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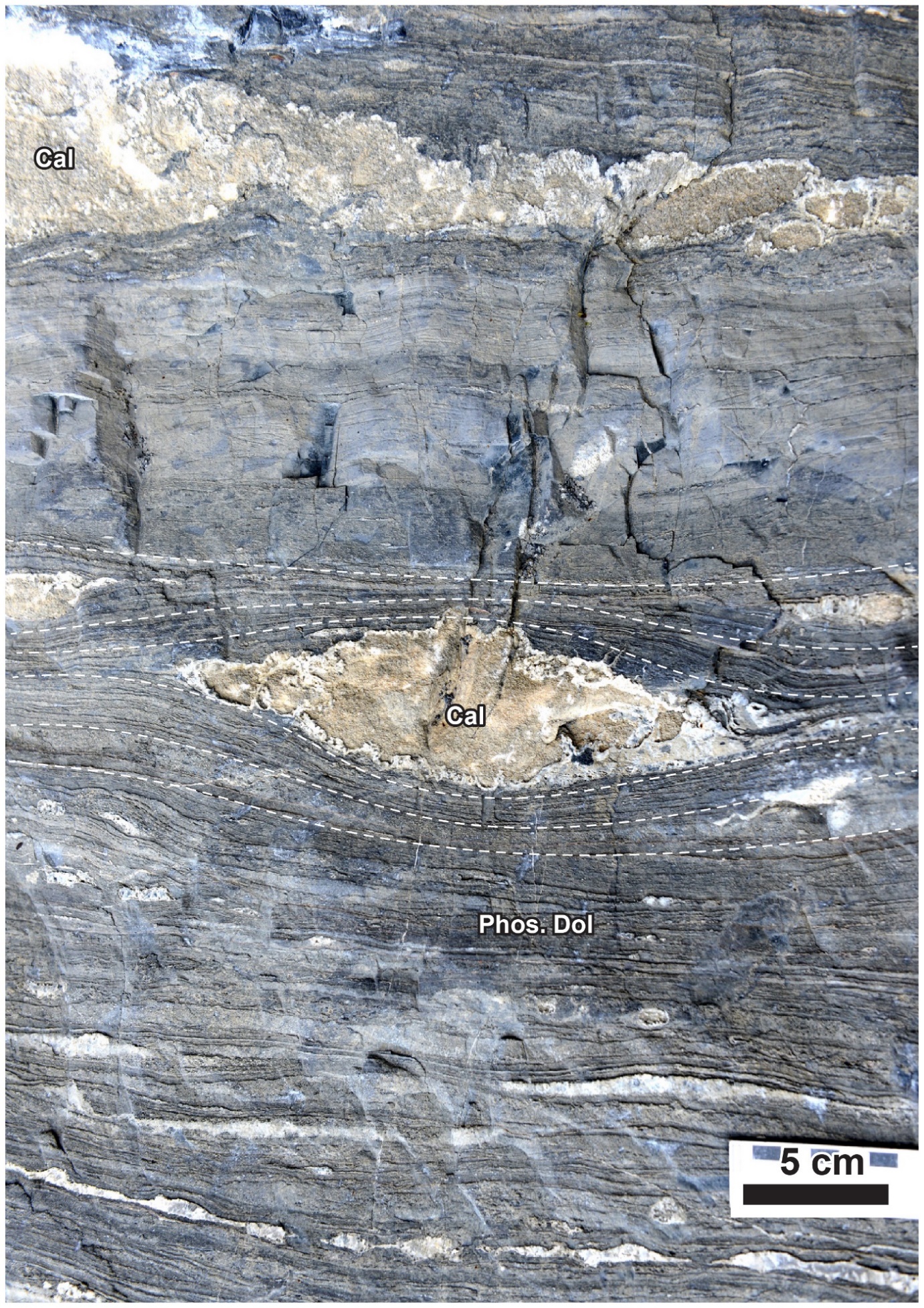
**Dynamic interplay of biogeochemical C, S, and Ba cycles in response to Shuram oxygenation event**

