# Building a coherent chronological framework for ice cores, marine sediment cores and speleothems over the last 640,000 years

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# Supplementary informations

## The fictitious depth of the composite speleothem

A composite speleothem does not have an intrinsic depth, as it results from the assemblage of multiple distinct speleothems [Cheng et al., 2016]. However, the Paleochrono-1.1 software requires depth values as tie points to integrate climate archives.
To address this constraint, we assigned a fictitious depth to the 655 dated horizons (U/Th measurements) used in Cheng et al. [2009, 2013, 2016] to date the $\delta^{18}O_{calcite}$ record. Specifically, we set a value of 1 mm per dated horizon, leading to a total depth of 655 mm. The depths of the tie points are then calculated by linear interpolation from the depths of the dated horizons.

## Figures

Figure 1: IODP U1308 age difference between its initial chronology and its background chronology ($\sigma$ of 1 and $\lambda$ of 2000 years) obtained with Paleochrono-1.1 over the last 640 ka. The age difference is calculated as per initial - background chronologies. A negative (positive) difference indicated that the new chronology leads (lags) the initial chronology. Gray rectangles indicate interglacials from MIS 15 to MIS 1.

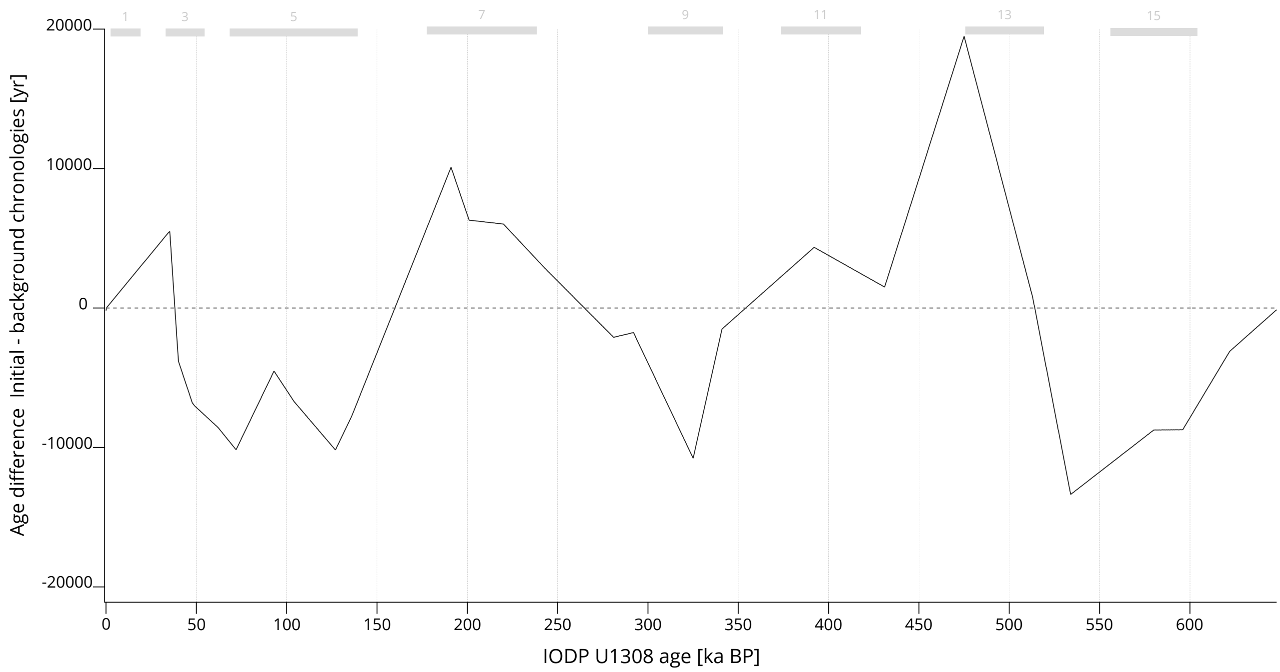


Figure 2: IODP U1308 age difference between its initial chronology and different test chronologies obtained with Paleochrono-1.1 over the last 640 ka. The age difference is calculated as per initial - test chronologies. The different curves show different assumptions made of the IODP U1308 prior parameters deposition rate uncertainty $\sigma$ and correlation length $\lambda$. The gray curve corresponds to the SM1 experiment, the orange curves correspond to SM1 (0.5-1000) and SM1 (0.5-5000), the pink curves correspond to SM1 (2-1000) and SM1 (2-5000). Bottom vertical bars represent the age of corresponding tie points. Gray rectangles indicate interglacials from MIS 15 to MIS 1.

