# Supplementary file

# Three-terraced evaporated ramp model for differentiation of the massive dolomitization process: Insights from the Lower Cambrian Longwangmiao Formation in the Sichuan Basin

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#### **Supplementary Text**

#### **METHODS**

Quantitative powder X-ray diffractometry was performed using a Bruker D2 Phaser instrument at the Geochemistry Laboratory at Chengdu University of Technology.

Analysis of the carbon and oxygen isotopes was performed using a Finnigan MAT253 gas mass spectrometer using the McCrea orthophosphate-dissolution technique and the NBS-18 standard in the Geochemistry Laboratory at Chengdu University of Technology. *In-situ* laser carbon and oxygen isotope analysis was completed at PetroChina Hangzhou Research Institute of Geology using a Finnigan MAT253 mass spectrometer.

The major and trace elements analysis was completed at the Research Institute of Qinghai–Tibetan Plateau, Chinese Academy of Sciences. The major element analysis was conducted using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) (PerkinElmer Company, model 5300V). Trace element analysis was conducted using an Inductively Coupled Plasma Mass Spectrometer ELAN DRC-e ICP-MS (PerkinElmer, USA). The concentrations of rare earth elements (REEs) are normalized using the Seawater standard (Kawabe et al., 1998). Eu anomalies (Eu/Eu\*) and Ce anomalies(Ce/Ce\*) are calculated as follow:  $\delta Eu=2\times Eu_n/(Sm_n+Gd_n)$  (Bau and Dulski, 1996);  $\delta Ce=Ce_n/(2\times Pr_n-Nd_n)$  (McLennan, 1989);. (La/Yb)<sub>n</sub>=La<sub>n</sub>/Yb<sub>n</sub>;  $\Sigma REE = SUM(La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu); \SigmaLREE = SUM(La, Ce, Pr, Nd, Sm,$  $Eu); <math>\Sigma HREE = SUM(Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu)$ ; the value marked by the symbol n is standardized by seawater;  $REE_n = REE/(REEs \times 10^6)$ .

Strontium isotope analysis was conducted using a Finnigan MAT-262 multi-collector thermal ionisation mass spectrometer at the State Key Laboratory of Reservoir Geology and Exploitation, Chengdu University of Technology.

Cathodoluminescence (CL) analysis was conducted at Southwest Petroleum University using a CL8200MK5 cold cathode device mounted on a CL microscope.

*In-situ* trace element analysis was completed by Wuhan Sample Solution Analytical Technology Co., Ltd., China. The *in-situ* analysis of the trace elements in minerals were determined using the LA-ICP-MS electron probe method. The GeolasPro laser ablation system was composed of a COMPexPro 102 ArF 193 nm excimer laser and a MicroLas optical system, with the ICP-MS model being Agilent 7900.

*In-situ* Sr isotope ratios were measured by a Neptune Plus MC-ICP-MS in combination with a Geolas HD excimer ArF laser ablation system at the Wuhan SampleSolution Analytical Technology Co., Ltd, Hubei, China.

Calcium isotope analysis was conducted using a Finnigan MAT-262 multi-collector thermal ionisation mass spectrometer at the State Key Laboratory of Reservoir Geology and Exploitation, Chengdu University of Technology.

The synthetic seismogram manufactures have been accomplished by using 35 Hz rake wavelet. One 2D seismic lines with a length of approximately 800 km were interpreted through boreholes for comparison of wave groups and energy characteristics.

#### SUPPLEMENTAL ASSESSMENT OF DIAGENETIC EFFECTS

#### (1) Evaluation of diagenetic alterations

The Mn/Sr ratios can be divided into three groups as < 2, 2 to 10, and > 10 to characterize little, mild and strong alteration extents. In the lower terrace, the Mn/Sr ratios are 0.24 to 3.58 (n = 41) which points to little diagenetic alteration. In the medium terrace, the Mn/Sr ratios are 0.97 to 5.64 (n = 31), indicating a mild extent of diagenetic alteration. The Mn/Sr ratios range from 4.34 to 9.98 (n = 46) in the higher terrace, implying mild diagenetic alteration to be effective indicators of the early diagenetic phase.

Within the Sichuan Basin, the average  $\delta^{18}$ O values are -6.82 ‰, -7.49 ‰, and -7.79 ‰, respectively, in the higher, lower and medium terrace, all suggesting little diagenetic alteration.

#### (2) Evaluation of detrital influence

The whole rock samples of the dolostone exhibit relatively high concentrations of Al and K, positively

correlated (Fig. S4a), indicating K mainly comes from terrigenous material, not seawater. The presence of terrigenous material influences the content of Na, Sr, Fe, and Mn in whole rock samples of the dolostone from the higher terrace, while its influence is weaker in the medium and lower terraces. Scatter plots of Al with Na, Sr, Fe, and Mn in higher terrace dolomite samples (Fig. S4c, e, g, i) show significant positive correlation. To eliminate terrigenous influence, samples with Al/(Ca + Mg) > 0.01 were removed (4 data points within dashed circle). After removal (Fig. S4d, f, h, j), no correlation between Al and Na, Sr, Fe, and Mn is evident, confirming the method's effectiveness. Thus, contaminated data are excluded from dolomitization fluid analysis.

Correlation analysis shows terrigenous material affects REE concentrations in higher terrace whole rock samples, with weaker effects on medium and lower terraces. Scatter plots of Zr, Sc, Th with  $\Sigma$  REEs in higher terrace dolomite samples (Fig. S4k, m, o) show significant positive correlation. Removing samples with Al/(Ca + Mg) > 0.01 (4 data points within dashed circle) eliminates correlation between Zr, Sc, Th, and  $\Sigma$  REE (Fig. S4l, n, p), validating the method. Contaminated data are excluded from dolomitization fluid analysis.