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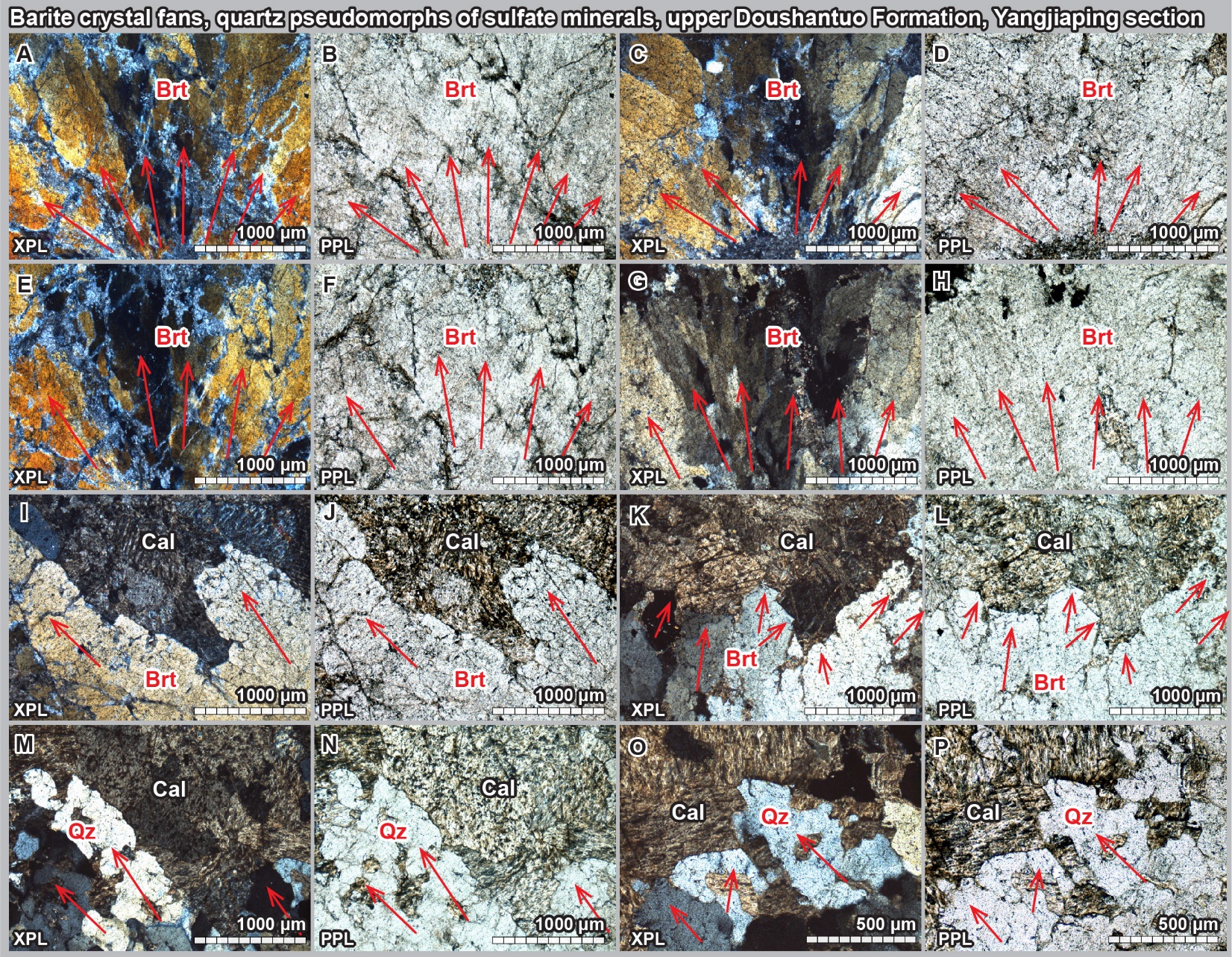
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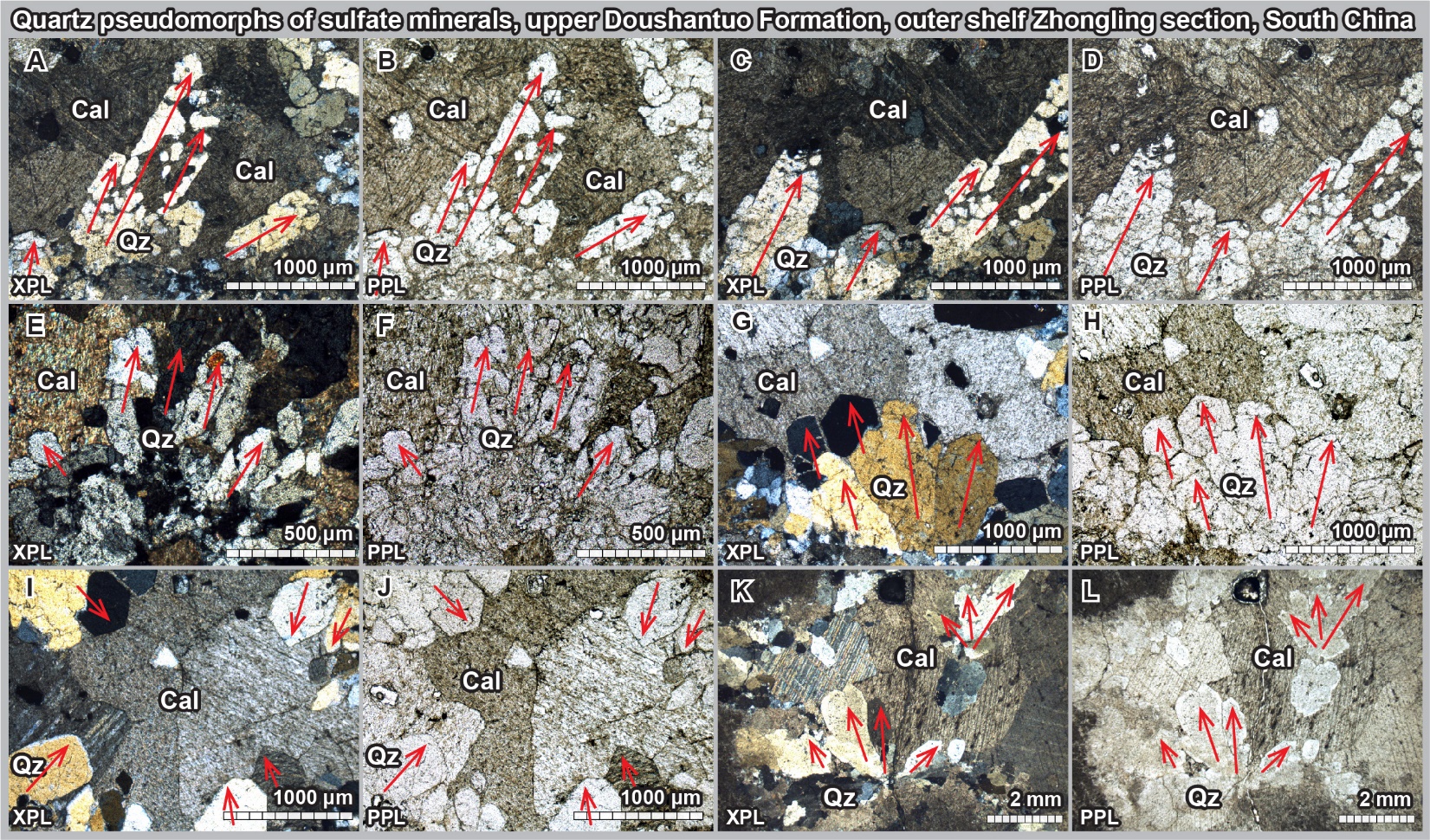