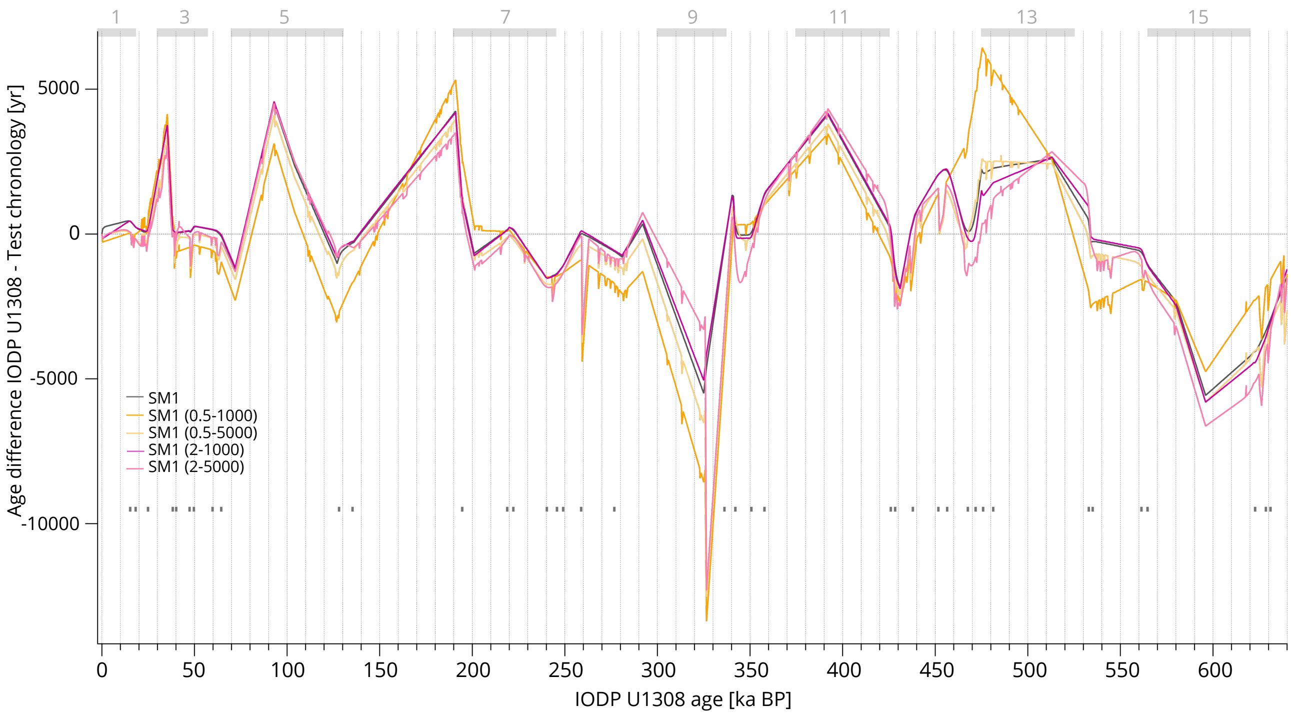


Figure 3: Evolution of climate over Terminations. a) Summer solstice insolation at 65°N [Laskar et al., 2004]. b) Atmospheric $CO_2$ concentration from EDC [Lüthi et al. [2008], Bereiter et al. [2015], Nehrbass-Ahles et al. [2020]] on AICC2023 age scale. c) $\delta^{18}O_{benthic}$ record from IODP U1308 on its initial age scale [Hodell et al., 2008]. d) Chinese $\delta^{18}O_{calcite}$ records on U-Th age scale [Cheng et al., 2016] e) IODP U1308 bulk $\delta^{18}O$ used as indirect IRD proxy on its initial age scale (axes are reversed) [Hodell et al., 2008]