Furthermore, we applied the same method to analyze the trace elements and rare earth elements in dolostone and partially dolomitized limestone samples obtained through LA-ICP-MS. The results showed that the influence of terrigenous material on these data was minimal (Fig. S4q-x).

#### References

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# Supplementary Tables

# Table S1. Major, trace elements and *in-situ* laser analysis of the LWMF, Sichuan Basin

mm         mm         22.42         29.89         71.48         90.21         90.25         91.25         91.00         10.20         0.00         0.00         0.01         20.01         10.5         0.01         20.01	Region	Lithology		MgO	CaO	K	Na	Fe	Al	Mn	Sr	Mg/Ca	Mn/Sr	Rb/Sr	Al/(Ca+ Mg)	Sc	Zr	Th	REE	Ce/Ce*	Eu/Eu*	(La/Yb) <sub>n</sub>					
Dr. ma         ma         200         10.47         10.4400         80.431         10.99         10.43         10.2         0.011         10.6         10.8         10.8         10.10         10.6         10.8         10.8         10.10         10.6         10.8         10.8         10.10         10.8		DG (n=13)	min	22 42	0 20 50	771 48	574 10	000 33	688.04	205.85	51 50	0.63	4 34	0.01	0.0020	0.58	0.06	0.15	4 30	4 51	0.67	2.01					
nem13,         as         22.24 (2.90)         151.12         02.81         02.44         0.84         0.44         0.42         0.80         0.000         13.5         0.17         0.00         1.5           Central Schuar         mm         22.27 (2.941         3661.3         51.466         153.85         1.00         1.01         20.7         2.00         0.01         1.01         2.00         0.00         2.35           Schuar         mm         22.37 (2.941         3661.3         1.01         1.01         1.01         2.00         0.01         1.00         1.01         0.02         0.000         1.38         1.31         6.61         4.80         0.00         2.35         0.00         2.35         0.00         2.35         0.00         1.01         0.00         1.02         1.01         0.00         1.01         0.00         1.01         0.00         1.01         0.00         1.01         0.00         0.01         1.01         0.00         0.01         0.01         0.00         0.01         0.00         0.01         0.01         0.00         0.01         0.01         0.00         0.01         0.01         0.01         0.01         0.01         0.01         0.01         0.01			may	22.42	30.57	3077.94	2463.02	6480 58	3334 33	1330.01	168 12	0.65	9.10	0.01	0.0020	3.66	3.81	6.95	11.05	5.54	1.07	7 71					
Sub         Sub <td rowspan="3"></td> <td>av</td> <td>22.01</td> <td>20.01</td> <td>1511.87</td> <td>928.88</td> <td>2941 40</td> <td>2001.63</td> <td>584 31</td> <td>86.68</td> <td>0.63</td> <td>6.72</td> <td>0.05</td> <td>0.0067</td> <td>1.35</td> <td>0.64</td> <td>1 30</td> <td>7.51</td> <td>5.00</td> <td>0.94</td> <td>3.46</td>			av	22.01	20.01	1511.87	928.88	2941 40	2001.63	584 31	86.68	0.63	6.72	0.05	0.0067	1.35	0.64	1 30	7.51	5.00	0.94	3.46					
mm         mm         22.37         23.41         38.44         158.87         20.98         10.94         5.64         0.90         2.52           Schum         mm         22.98         10.87         20.857         27.95         10.98         10.91         10.81         0.06         3.86         12.4         5.24         22.10         0.06         1.87         0.06         1.87         0.06         1.88         0.06         1.05         0.06         0.05         0.06         0.06         1.88         0.06         1.05         0.06         0.05         0.06         0.06         1.88         0.06         0.06         1.88         0.06         0.05         0.06		(11 15)	SD	0.17	0.28	608.08	601.35	1704 72	817 30	318 56	38.29	0.04	1.48	0.03	0.0007	0.97	1 11	2.07	2.78	0.30	0.11	1.53					
Central Basin         DM max         20.8         50.21         85.74         25.85         101         0.0101         64.54         0.021         0.027         0.028         0.028         0.020         0.021         0.027         0.028         0.028         0.021         0.023         0.021			min	22 37	20.20	586.13	514.66	1538.87	740.96	310.50	50.29	0.00	5.66	0.04	0.0029	0.97	0.13	0.14	6.58	4 50	0.11	2 35					
Schum         (me)         m.         27.7         29.90         (dis)         13.1         95.41         6.42         42.04         0.00         0.003         13.2         13.1         86.1         6.81         0.004         1.12           (the)         mm         22.56         20.3         37.14         51.65         202.06         107.23         102.00         11.65         50.1         14.00         20.00         11.01         11.01         11.06         50.0         14.0         10.00         11.06         50.0         14.00         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.00         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0         11.06         50.0 <td< td=""><td>Control</td><td>DM</td><td>may</td><td>22.37</td><td>30.21</td><td>1857.40</td><td>2585 57</td><td>7728.00</td><td>3646 29</td><td>1301.80</td><td>183.60</td><td>0.64</td><td>9.00</td><td>0.02</td><td>0.0020</td><td>3.86</td><td>3 25</td><td>4 22</td><td>10.30</td><td>5.05</td><td>1.00</td><td>5.22</td></td<>	Control	DM	may	22.37	30.21	1857.40	2585 57	7728.00	3646 29	1301.80	183.60	0.64	9.00	0.02	0.0020	3.86	3 25	4 22	10.30	5.05	1.00	5.22					