**Figs. S1 and S2:** Enlarged photos of the calcite lenses (after gypsum) in the uppermost Doushantuo Formation, outer shelf Nanbeizhen section, South China. The Nanbeizhen section is located very close to and in the SW direction of the Zhongling section. Note thewarping laminations surrounding the nodules, indicating that the calcite lenses formed before sediment compaction.



**Fig. S3.** Paired XPL and PPL petrographic images of sulfate minerals from the upper Doushantuo Formaiton, outer shelf Yangjiaping section, Hunan Province, South China. Red arrows denote crystal directions of sulfate minerals (or their pseudomorphs when they are silicified). **(A–L)** Barite crystals associated with 13C-depleted calcite. Note the undulatory extinction of barite crystals. **(M–P)** Quartz pseudomorphs of sulfate minerals. Sample codes and stratigraphic positions: A–L (YJP-R4, 105 m, Yangjiaping), M–P (YJP-R5, 105 m, Yangjiaping). Images A, C, O are from [Cui et al. (2016)](#_ENREF_2). Abbreviations: Brt = barite; Cal = calcite; PPL = plane polarized light; Qz = quartz; XPL = cross polarized light.



**Fig. S4.** Paired XPL and PPL petrographic images of silificied sulfate minerals from the upper Doushantuo Formaiton, outer shelf Zhongling section, Hunan Province, South China. Red arrows denote crystal directions of silicified sulfate minerals. Sample codes and stratigraphic positions: A–J (14ZL-4.5, 254.5 m, Zhongling), K–L (12ZL-21.6, 237.4 m, Zhongling). Images C, I, K, L are from [Cui et al. (2017)](#_ENREF_3). Abbreviations: Cal = calcite; PPL = plane polarized light; Qz = quartz; XPL = cross polarized light.