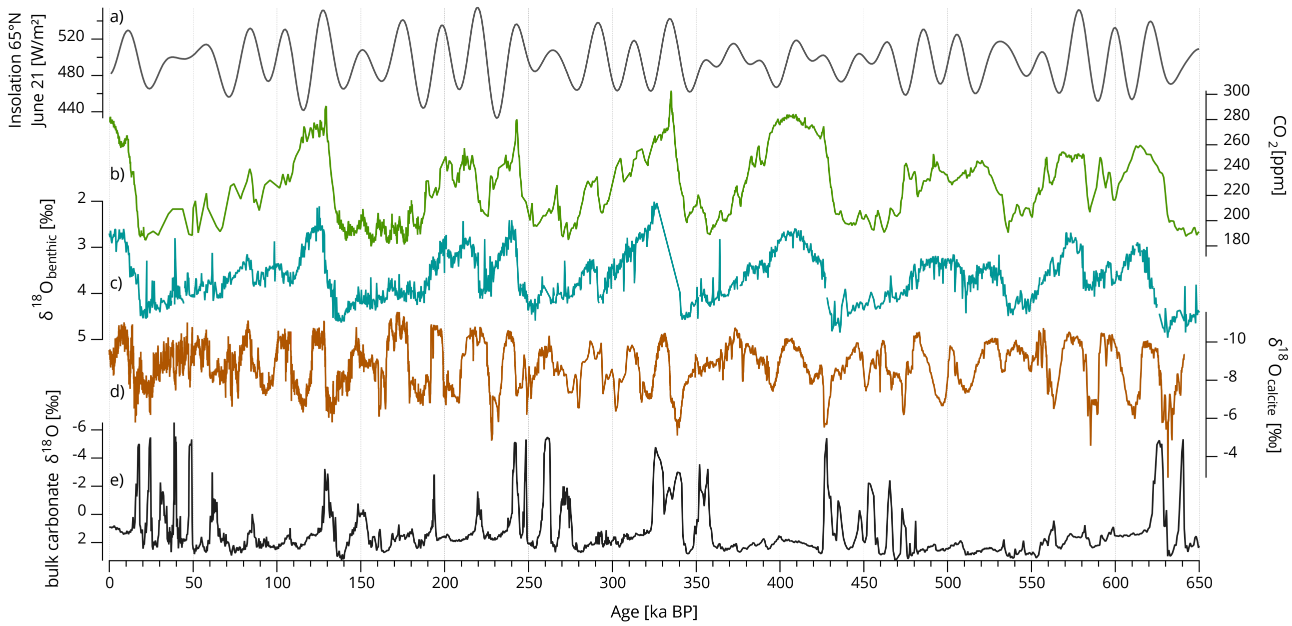


Figure 4: Representations of new chronologies over the last 640 ka. a) Summer solstice insolation at 65°N [Laskar et al., 2004]. b) Atmospheric $CO_2$ concentration from EDC [Lüthi et al. [2008], Bereiter et al. [2015], Nehrbass-Ahles et al. [2020]] on the SI1 timescale (gray), on SI2 (blue), and on SI3 (red). c) $\delta^{18}O_{benthic}$ record from IODP U1308 on its initial age scale (black, Hodell et al. [2008]), and on SM1, SM2 (100 yr) and SM2 (2000 yr). A vertical shift of + 2 ‰was applied to the four experiments SM1 (0.5-1000), SM1 (0.5-5000), SM1 (2-1000) and SM1 (2-5000) to improve visual clarity.

