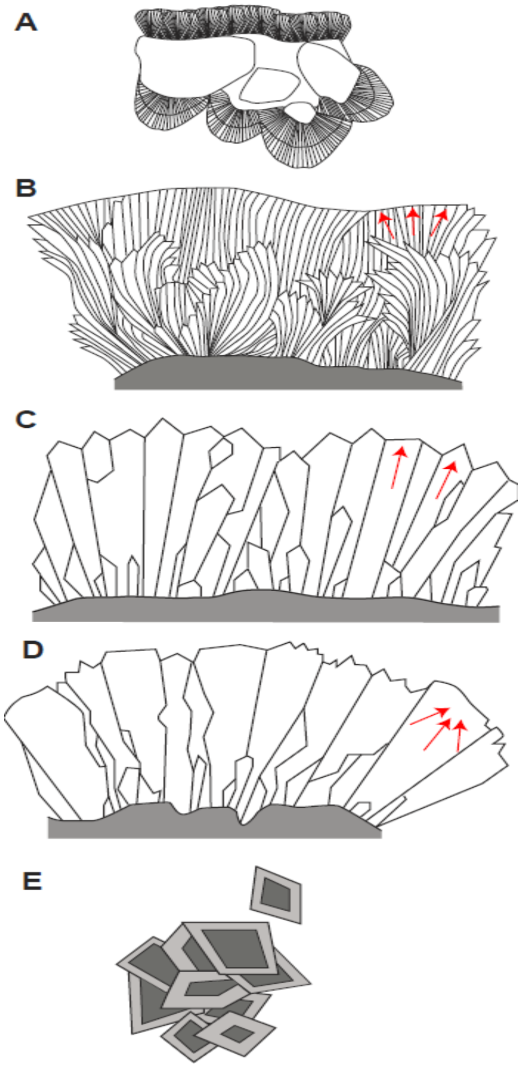
- **High Sr isotope (0.70807-0.7094)**
- **C and O isotope with Ediacaran seawater characteristics**



Halverson G. P.
2007, Palaeogeography, Palaeoclimatology, Palaeoecology 256: 103–129



Shi Z J, et al. 2013，Science China: Earth Sciences, 56: 192-202



Although these carbonates are composed of dolomite, textural evidence indicates an originally aragonitic mineralogy for depositional components, in common with many other Neoproterozoic carbonates.

Fibrous dolomite	Occurrence	Crystal form	Extinction	Inclusion pattern	Catholuminescence
Type A	Isopachous fringes < 1 mm thick	Acicular to columnar, planar growth surface	Uniform	Substrate parallel growth banding, substrate normal inclusion defined crystallites	Mostly non-luminescent
Type B	Isopachous fringes up to 2 mm thick	Columnar with rhombohedral terminations	Uniform	Inclusion defined crystallites, random, and elongate, bladed, triangular shaped.	Non-luminescent relic structures surrounded by red luminescence
Type C	Isopachous fringes to botryoids	Acicular, columnar and wedge-shaped, smooth growth surfaces	Undulose	As for type A	Dull or non-luminescent
Type D	Isopachous fringes thickening in cavity corners	Acicular	Uniform	As for type A	Dull or non-luminescent

BECK SPRING DOLOMITE, PRECAMBRIAN, CALIFORNIA From Tucker (1983)

DOLOMITE CEMENTS FOUND IN THE OODNAMINTA REEF COMPLEX, AUSTRALIA

Modified from Hood and Wallace (2012, their Fig. 12)