Bhoan         000         520         627 </td <td>Central</td> <td>(n=6)</td> <td>шал</td> <td>22.98</td> <td>20.00</td> <td>1065 16</td> <td>088 12</td> <td>2281 54</td> <td>1851 47</td> <td>570.88</td> <td>78.84</td> <td>0.64</td> <td>7.40</td> <td>0.11</td> <td>0.0150</td> <td>1.21</td> <td>0.82</td> <td>1 21</td> <td>8.61</td> <td>4.81</td> <td>0.06</td> <td>3.42</td>	Central	(n=6)	шал	22.98	20.00	1065 16	088 12	2281 54	1851 47	570.88	78.84	0.64	7.40	0.11	0.0150	1.21	0.82	1 21	8.61	4.81	0.06	3.42					
ubber terrace         max         22.58         23.51         24.51         26.21         26.23         26.24         65.23         41.64         50.24         45.3         41.64         50.20         45.8         41.64         83         41.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.64         83         44.74         83	Basin	(11-0)	av.	0.22	0.27	1005.10	701 70	2201.54	1072.02	402.05	51.00	0.04	1.55	0.03	0.0003	1.51	1 22	1.51	1.40	4.81	0.90	1.12					
higher (rm*e)         iso         <	(the		min	22 26	20.27	271 48	516.56	2028 52	582.18	370.20	46.60	0.00	1.55	0.04	0.0039	0.76	0.14	0.52	1.40	1.20	0.04	1.12					
Cords (max)         Cords (max) <thcords (max)         <thcords (max)</thcords </thcords 	higher	CD	max	22.30	29.55	2401.26	1576.04	5026.32	2066 00	995 09	146.00	0.03	4.00	0.01	0.0020	2.05	1 97	6 17	11 69	5.70	1.04	7.49					
Namesy         (m <sup>-0</sup> )         SD         0.02         0.02         0.02         0.02         0.02         0.02         0.02         0.02         0.02         0.03         0.00         0.01	terrace)	(n=8)	max	23.00	20.03	2401.20	722.05	2159 51	2800.08	524.05	140.14	0.64	6.85	0.14	0.0100	3.05	4.8/	0.17	7 20	5.02	0.04	7.48					
Seturem Basin Basin Berlin Basin Berlin Berlin Basin Berlin Ber	terrace)	(11-8)	av.	22.80	0.20	(42.26	245.04	1076.05	757.27	165 40	20.22	0.04	0.79	0.03	0.0003	0.76	1.02	1.70	2.44	5.05	0.90	1.02					
In-stite DM         mm         20:3         20:2         38:3         1:2         32:3         1:2         30:3         1:2         1:3			SD	0.24	0.39	515.07	345.04	10/0.05	191.62	272.15	29.33	0.00	1.51	0.04	0.0026	0.70	1.38	1.84	2.44	0.49	0.05	1.85					
(n=10)         (m=1)         (m=1) <t< td=""><td></td><td></td><td>min</td><td>20.34</td><td>29.24</td><td>313.87</td><td>230.33</td><td>1040.30</td><td>181.02</td><td>2/3.13</td><td>39.42</td><td>0.55</td><td>4.45</td><td>0.01</td><td>0.0010</td><td>0.05</td><td>0.17</td><td>0.04</td><td>5.14</td><td>4.39</td><td>0.85</td><td>3.74</td></t<>			min	20.34	29.24	313.87	230.33	1040.30	181.02	2/3.13	39.42	0.55	4.45	0.01	0.0010	0.05	0.17	0.04	5.14	4.39	0.85	3.74					
(m-19)         No. 21:15         29:00         17:20         12:30         29:30         12:30         29:30         12:30		In-situ DM	max	21.89	31.22	888.01	/34.42	21/9.49	580.77	38/.1/	/3.30	0.63	8.00	0.03	0.0020	0.16	2.02	0.36	6./1	6.73	1.34	15.48					
Southern Bischung Bischun		(n=19)	av.	21.15	29.90	6//.3/	432.88	1359.51	415.58	299.94	52.99	0.60	5.83	0.01	0.0015	0.10	0.59	0.11	4.31	5.33	1.03	7.55					
Southern Result         max         20.3         20.4         10.4         21.0         20.3         23.4         0.00         0.01         0.12         0.09         0.12         0.09         4.80           (m7)         ans         10.7         20.94         10.7         12.9         0.00         0.00         0.00         0.00         0.01         0.02         0.02         0.00			SD	0.49	0.50	115.14	147.02	334.29	109.77	27.44	9.81	0.02	1.08	0.01	0.0005	0.03	0.53	0.09	0.88	0.56	0.13	2.87					
b(k)         max         20.32         29.94         (1.68)         4.22         0.01         0.0400         0.944         0.13         0.17         5.22         5.30         1.09         4.83         1.12           str         intro         1.83         2.23         2.407         1.52         3.42         0.04         0.021         <			mın	19.25	29.16	245.41	507.62	1180.90	/32.10	315.17	70.55	0.54	4.00	0.02	0.0030	0.32	0.05	0.12	3.09	4.54	0.82	2.33					
(m <sup>-1</sup> )         as.         (b, b)         (b, b) <td></td> <td>DG</td> <td>max</td> <td>20.39</td> <td>29.94</td> <td>1087.41</td> <td>585.27</td> <td>1/6/.2/</td> <td>1068.81</td> <td>325.52</td> <td>79.30</td> <td>0.58</td> <td>4.52</td> <td>0.07</td> <td>0.0040</td> <td>0.94</td> <td>0.13</td> <td>0.67</td> <td>5.62</td> <td>5.00</td> <td>1.09</td> <td>4.68</td>		DG	max	20.39	29.94	1087.41	585.27	1/6/.2/	1068.81	325.52	79.30	0.58	4.52	0.07	0.0040	0.94	0.13	0.67	5.62	5.00	1.09	4.68					
Image         Sub         0.40         0.25         0.00         0.02         0.000         0.00000         0.0000         0.0000		(n=/)	av.	19.76	29.59	566.79	542.67	1542.90	820.48	319.81	74.57	0.56	4.30	0.04	0.0031	0.62	0.09	0.32	4.19	4.79	0.95	3.12					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			SD	0.40	0.25	329.90	26.07	191.96	121.55	3.66	3.54	0.01	0.22	0.02	0.0004	0.26	0.03	0.19	1.05	0.15	0.11	0.84					