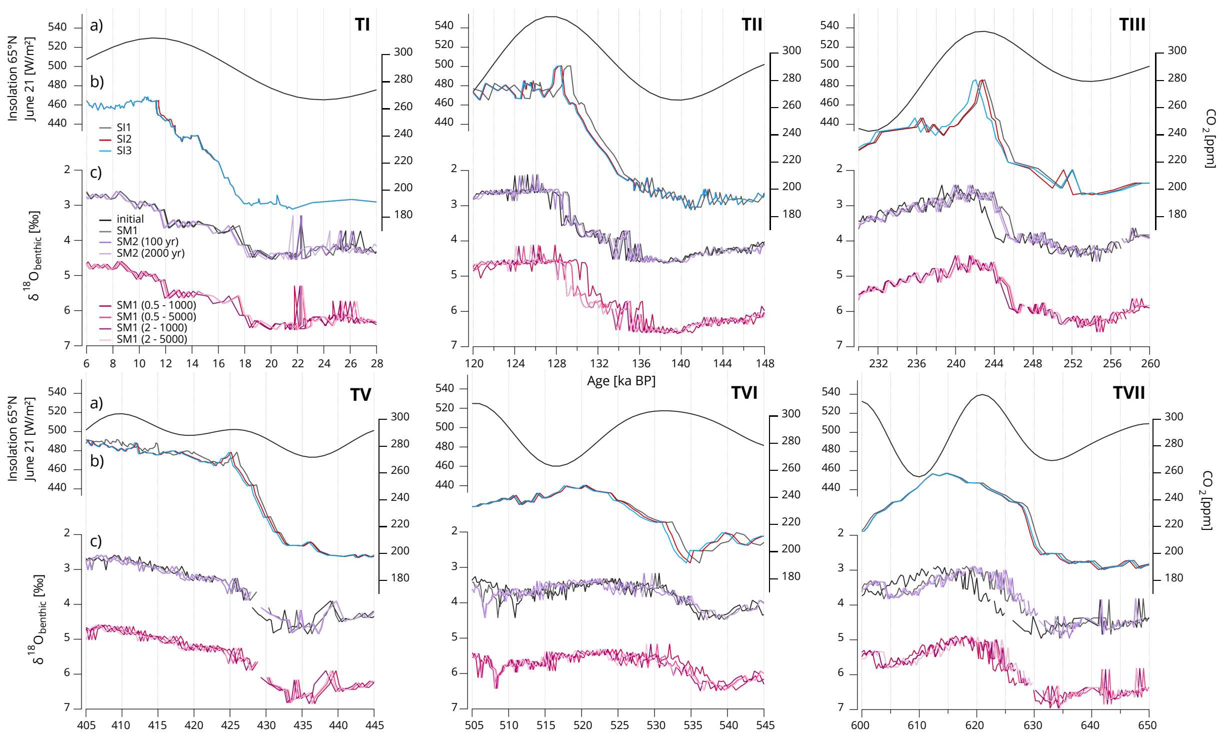
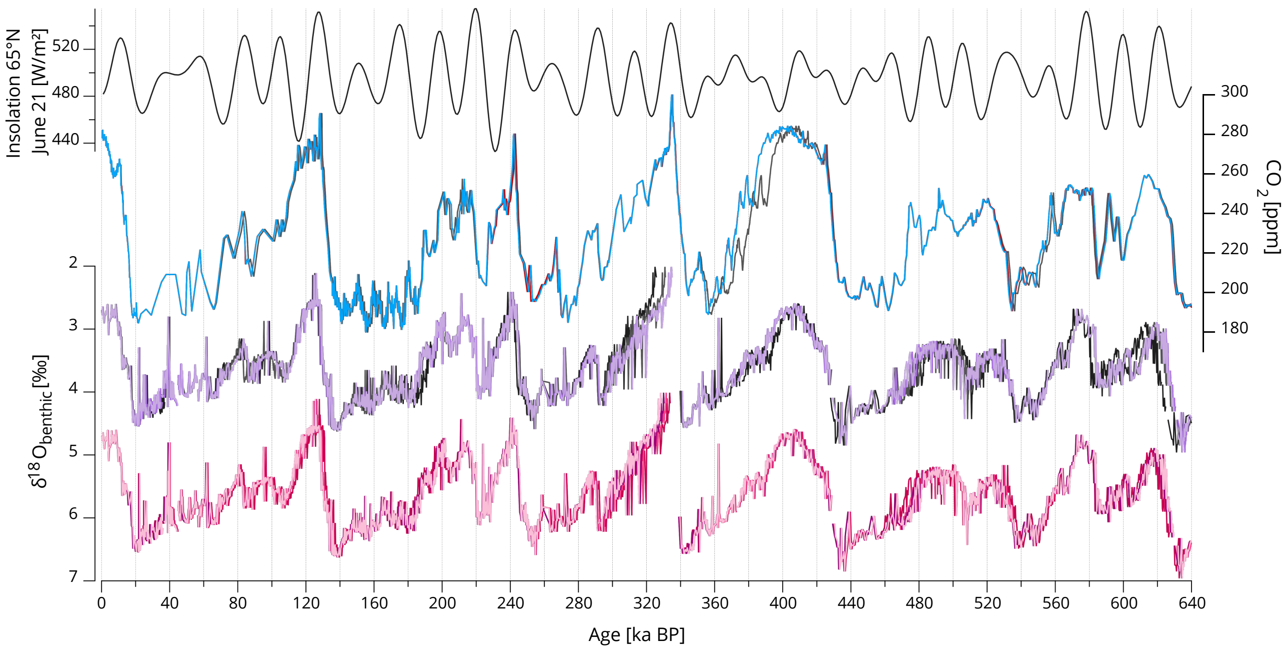