**Table S1:** Data of the Upper Clemente Formation at the CR-1 and CR-2 sections, Cerro Rajón, Sonora State, Mexico. Samples were dissolved by 1 M HCl for Ba concentration analysis. Detailed analytical method of [Ba] analysis follows the study of [Zhang et al. (2019)](#_ENREF_10). Data source: δ13C and δ18O data ([Loyd et al., 2012](#_ENREF_7); [Loyd et al., 2013](#_ENREF_8)); Ba concentration data (this study).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Clemente | Lab  number | Sample  number | Height  (m) | δ13C  (‰, VPDB) | δ18O  (‰, VPDB) | [Ba]  (ppm) |
| CR–1 | CRC–1 | CRC-110 | 138.50 | 0.79 | –12.20 | 154.63 |
| CR–1 | CRC–2 | CRC-160 | 188.50 | 3.82 | –10.23 | 8.62 |
| CR–1 | CRC–3 | CRC-190 | 218.50 | 2.56 | –9.47 | 16.34 |
| CR–1 | CRC–4 | CRCm–203 | 231.50 | –0.08 | –8.30 | 61.21 |
| CR–1 | CRC–5 | CRCm–310 | 338.50 | 1.17 | –4.59 | 21.93 |
| CR–1 | CRC–6 | CRCm–328 | 356.50 | –1.32 | –5.88 | 21.67 |
| CR–1 | CRC–7 | CRCm–333 | 361.50 | –3.02 | –7.45 | 674.85 |
| CR–1 | CRC–8 | CRCm–334.6 | 363.10 | –7.52 | –10.35 | 39.98 |
| CR–1 | CRC–9 | CRCm–335.7 | 364.20 | –8.59 | –14.90 | 31.76 |
| CR–1 | CRC–10 | CRCM–UL1 | 373.50 | –8.06 | –16.30 | 47.59 |
| CR–1 | CRC–11 | CRCM–UL2 | 373.50 |  |  | 57.04 |
| CR–1 | CRC–12 | CRCM–40mbp | 383.50 | –8.61 | –6.40 | 35.84 |
| CR–1 | CRC–13 | CRCM–30mbp | 393.50 | –7.58 | –9.06 | 13.05 |
| CR–1 | CRC–14 | CRCM–427mbp | 396.50 | –7.46 | –9.41 | 117.95 |
| CR–1 | CRC–15 | CRCM–bp | 423.50 | –5.90 | –9.05 | 13.99 |
| CR–1 | CRC–16 | CRG–0 | 500.50 | 0.00 | –2.93 | 5.64 |
| CR–1 | CRC–17 | CRG–45 | 545.50 | 3.02 | –3.11 | 3.74 |
| CR–1 | CRC–18 | CRG–65 | 565.50 | 1.29 | –3.79 | 1.90 |
| CR–1 | CRC–19 | CRG–80 | 580.50 | 2.14 | –3.04 | 6.01 |
| CR–1 | CRC–20 | CRG–135 | 630.50 | 2.53 | –2.04 | 2.76 |
| CR–1 | CRC–21 | CRPa–0 | 660.50 | –1.00 | –5.37 | 2.57 |
| CR–1 | CRC–22 | CRPa–22 | 672.50 | –1.60 | –3.37 | 4.27 |
| CR–1 | CRC–23 | CRPa–40 | 690.50 | 2.32 | –3.83 | 3.14 |
| CR–1 | CRC–24 | CRPa–80 | 730.50 | 1.30 | –2.81 | 2.55 |
| CR–1 | CRC–25 | CRPa–97 | 747.50 | –0.59 | –3.24 | 1.98 |
| CR–2 | CO–1 | CO–0 | 0.00 | –5.00 | –8.50 | 120.48 |
| CR–2 | CO–2 | CO–30 | 0.30 | –4.80 | –9.60 | 420.29 |
| CR–2 | CO–3 | CO–60 | 0.60 | –5.30 | –7.70 | 112.15 |
| CR–2 | CO–4 | CO–90 | 0.90 | –9.30 | –10.50 | 146.37 |
| CR–2 | CO–5 | CO–120 | 1.20 | –8.20 | –12.10 | 221.58 |
| CR–2 | CO–6 | CO–150 | 1.50 | –9.60 | –12.80 | 28.75 |
| CR–2 | CO–7 | CO–200 | 2.00 | –9.20 | –12.60 | 20.25 |
| CR–2 | CO–8 | CO–230 | 2.30 | –8.30 | –12.60 | 150.21 |
| CR–2 | CO–9 | CO–260 | 2.60 | –8.10 | –13.40 | 62.56 |

**Table S2:** Geochemical data of the upper Doushantuo Formation at the outer shelf Yangjiaping section, Hunan Province, South China. Samples were dissolved by 0.4 M HNO3 for Ba concentration analysis. Detailed analytical method of [Ba] analysis follows the studies of [Liu et al. (2016)](#_ENREF_5) and [Liu et al. (2021)](#_ENREF_6). Data source: δ13C and δ18O data ([Cui et al., 2015](#_ENREF_1)); Ba concentration data (this study).