CD southern         mix         10.9         51.6         10.87         57.87         233.33         2091.14         41.00         8.043         0.038         12.2         0.53         1.03         3.09           Southern         min         20.02         12.87         133.51         155.22         159.20         10.02         0.051         0.02         0.051         0.15			min	19.18	28.92	514.25	507.01	1184.55	1289.51	213.07	60.94	0.52	2.93	0.02	0.0050	0.48	0.02	0.24	4.44	3.35	0.70	2.09					
(m=10)         av.         19.60         29.7         124.21         19.84         13.84         16.4         10.6         0.006         0.008         0.28         0.29         0.48         0.25         0.48         0.21         0.48         0.21         0.15         0.05         0.055         0.005         0.055         0.055         0.055         0.005         0.055         0.01         0.0000         0.03         0.05         0.01         0.000		CD	max	19.95	31.16	1983.76	577.85	2333.33	2091.14	416.06	88.93	0.58	5.64	0.09	0.0080	1.22	0.53	0.78	7.95	5.33	1.03	3.09					
Southern Basim (the medium)         Sou 0.28         0.61         431.26         23.8.1         93.62         0.02         0.011         0.23         0.17         0.18         0.54         0.11         0.53           Basim (the medium)         min         20.02         28.90         128.3         33.02         148.12         23.81         94.26         0.62         0.13         0.43         0.07         0.44         0.050         0.15         0.63         0.64         0.050         0.050         0.051         0.63         0.64         0.060         0.15         0.051         0.64         0.64         0.66         0.44         0.17         0.060         0.051         0.052         0.06         0.22         0.17         0.18         0.16         0.33         0.10         0.0000         0.030         0.04         0.03         0.04         0.030         0.060         0.060         0.060         0.060         0.060         0.060         0.060         0.060         0.060         0.060         0.060         0.060         0.061         0.060         0.061         0.060         0.061         0.060         0.061         0.060         0.061         0.060         0.061         0.060         0.061         0.060         <		(n=10)	av.	19.60	29.77	1242.11	540.70	1824.42	1598.54	318.43	76.47	0.56	4.21	0.06	0.0060	0.88	0.29	0.47	6.16	4.62	0.88	2.53					
Sichuan         min         2002         28.49         117.28         59.49         132.2         28.59         30.2         0.40         0.0050         0.15         0.15         0.15         0.15         0.15         0.15         0.15         0.15         0.15         0.15         0.15         0.15         0.15         0.05         0.052         0.44         0.052         0.051         0.084         0.02         0.055         0.000         0.0000         0.03         0.05         0.001         0.0000         0.031         0.05         0.01         0.0000         0.031         0.05         0.01         0.0001         0.031         0.03         0.01         0.00         0.0000         0.023         0.03         0.03         0.03         0.01         0.00         0.0000         0.031         0.03	Southern		SD	0.28	0.67	431.26	22.02	387.54	305.62	60.83	9.11	0.02	0.95	0.02	0.0011	0.23	0.17	0.18	1.18	0.54	0.11	0.32					
Basin (the medium         max         20.88         [1:89]         1:41:4         67:30         233:7.21         [3:30:12]         339:81         94:26         0.62         0.62         0.005         0.46         0.023         0.51         0.83         0.22         0.51         0.023         0.51         0.023         0.55         0.023         0.51         0.023         0.55         0.023         0.05         0.04         0.023         0.05         0.04         0.03         0.05         0.04         0.03         0.063         0.05         0.04         0.03         0.06         0.05         0.04         0.03         0.06         0.05         0.04         0.03         0.06         0.05         0.04         0.03         0.05         0.01         0.000         0.000         0.000         0.000         0.000         0.000         0.001         0.011	Sichuan		min	20.02	28.49	1172.83	530.20	1455.94	1342.12	238.15	75.22	0.59	3.02	0.04	0.0050	0.15	0.15	0.07	3.14	4.54	0.82	2.12					
	Basin	DM	max	20.98	28.95	1443.14	679.36	2337.32	1530.22	339.81	94.26	0.62	4.13	0.07	0.0060	0.93	0.51	0.85	4.92	4.91	1.06	2.88					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	(the	(n=5)	av.	20.47	28.82	1264.43	599.57	2012.64	1416.21	299.44	81.76	0.60	3.68	0.05	0.0052	0.46	0.32	0.35	4.14	4.67	0.96	2.49					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	medium		SD	0.35	0.20	108.86	60.18	357.71	91.57	39.87	7.92	0.01	0.55	0.01	0.0004	0.30	0.14	0.30	0.69	0.15	0.09	0.28					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	terrace)		min	20.05	29.00	428.22	234.79	1270.94	132.43	174.21	69.09	0.57	2.14	0.00	0.0000	0.03	0.08	0.07	1.90	4.28	0.88	1.06					