Figure 5: Representations of new chronologies over the last 640 ka. a) Summer solstice insolation at 65°N [Laskar et al., 2004]. b) Atmospheric $CO_2$ concentration from EDC [Lüthi et al. [2008], Bereiter et al. [2015], Nehrbass-Ahles et al. [2020]] on the SI1 timescale (gray), on SI2 (blue), and on SI3 (red). c) $\delta^{18}O_{benthic}$ record from IODP U1308 on its initial age scale (black, Hodell et al. [2008]), and on SM1, SM2 (100 yr) and SM2 (2000 yr). A vertical shift of + 2 ‰was applied to the four experiments SM1 (0.5-1000), SM1 (0.5-5000), SM1 (2-1000) and SM1 (2-5000) to improve visual clarity.



## Stratigraphic links

### EDC - speleothem

Table 1: $\delta^{18}O_{calcite}$ - $\delta^{18}O_{atm}$ stratigraphic links used for the Chinese speleothem composite and EDC in the **SI1** experiment

| EDC depth (m) | EDC gas age (ka BP) | Speleothem age (ka BP) |
|---|---|---|
| 1485.61 | 107.79 | 108.50 |
| 1585.20 | 120.22 | 120.90 |
| 1706.92 | 128.73 | 128.80 |
| 1903.01 | 159.30 | 160.40 |
| 1921.37 | 162.95 | 163.00 |
| 1931.13 | 164.89 | 165.20 |
| 1997.19 | 179.40 | 178.30 |
| 2050.18 | 191.28 | 191.80 |
| 2096.02 | 200.25 | 199.00 |
| 2139.91 | 208.22 | 207.90 |
| 2160.01 | 211.40 | 209.30 |
| 2229.99 | 225.89 | 225.30 |
| 2232.88 | 226.76 | 227.60 |
| 2258.68 | 233.69 | 233.20 |
| 2300.06 | 242.10 | 242.20 |
| 2332.74 | 248.54 | 248.40 |
| 2363.62 | 259.36 | 258.70 |
| 2376.66 | 264.43 | 264.40 |
| 2409.39 | 277.70 | 279.00 |
| 2451.16 | 290.73 | 289.00 |
| 2466.27 | 295.92 | 293.90 |
| 2475.81 | 299.73 | 301.30 |
| 2490.37 | 304.88 | 304.90 |
| 2522.11 | 316.70 | 316.60 |
| 2582.63 | 334.03 | 334.30 |
| 2599.92 | 338.17 | 337.90 |
| 2664.62 | 376.73 | 377.30 |
| 2679.89 | 384.56 | 385.70 |
| 2707.22 | 397.87 | 398.50 |
| 2776.91 | 424.88 | 425.90 |
| 2784.70 | 429.08 | 428.80 |
| 2791.70 | 436.03 | 434.50 |
| 2793.91 | 438.69 | 440.30 |
| 2838.23 | 485.38 | 483.90 |
| 2857.55 | 498.16 | 500.60 |
| 2873.92 | 509.07 | 504.10 |
| 2894.57 | 523.64 | 521.00 |
| 2904.64 | 531.48 | 531.30 |
| 2909.14 | 535.19 | 534.90 |