Mimetic dolomitization of fibrous cements

Secular changes in the amount and texture of dolomite

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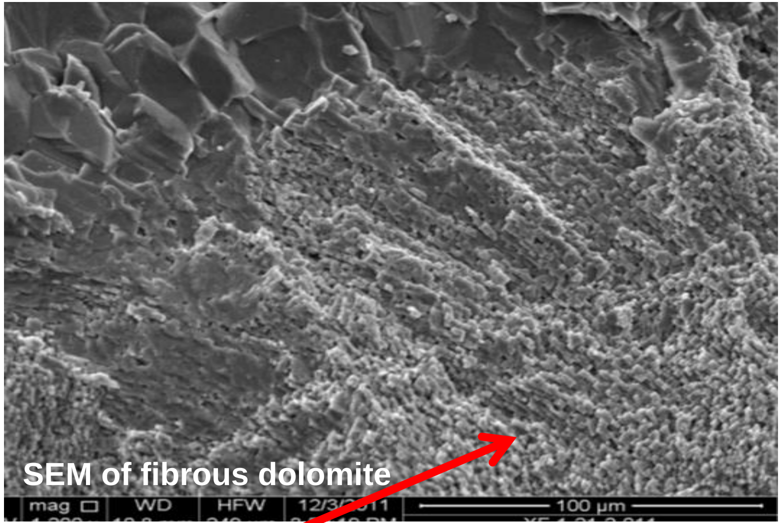
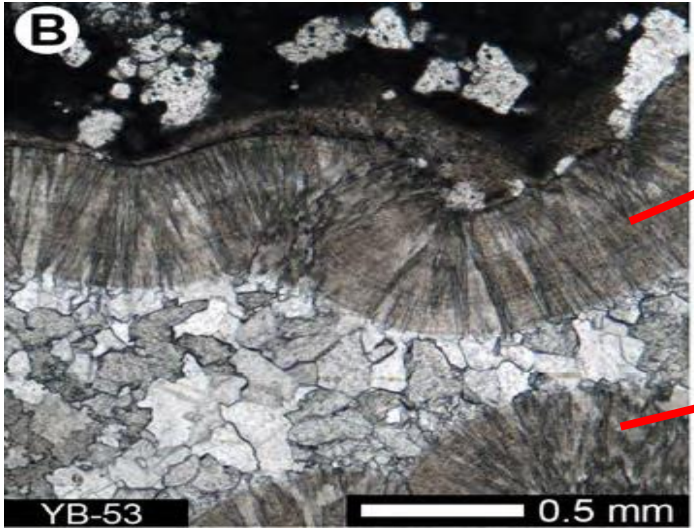
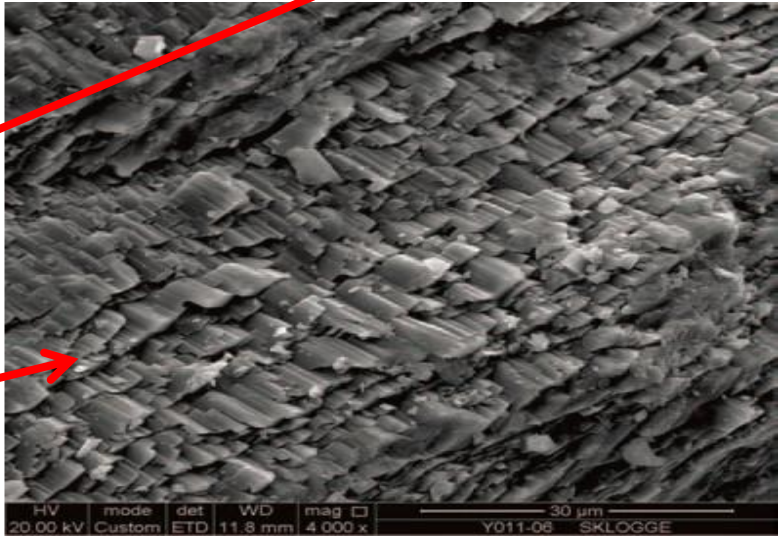
ABSTRACT

The amount of dolomite in Cenozoic carbonates is lower than throughout most of the Paleozoic, a difference that could be due to changes in either chemical conditions or physical conditions that lead to extensive dolomitization. The abundance of mimetic (texturally retentive) dolomites in the Cenozoic suggests that chemical conditions were unusually favorable for dolomite formation, and, therefore, it must be physical conditions that explain the paucity of Cenozoic dolomites. One reasonable explanation for the paucity of Cenozoic dolomites is that glacio-eustatic sea-level fluctuations reduced the amount of time carbonate sediments were in contact with dolomitizing solutions.