$ \left( \begin{array}{c} (n^{-5}) & av. 20.69 \\ P3.47 & 600.23 \\ P3.48 & 49 \\ P3.40 & 79 \\ P3.40 & 79 \\ P3.40 & 79 \\ P3.40 & 79 \\ P3.40 & 72 \\ P3.40 $		In-situ DG	max	21.69	29.70	806.29	502.94	1621.39	599.62	259.63	108.16	0.63	3.76	0.02	0.0020	0.25	1.45	0.37	3.32	6.73	1.15	2.46					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		(n=5)	av.	20.69	29.47	600.23	388.49	1515.82	378.22	216.32	84.55	0.59	2.62	0.01	0.0012	0.11	0.58	0.25	2.68	5.70	1.02	1.54					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			SD	0.79	0.29	154.02	97.01	140.84	194.97	32.77	14.37	0.03	0.67	0.01	0.0008	0.08	0.57	0.12	0.51	1.23	0.11	0.56					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			min	0.40	52.58	385.22	15.99	610.20	221.23	87.14	72.66	0.01	0.97	0.00	0.0010	0.04	0.05	0.06	3.20	2.77	0.70	0.98					
$ \left( \begin{array}{c c c c c c c c c c c c c c c c c c c $		In-situ CC	max	1.84	54.60	629.11	164.87	876.69	500.81	176.54	108.65	0.03	1.62	0.01	0.0020	0.24	0.69	0.35	4.37	6.24	1.17	2.12					
SD         0.65         0.97         109.17         85.46         119.73         116.48         39.87         16.44         0.01         0.29         0.01         0.0066         0.08         0.30         0.12         0.48         0.00         0.0016         0.02         0.04         0.256         4.60         0.89         2.13           DG (n=8)         max         21.85         30.71         135.52         567.03         176.04         181.62         191.16         104.60         0.63         2.09         0.08         0.0006         1.34         0.44         0.17         10.9         0.18         0.001         0.44         10.12         7.7         0.77         3.01           MD         max         21.42         30.44         138.92         155.93         33.22         10.55         0.02         0.044         0.025         0.05         0.23         0.65         2.06         1.03.0         1.03         4.14         1.03         1.03         1.14         1.03         1.03         1.14         1.03         0.03         0.044         0.09         0.021         0.056         0.04         0.021         0.56         4.04         0.04         0.022         0.65         2.05         1.0		(n=4)	av.	1.03	53.80	490.41	90.12	785.89	378.24	118.03	96.86	0.02	1.21	0.00	0.0015	0.13	0.50	0.21	3.76	4.76	0.98	1.47					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			SD	0.65	0.97	109.17	85.46	119.73	116.48	39.87	16.44	0.01	0.29	0.01	0.0006	0.08	0.30	0.12	0.48	1.63	0.20	0.48					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			min	21.18	29.29	321.45	432.17	627.44	317.56	84.21	58.62	0.58	0.88	0.00	0.0010	0.06	0.02	0.04	2.56	4.60	0.89	2.13					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		DG	max	21.89	30.71	1335.52	567.03	1766.04	1816.28	191.16	104.60	0.63	2.09	0.08	0.0060	1.34	0.41	0.78	6.09	5.01	1.06	4.01					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		(n=8)	av.	21.65	29.91	736.83	509.50	1310.95	658.06	129.12	87.36	0.61	1.50	0.04	0.0023	0.50	0.13	0.25	4.49	4.77	0.97	3.01					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			SD	0.23	0.53	295.21	50.09	461.14	515.39	33.92	13.56	0.02	0.40	0.03	0.0017	0.44	0.12	0.27	1.09	0.18	0.06	0.60					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			min	21.14	29.47	648.23	501.52	627.44	1080.68	83.24	80.97	0.59	1.02	0.02	0.0040	0.25	0.05	0.23	4.66	4.49	0.84	1.89					
$ \left  \begin{array}{c c c c c c c c c c c c c c c c c c c $		DM	max	21.82	30.44	1389.34	585.23	1603.93	1581.16	196.09	95.27	0.62	2.38	0.04	0.0050	0.56	0.22	0.56	5.26	5.01	1.03	4.12					
$ \left  \begin{array}{c c c c c c c c c c c c c c c c c c c $		(n=6)	av.	21.45	30.03	1059.40	540.28	1185.52	1265.16	121.22	85.31	0.60	1.43	0.03	0.0043	0.40	0.12	0.36	4.84	4.78	0.94	3.14					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			SD	0.27	0.36	298.26	31.99	327.17	214.33	44.28	5.19	0.01	0.55	0.01	0.0005	0.12	0.06	0.11	0.22	0.24	0.08	0.79					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			min	21.61	29.12	303.95	424.51	891.71	568.14	86.00	80.00	0.63	0.93	0.01	0.0020	0.46	0.04	0.06	3.16	4.41	0.90	2.47					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		CD	max	21.88	29.27	900.81	498.78	1256.26	845.17	319.00	98.56	0.63	3.58	0.06	0.0030	0.87	0.16	0.90	4.86	4.61	1.07	3.20					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		(n=4)	av.	21.80	29.19	582.82	461.74	1019.10	757.75	221.50	90.85	0.63	2.49	0.03	0.0028	0.61	0.10	0.44	3.77	4.49	0.95	2.83					
Sichuan Basin (the lower         min         1.05         49.98         384.08         179.46         419.69         211.70         108.43         134.10         0.02         0.46         0.01         0.16         0.40         0.12         2.57         3.50         0.95         2.49           max         3.70         53.59         991.02         209.92         1068.17         846.81         154.90         237.64         0.06         0.99         0.04         0.0030         0.44         0.26         0.29         4.84         5.59         1.00         4.26           iower         av.         1.76         51.29         64.88         193.60         744.88         514.11         128.12         187.77         0.03         0.71         0.02         0.0019         0.27         14         0.48         0.69         0.56           inratific form         1.25         24.69         9.69         218.40         245.81         18.01         36.52         0.02         0.16         0.01         0.000         0.03         0.14         0.66         21.8         4.26           (n=5)         max         21.01         30.05         530.01         377.81         689.90         469.45         103.68	Eastern		SD	0.13	0.06	301.04	30.32	163.02	128.97	104.45	7.80	0.00	1.27	0.02	0.0005	0.18	0.05	0.36	0.75	0.08	0.08	0.34					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Sichuan		min	1.05	49.98	384.08	179.46	419.69	211.70	108.43	134.10	0.02	0.46	0.01	0.0010	0.16	0.04	0.12	2.57	3.50	0.95	2.49					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Basin	MS	max	3.70	53.59	991.02	209.92	1068.17	846.81	154.90	237.64	0.06	0.99	0.04	0.0030	0.44	0.26	0.29	4.84	5.59	1.09	4.26					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	(the	(n=7)	av.	1.76	51.29	664.88	193.60	744.88	514.14	128.12	187.77	0.03	0.71	0.02	0.0019	0.27	0.14	0.24	3.80	4.93	1.03	3.42					
$ \begin{array}{c} \mbox{terrace} \\ In-situ DG \\ (n=5) \\ \hline max & 21.01 \\ (n=5) \\ \hline max & 21.01 \\ n=5 \\ \hline max & 21.01 \\ n=$	lower		SD	0.98	1.25	246.69	9.69	218.40	245.81	18.01	36.52	0.02	0.16	0.01	0.0009	0.11	0.08	0.06	0.76	0.69	0.05	0.56					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	terrace)		min	19.71	29.63	220.07	224.93	459.41	79.66	82.35	43.23	0.56	0.66	0.00	0.0000	0.03	0.11	0.06	2.18	4.10	0.69	0.87					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		In-situ DG	max	21.01	30.05	530.01	377.81	689.90	469.45	103.68	124.03	0.60	1.91	0.07	0.0020	0.15	1.88	0.49	3.12	6.08	1.28	4.26					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		(n=5)	av.	20.45	29.79	342.15	331.28	610.08	206.25	89.61	74.85	0.58	1.33	0.04	0.0010	0.06	1.06	0.22	2.70	4.86	0.99	2.55					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			SD	0.48	0.17	115.29	62.54	90.00	151.30	8.69	29.73	0.02	0.45	0.03	0.0007	0.05	0.71	0.20	0.34	0.80	0.26	1.29					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$			min	0.16	47.88	198.93	9.64	134.17	100.25	31.79	100.71	0.00	0.24	0.00	0.0000	0.00	0.01	0.00	1.92	3.98	0.54	1.81					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		In-situ CC	max	4.44	55.66	499.16	200.57	470.72	696.35	69.64	136.48	0.08	0.65	0.02	0.0030	0.29	1.24	0.49	4.36	5.63	1.16	12.92					
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		(n=11)	av.	0.78	53.97	302.67	99.69	268.40	252.56	41.06	119.23	0.01	0.35	0.00	0.0010	0.11	0.33	0.21	2.92	4.74	0.89	6.36					
Partially dolomitized (n=8)         min         / <th <="" th="">         /         /         /</th>	/         /         /		l ` ´	SD	1.22	2.34	89.27	60.80	116.69	161.23	12.01	13.10	0.02	0.13	0.01	0.0008	0.09	0.36	0.18	0.76	0.61	0.19	3.35				
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $		Partially	min	/	/	1	/	/	/	/	83.32	0.14	0.62	/	/	1	/	1	/	/	/	/					
limestone         av.         / <th <="" th="">         /         /         /         /         /         /         /         /         /         /         /         /         /         /         /         /         /         /         /         <th <="" th="">         /         /         <th <="" th=""> <th <="" th="">         /         /         <th <<="" td=""><td></td><td>dolomitized</td><td>max</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>176.00</td><td>0.25</td><td>1.81</td><td></td><td>/</td><td>/</td><td>/</td><td>/</td><td></td><td>/</td><td>/</td><td>/</td></th></th></th></th></th>	/         /         /         /         /         /         /         /         /         /         /         /         /         /         /         /         /         /         / <th <="" th="">         /         /         <th <="" th=""> <th <="" th="">         /         /         <th <<="" td=""><td></td><td>dolomitized</td><td>max</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>176.00</td><td>0.25</td><td>1.81</td><td></td><td>/</td><td>/</td><td>/</td><td>/</td><td></td><td>/</td><td>/</td><td>/</td></th></th></th></th>	/         / <th <="" th=""> <th <="" th="">         /         /         <th <<="" td=""><td></td><td>dolomitized</td><td>max</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>176.00</td><td>0.25</td><td>1.81</td><td></td><td>/</td><td>/</td><td>/</td><td>/</td><td></td><td>/</td><td>/</td><td>/</td></th></th></th>	<th <="" th="">         /         /         <th <<="" td=""><td></td><td>dolomitized</td><td>max</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>176.00</td><td>0.25</td><td>1.81</td><td></td><td>/</td><td>/</td><td>/</td><td>/</td><td></td><td>/</td><td>/</td><td>/</td></th></th>	/         / <th <<="" td=""><td></td><td>dolomitized</td><td>max</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>/</td><td>176.00</td><td>0.25</td><td>1.81</td><td></td><td>/</td><td>/</td><td>/</td><td>/</td><td></td><td>/</td><td>/</td><td>/</td></th>	<td></td> <td>dolomitized</td> <td>max</td> <td>/</td> <td>/</td> <td>/</td> <td>/</td> <td>/</td> <td>/</td> <td>/</td> <td>176.00</td> <td>0.25</td> <td>1.81</td> <td></td> <td>/</td> <td>/</td> <td>/</td> <td>/</td> <td></td> <td>/</td> <td>/</td> <td>/</td>		dolomitized	max	/	/	/	/	/	/	/	176.00	0.25	1.81		/	/	/	/		/	/	/
(n=8) SD / / / / / / / / / / / 34.57 0.04 0.44 / / / / / / / / / / / / /		limestone	av.		. /	/	/	/	/	/	125.85	0.18	1.17		/	/	/	/	. /	/	/	/					
		(n=8)	SD	/	/	/	/	/	/	/	34.57	0.04	0.44	/	/	/	/	/	/	/	/	/					