| | | |
|---|---|---|
| 2917.53 | 543.25 | 549.10 |
| 2930.36 | 553.57 | 555.60 |
| 2937.72 | 557.84 | 559.10 |
| 3002.71 | 585.70 | 583.00 |
| 3009.86 | 593.00 | 590.00 |
| 3018.09 | 603.99 | 602.70 |
| 3027.90 | 616.41 | 615.20 |
| 3038.00 | 628.83 | 627.50 |
| 3040.00 | 631.56 | 633.00 |
| 3043.26 | 638.12 | 638.20 |

Table 2: $\delta^{18}O_{calcite}$ - $CH_4$ stratigraphic links used for the Chinese speleothem composite and EDC in the **SI2** experiment.

| **EDC depth (m)** | **EDC gas age (ka BP)** | **Speleothem age (ka BP)** |
|---|---|---|
| 421.92 | 11.514 | 11.976 |
| 481.88 | 15.004 | 14.866 |
| 691.81 | 32.944 | 32.697 |
| 705.09 | 34.188 | 34.175 |
| 721.46 | 35.627 | 35.565 |
| 927.41 | 54.496 | 54.97 |
| 987.43 | 59.739 | 59.861 |
| 1258.1 | 86.409 | 84.481 |
| 1727.11 | 129.90 | 128.99 |
| 2307.4 | 242.99 | 242.76 |
| 2337.9 | 250.08 | 248.97 |
| 2586.5 | 334.72 | 334.72 |
| 2781.35 | 427.08 | 426.42 |
| 2907.6 | 533.79 | 532.56 |
| 2999.3 | 582.76 | 583.68 |
| 3040.4 | 632.16 | 627.93 |

Table 3: $\delta^{18}O_{calcite}$ - $CH_4$ stratigraphic links used for the Chinese speleothem composite and EDC in the **SI2** experiment.

| **EDC depth (m)** | **EDC gas age (ka BP)** | **Speleothem age (ka BP)** |
|---|---|---|
| 421.7 | 11.342 | 11.402 |
| 477.45 | 14.724 | 14.622 |
| 690.55 | 32.819 | 32.667 |
| 704 | 34.1 | 34.033 |
| 720.71 | 35.547 | 35.311 |
| 921.79 | 54.035 | 54.402 |
| 985.11 | 59.507 | 59.77 |
| 1251.24 | 85.82 | 84.176 |
| 1724.58 | 129.75 | 128.7 |
| 2306.8 | 242.92 | 241.98 |
| 2335.2 | 249.23 | 248.81 |
| 2585.62 | 334.56 | 334.28 |
| 2781 | 426.89 | 425.91 |
| 2906.4 | 532.82 | 530.9 |
| 2997.6 | 581.7 | 583.09 |
| 3038 | 628.79 | 626.35 |