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| --- | --- | --- | --- | --- | --- | --- |
| Yangjiaping  section | Height  (m) | Lithology | Carbonate  (wt.%) | δ13C  (‰,VPDB) | δ18O  (‰,VPDB) | [Ba]  ppm |
| Yd1 | 1 | limestone | 68.1 | 5.2 | ‒6.0 | 15.80 |
| Yd2 | 4 | limestone | 69.3 | 4.8 | ‒5.8 | 20.42 |
| Yd3 | 8 | dolostone | 62.3 | 4.8 | ‒6.0 | 31.26 |
| Yd5 | 16 | dolostone | 70.1 | 4.8 | ‒6.3 | 12.53 |
| Yd6 | 20 | limestone | 81 | 4.7 | ‒6.7 | 15.54 |
| Yd8 | 28 | phosphatic limestone | 97.2 | 7.1 | ‒7.6 | 3.64 |
| Yd9 | 32 | limestone | 97.6 | 6.7 | ‒7.6 | 5.62 |
| Yd10 | 36 | limestone | 94.4 | 6.8 | ‒6.6 | 7.11 |
| Yd11 | 40 | dolostone | 76.6 | 6.2 | ‒5.6 | 11.92 |
| Yd12 | 44 | dolostone | 96.7 | 6 | ‒5.1 | 12.24 |
| Yd13 | 49 | limestone | 95.2 | 6.5 | ‒7.0 | 8.70 |
| Yd14 | 53 | limestone | 96.2 | 6.2 | ‒7.3 | 5.76 |
| Yd15 | 56 | oolitic limestone | 97.6 | 6.4 | ‒6.7 | 10.49 |
| Yd16 | 60 | oolitic limestone | 97.3 | 6.9 | ‒6.9 | 7.53 |
| Yd17 | 65 | oolitic limestone | 98.7 | 6.9 | ‒7.4 | 6.53 |
| Yd18 | 70 | oolitic limestone | 98.4 | 6.9 | ‒7.7 | 9.49 |
| Yd19 | 75 | oolitic limestone | 98.9 | 6.7 | ‒7.7 | 8.72 |
| Yd20 | 79 | oolitic limestone | 97.5 | 3.8 | ‒8.0 | 6.66 |
| Yd21 | 84 | oolitic limestone | 73.9 | 3.4 | ‒8.3 | 5.20 |
| Yd22 | 88 | oolitic limestone | 91.3 | 4.6 | ‒6.4 | 12.95 |
| Yd23 | 94 | dolostone | 63.4 | 3.5 | ‒5.3 | 17.95 |
| Yd24 | 96 | oolitic limestone | 98.7 | ‒1.8 | ‒6.8 | 10.56 |
| Yd25 | 98 | limestone | 84.3 | ‒2.7 | ‒5.1 | 27.50 |
| Yd26 | 103.4 | phosphorite | 59 | ‒6.8 | ‒6.3 | 137.25 |

**Table S3:** Sample list of the SEM-EDS images. See online PowerPoint slides for detailed results.

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| --- | --- | --- | --- | --- | --- | --- |
| Sample #  ([McFadden et al., 2008](#_ENREF_9)) | Sample #  ([Cui et al., 2021](#_ENREF_4)) | Height above Nantuo diamictite, Jiulongwan | δ13Ccarb  (VPDB, microdrilled,  GS-IRMS) | SEM-EDS results | Stratigraphic  position | Lithology |
| SSFT39.6 | Sample S4 | 110.6 m | –8.9‰ | Barite, pyrite | EN3b, Mb. IV | Dolomitic limestone |
| HND9.1 | Sample S5 | 121.9 m | –9.1‰ | Barite, pyrite | EN3b, Mb. IV | Dolomitic limestone |
| HND18.05 | Sample S7 | 130.9 m | –8.6‰ | Barite, pyrite, including pyrite pseudomorph of evaporite minerals | EN3b, Mb. IV | Dolomitic limestone |
| HND27.75\* | Sample S8 | 140.55 m | –8.4‰ | Barite, pyrite | EN3b, Mb. IV | Dolomitic limestone |

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