Duncan F. Sibley, GEOLOGY, v. 19, p. 151-154, 1991







(5) Seawater characteristics

a. Paleotemperature: 15-30 ℃

$$t(℃)=16.9-4.38(\delta^{13}C-\delta^{18}O_w)+0.10(\delta^{13}C-\delta^{18}O_w)^2$$

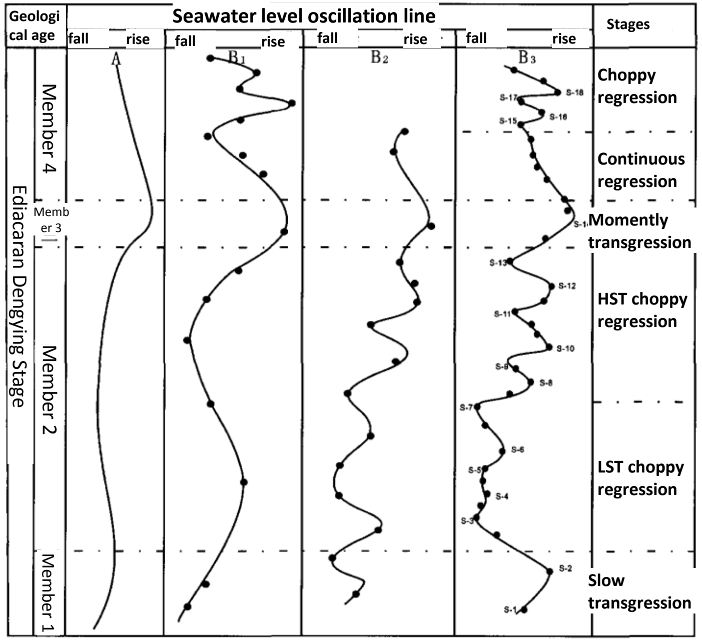
Zhang X. L. 1985;Shackleton, 1974

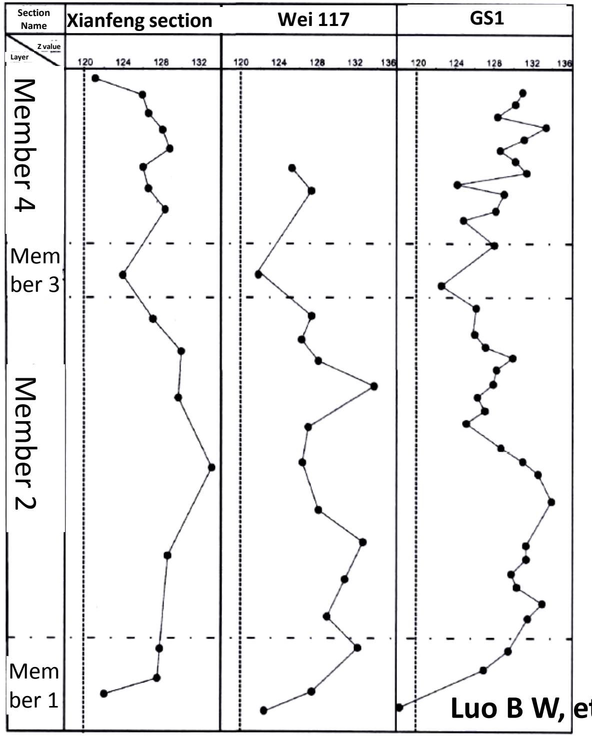
b. Paleosalinity: Z>120,

$$Z=2.048\times(\delta^{13}C+50)+0.498\times(\delta^{18}O+50)$$

Keith M L, Weber J N, 1964

c. Seawater level oscillation





Luo B W, et al. 2013

Summary

- **Abundant early marine dolomite precipitation implies a radically different seawater chemistry for the Ediacaran Period.**
- **In Ediacaran Period, there was high seawater salinity, high CO_2 partial pressure, anoxic and hot, evaporative condition.**
- **Abundant marine dolomite precipitation might be associated with the metabolic process of widespread bacteria both under anaerobic or aerobic environments.**
- **Perhaps the aragonite-dolomite sea is associated with the flourishing of microbial and the extreme Neoproterozoic glacial events and/or ocean anoxia.**

Thank you for your attention.

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