### IODP U1308 - speleothem

Table 4: $\delta^{18}O_{calcite}$ - IRD stratigraphic links used for IODP U1308 and the Chinese speleothem composite in **SM1** experiment

| Depth IODP U1308 [mcd] | Age IODP U1308 on his age scale [ka BP] | Age speleothem composite on his age scale [ka BP] |
|---|---|---|
| 0.82 | 15.252 | 14.8 |
| 0.98 | 18.228 | 18.0 |
| 1.34 | 24.924 | 24.8 |
| 2.45 | 38.229 | 38.2 |
| 2.80 | 40.10 | 40.0 |
| 3.44 | 47.323 | 47.2 |
| 3.62 | 49.68 | 49.4 |
| 4.34 | 59.76 | 59.6 |
| 4.68 | 64.43 | 64.4 |
| 8.80 | 128.07 | 128.4 |
| 9.14 | 135.36 | 135.6 |
| 11.85 | 194.52 | 193.4 |
| 13.58 | 218.915 | 218.8 |
| 13.81 | 222.20 | 222.0 |
| 15.12 | 240.25 | 241.8 |
| 15.52 | 245.77 | 247.2 |
| 15.76 | 249.10 | 250.2 |
| 16.46 | 258.81 | 258.6 |
| 17.75 | 276.70 | 277.2 |
| 21.72 | 336.17 | 334.0 |
| 21.91 | 342.06 | 342.2 |
| 22.40 | 350.74 | 351.0 |
| 22.80 | 357.83 | 356.4 |
| 27.06 | 426.03 | 425.8 |
| 27.22 | 428.37 | 429.8 |
| 27.66 | 437.89 | 437.4 |
| 28.18 | 451.67 | 449.60 |
| 28.36 | 456.45 | 454.20 |
| 28.78 | 467.58 | 467.80 |
| 28.94 | 471.82 | 472.20 |
| 29.14 | 475.84 | 475.40 |
| 29.66 | 481.30 | 479.80 |
| 34.80 | 532.88 | 531.60 |
| 34.98 | 535.05 | 535.20 |
| 36.49 | 561.36 | 561.80 |
| 36.68 | 564.67 | 565.80 |
| 39.92 | 622.71 | 627.40 |
| 40.25 | 628.55 | 632.40 |
| 40.39 | 631.03 | 634.20 |
| 40.96 | 641.12 | 641.00 |

Table 5: $\delta^{18}O_{calcite}$ - IRD stratigraphic links used for IODP U1308 and the Chinese speleothem composite in **SM2** experiment

| Depth IODP U1308 [mcd] | Age IODP U1308 on his age scale [ka BP] | Age speleothem composite on his age scale [ka BP] |
|---|---|---|
| 0.82 | 15.25 | 14.8 |
| 0.98 | 18.23 | 18.0 |
| 1.34 | 24.92 | 24.8 |
| 2.45 | 38.23 | 38.2 |
| 2.80 | 40.10 | 40.0 |
| 3.44 | 47.32 | 47.2 |
| 3.62 | 49.68 | 49.4 |
| 4.34 | 59.76 | 59.6 |
| 4.68 | 64.43 | 64.4 |
| 6.01 | 88.5 | 88.78 |
| 8.80 | 128.08 | 128.4 |
| 9.14 | 135.36 | 135.6 |
| 10.01 | 155.49 | 156.78 |
| 11.71 | 192.93 | 190.0 |
| 11.85 | 194.52 | 193.4 |
| 15.12 | 240.25 | 241.8 |
| 15.52 | 245.77 | 247.2 |
| 15.76 | 249.10 | 250.2 |
| 16.46 | 258.81 | 258.6 |
| 16.80 | 263.53 | 262.40 |
| 21.91 | 342.06 | 342.2 |
| 22.40 | 350.74 | 351.0 |
| 22.80 | 357.83 | 356.4 |
| 27.06 | 426.03 | 425.8 |
| 27.22 | 428.37 | 429.8 |
| 27.66 | 437.89 | 437.4 |
| 28.18 | 451.67 | 449.60 |
| 28.36 | 456.45 | 454.20 |
| 28.59 | 462.55 | 461.84 |
| 28.78 | 467.58 | 467.80 |
| 34.68 | 531.75 | 529.60 |
| 34.98 | 535.05 | 536.20 |
| 36.49 | 561.36 | 561.80 |
| 36.68 | 564.67 | 565.80 |
| 39.80 | 620.40 | 627.00 |
| 40.39 | 631.03 | 635.40 |
| 40.76 | 637.58 | 637.00 |
| 40.96 | 641.12 | 641.00 |

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