# Table S2. The crystalline order of dolomite for the LWMF, Sichuan Basin

Region	Lithology		Order degree	Region	Lithology		Order degree	Region	Lithology		Order degree
		min	0.66			min	0.55			min	0.50
Central Sichuan Basin (the higher terrace)	DG	max	0.83	Southern Sichuan Basin (the medium terrace)	DG (n=5)	max	0.74	Eastern Sichuan Basin (the lower terrace)	DG (n=5)	max	0.75
	(n=9)	av.	0.73			av.	0.65			av.	0.65
		SD	0.06			SD	0.07			SD	0.10
		min	0.61		CD (n=3)	min	0.67		DM (n=5)	min	0.56
	DM (n=3)	max	0.65			max	0.71			max	0.75
		av.	0.63			av.	0.69			av.	0.63
		SD	0.02			SD	0.02			SD	0.08
		min	0.63			min	0.62		CD (n=3)	min	0.67
	CD	max	0.81		DM	max	0.64			max	0.70
	(n=3)	av.	0.74		(n=2)	av.	0.63			av.	0.69
		SD	0.10			SD	0.01			SD	0.02

Region	<b>T</b> 14 1		$\delta^{13}C$	$\delta^{18}O$	870 1860	Desien	x :: 1		$\delta^{13}C$	$\delta^{18}O$	870-/860-
Region	Lithology		VP	DB	<sup>87</sup> Sr/ <sup>80</sup> Sr	Region	Lithology		VP	δ¹*Ο           VPDB           -8.87           -8.47           -8.75           0.19           -9.27           -7.02           -8.02           0.72           -6.87           -5.26           -5.86           0.57           -7.20           -7.20           -7.20           -7.20           -7.14           0.09           -8.95           -7.91           -8.46           0.36           -6.71           -5.90           -6.34           0.39           -8.81           -8.27           -8.47           0.22           -8.03           -5.69           -7.22	*/Sr/**Sr
		min	-1.17	-7.71	0.709185	Southern	In-situ CC (n=4)	min	-0.13	-8.87	0.708821
	DG	max	-0.07	-5.61	0.713990	Sichuan		max	0.36	-8.47	0.709142
	(n=13)	av.	-0.63	-6.72	0.710769	(the medium		av.	0.11	-8.75	0.708963
		SD	0.35	0.58	0.001530	terrace)		SD	0.22	0.19	0.000135
Central		min	-0.64	-6.80	0.709427			min	-0.37	-9.27	0.709070
	DM	max	0.00	-5.36	0.712899		DG	max	0.29	-7.02	0.710249
	(n=6)	av.	-0.28	-6.03	0.710118		(n=8)	av.	-0.27	-8.02	0.709781
Sichuan		SD	0.29	0.51	0.001368			SD	0.23	0.72	0.000443
(the higher		min	-0.84	-7.32	0.709371			min	-0.65	-6.87	0.708851
terrace)	CD (n=8)	max	0.00	-5.92	0.714694		DM (n=6)	max	0.91	-5.26	0.709962
		av.	-0.33	-6.70	0.711019			av.	0.17	-5.86	0.709571
		SD	0.27	0.52	0.001642			SD	0.58	0.57	0.000440
	In-situ DM (n=9)	min	-0.37	-6.96	0.710211		CD (n=4)	min	-0.58	-7.20	0.709144
		max	0.23	-5.50	0.710686	Eastern Sichuan Basin (the lower		max	-0.23	-7.01	0.709854
		av.	-0.13	-6.32	0.710429			av.	-0.40	-7.14	0.709384
		SD	0.23	0.50	0.000138			SD	0.15	0.09	0.000319
		min	-0.41	-9.02	0.709255		MS (n=7)	min	-0.78	-8.95	0.708693
	DG (n=7)	max	0.66	-7.07	0.709928			max	0.31	-7.91	0.709135
		av.	0.16	-7.84	0.709696			av.	-0.41	-8.46	0.708880
		SD	0.47	0.80	0.000253	terrace)		SD	0.39	0.36	0.000155
		min	-1.90	-8.38	0.709546			min	-0.57	-6.71	0.709372
	CD (n=10)	max	-0.28	-7.18	0.709961		In-situ DG	max	0.65	-5.90	0.709883
Southern		av.	-1.20	-7.79	0.709790		(n=4)	av.	-0.03	-6.34	0.709578
Sichuan Basin		SD	0.57	0.39	0.000137			SD	0.51	0.39	0.000251
(the	DM (n=5)	min	-2.52	-8.58	0.709732		In-situ CC (n=5)	min	-0.86	-8.81	0.708758
terrace)		max	-0.01	-7.23	0.709988			max	-0.08	-8.27	0.709084
		av.	-1.85	-7.72	0.709854			av.	-0.44	-8.47	0.708954
		SD	1.05	0.55	0.000101			SD	0.28	0.22	0.000141
		min	-1.03	-7.80	0.709558			min	-0.62	-8.03	/
	In-situ DG	max	-0.51	-7.03	0.709911		Partially dolomitized	max	1.08	-5.69	/
	(n=4)	av.	-0.72	-7.41	0.709726		limestone	av.	0.40	-7.22	/
		SD	0.22	0.39	0.000148		(11-0)	SD	0.54	0.75	/

# Table S3. Carbon, oxygen and strontium isotope data for the LWMF, Sichuan Basin

# Table S4. Calcium isotope data for the LWMF, Sichuan Basin

Pagion	Lithology		$\delta^{44/40}$ Ca	Pagion	Lithology		$\delta^{44/40}$ Ca
Region	Liulology		(‰, Seawater)	Region	Litilology		(‰, Seawater)
		min	-1.27	Southern Sichuan		min	-1.07
	DG	max	-0.94	Basin	DM	max	-0.94
	(n=4)	av.	-1.14	(the medium	(n=2)	av.	-1.01
		SD	0.14	terrace)		SD	0.09
Central Sichuan		min	-1.05			min	-1.49
Basin	DM	max	-1.05		DG (n=2)	max	-1.44
(the higher terrace)	(n=1)	av.	-1.05			av.	-1.47
		SD	/			SD	0.04
		min	-1.18			min	-1.47
	CD	max	-1.17		DM	max	-1.23
	(n=2)	av.	-1.18	F ( 0'1	(n=6)	av.	-1.35
		SD	0.01	Eastern Sichuan		SD	0.08
		min	-1.27	(the lease terms of		min	-1.11
	DG	max	-1.18	(the lower terrace)	MS	max	-1.01
Southern	(n=3)	av.	-1.23	1	(n=4)	av.	-1.07
Sichuan Basin		SD	0.05			SD	0.05
(the medium terrace)		min	-1.25		Partially	min	-1.17
	CD	max	-1.06	]	dolomitized	max	-0.94
	(n=2)	av.	-1.16	]	limestone	av.	-1.08
		SD	0.13	1	(n=8)	SD	0.08

#### **Supplementary figures**



Fig. S1. (a) Dolomudstone, GS10, 4630.8m, PPL; (b) Calcareous dolograinstone, LG1, 4835.08m, PPL; (c) Calcareous dolograinstone, Laoqihe outcrop, PPL;



**Fig. S2.** Depositional setting of the Longwangmiao Formation in the Sichuan Basin. (a) Vermilion sandy mudstone, mixed tidal flat, Fandian outcrop, Southern Sichuan Basin (the medium terrace); (b) sandy dolostones, with terrigenous clasts, CPL, mixed tidal flat, MX202, 4750.84 m, Central Sichuan Basin (the higher terrace); (c) tempestite beds, Sa: Graded bedding section. Gravel dolostones and fine dolograinstones with graded or massive beds; yellow dotted line: irregular scour surfaces and groove casts were developed on the bottom and had abrupt contact with the underlying layers, GS10, 4689.39 ~ 4689.56 m, Central Sichuan Basin (the higher terrace); (d) patchy dolostone, black mottles and white mottles are irregular and staggered in size, Laoqihe outcrop, Eastern Sichuan Basin (the lower terrace); (e) calcareous dolostone, PPL, calcite with red color under staining of Alizarin Red solution, Laoqihe outcrop, Eastern Sichuan Basin (the lower terrace); (f) tempestite beds, grainstones, gravel limestones and fine grainstones with graded or massive beds; yellow dotted line: irregular scour surfaces and groove casts were developed on the bottom and had abrupt contact with the lower terrace); (f) tempestite beds, grainstones, gravel limestones and fine grainstones with graded or massive beds; yellow dotted line: irregular scour surfaces and groove casts were developed on the bottom and had abrupt contact with the underlying layers, Shiliu outcrop, Eastern Sichuan Basin (the lower terrace) and (g) bioclastic limestone, high shale content, PPL, Shiliu outcrop, Eastern Sichuan Basin (the lower terrace).



**Fig. S3.** (a) Lateral correlation profile of the Longwangmiao Formation Facies from the borehole MX12 to borehole CS1, Sichuan Basin (the location of the profile can be found in Fig. 1 as marked by B-B') and (b) seismic reflection characteristics of the paleogeography of the Longwangmiao Formation, with the bottom of the Xixiangchi Formation horizon flattening through the boreholes ZY1 and JS1(the location of the profile can be found in Fig. 1 as marked by C-C').



**Fig. S4.** Scatterplots of the trace elements within the dolostones in Central Sichuan Basin (the higher terrace), Southern Sichuan Basin (the medium terrace) and Eastern Sichuan Basin (the lower terrace). Scatterplot of (a) K-Al; (b) K\*-Al; (c) Na-Al; (d) Na\*-Al; (e) Sr-Al; (f) Sr\*-Al; (g) Mn-Al; (h) Mn\*-Al; (i) Fe-Al; (j) Fe\*-Al; (k) REE-Sc; (l) REE\*-Sc; (m) REE-Zr; (n) REE\*-Zr; (o) REE-Th; (p) REE\*-Th; (q) *in-situ* Na-*in-situ* Al; (r) *in-situ* K-*in-situ* Al; (s) *in-situ* Sr-*in-situ* Al; (t) *in-situ* Mn-*in-situ* Al; (u) *in-situ* Fe-*in-situ* Al; (v) *in-situ* REE-*in-situ* Sc; (w) *in-situ* REE-*in-situ* Zr; (x) *in-situ* REE-*in-situ* Th.