Appendix 1: Stable Isotope Analysis

Six oyster shells from Grassridge were cut perpendicular to layering and small sections (1 cm3) with no apparent discoloration and recrystallization were selected for standard stable isotopes analysis. Two or three fragments (2-3 g) from different parts of each section were chip off and homogenized in a mortar and pestle. δ13C and δ18O were measured at least in triplicate on a Thermo GasBench-II coupled to a Delta-V at the Geochemical Laboratory of Utrecht University, Netherlands. Raw values were corrected for drift and samples size using lab-standard Naxos: a marble from the Greek island (50-125 mu), calibrated versus NBS-19 and 18 to be +2.1 ‰ VPDB δ13C and -6.8 ‰ VPDB δ18O. A control sample IAEA-CO-1 (+2.5; -2.4 ‰ VPDB δ18O) measured also in triplicate during the analysis gave: +2.5 ‰ VPDB δ13C, with a standard deviation of 0.04; and -2.4 ‰ VPDB δ18O, with a standard deviation of 0.1.

Table 1: C and O isotope compositions of six oyster shells from the Alexandria Fm. (GR samples)

|  |  |  |
| --- | --- | --- |
| **Oyster sample** | **δ13C (‰ VPDB)** | **δ18O (‰ VPDB)** |
| PE1 | -4.0 | -1.5 |
| PE2 | -3.8 | -1.6 |
| PE3 | -4.2 | -1.7 |
| PE4 | -4.3 | -1.7 |
| PE5 | -4.8 | -2.0 |
| PE6 | -4.0 | -1.7 |
| Precision and accuracy better than 0.1‰ | | |

Oyster shell samples have δ13C values between -4.8 and -3.8 ‰ VPDB (-4.2 ‰ in average), and δ18O values between -2.0 and -1.5 ‰ VPDB (-1.7 ‰ in average). The results are consistent with the SIMS and clumped isotope measurements, although these other methods give a larger range of values most likely because of sampling different growth intervals of the shells using the ion beam and hand-drill compared to the crushing of small sections.

Appendix 2: Leaching 87Sr/86Sr for Thermal Ionization Mass Spectrometry (TIMS) Analysis

Fossil and rock samples from the different sequences were prepared for 87Sr/86Sr measurement at the TIMS lab facility in the Massachusetts Institute of Technology (MIT), USA. Six oyster shells were cut perpendicular to layering, cleaned via sonication in water and ethanol. Domains with no apparent discoloration or recrystallization were drilled to about 1-3 mm diameter and depth (Figure 1).

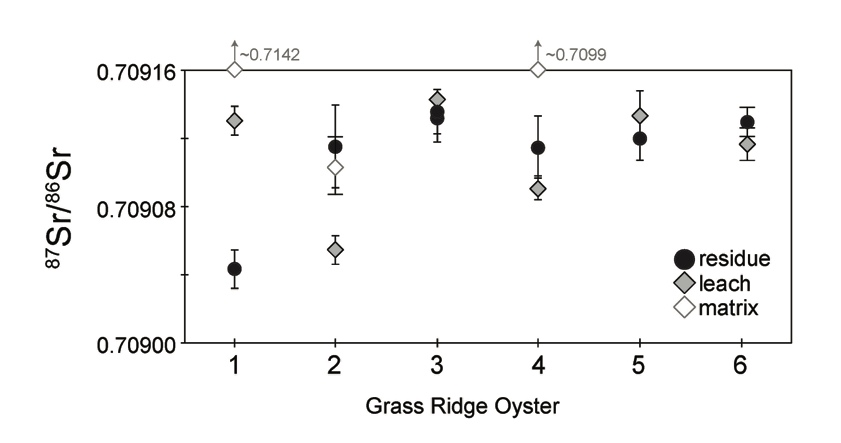
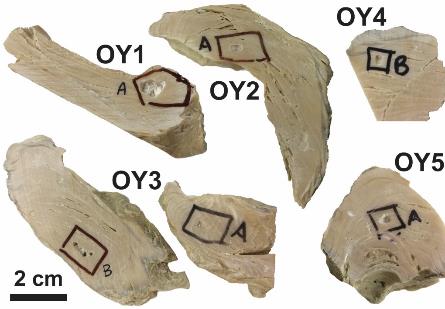


Figure 1: Drilled oyster shells from the Alexandria Formation (GR samples) and 87Sr/86Sr measurements of their residues, leaches and the matrix material. This method reveals similar results around ca. 0.70912, except for Oyster#1 that was drilled more coarsely and some of the matrix samples, which are significantly higher, indicating a source of contamination.

The collected powders were cleaned using a procedure modified after Martin and Haley (2000) and Schildgen et al. (2014). To remove clay and other fine particles, each powder was vortexed and sonicated in three rounds of 50 % methanol with the supernatant removed. To leach potential surficial contamination and loosely bound Sr from interlayers of clays and iron oxides, the powder was first vortexed and ultra-sonicated in 0.2 M ammonium acetate three times with centrifugation and removal of the supernatant. The remaining residue was then leached for 80 min at 25 °C in 0.5 mL acetic acid. During this final step of the leaching procedure, we collected some leaches from the samples for analysis (labeled ‘leaches’). The residues were washed repeatedly in water, and together with the leaches, as well as three additional samples of matrix material surrounding the shell fossils were dissolved in concentrated nitric acid and hydrogen peroxide and dried down.

Eleven shark teeth and three sets of 3 or 4 small coral fragments from the Bathurst Formation, and sea-urchin spine and plate fragments extracted from the limestone of Needs Camp Lower Quarry were also prepared. Each sample was coarsely crushed using an agate mortar and pestle, and pristine domains were handpicked under a binocular microscope. The selected fragments were more finely powdered. These powders were vortexed and sonicated three times in water and twice in 50 % methanol, with the supernatant removed at each step. The remaining powder was reacted for 10 min in 1.4 M acetic acid and the acid supernatant was removed. This supernatant was collected for one of the shark teeth (labeled ‘leach’). For the other samples only the leaches were used since there was no residual solid. The residues were rinsed in water. The residues and leaches were then dissolved in concentrated nitric acid and hydrogen peroxide and dried down.

Following sample preparation, all residues and leaches were dissolved in 3.5 M nitric acid and processed through ion exchange columns using Eichrom Sr-Spec resin. The laboratory blank for Sr separation chemistry is 50-100 picograms and is negligible because micrograms of Sr were analyzed per sample. The Sr cut was dried down with phosphoric acid and loaded in a tantalum chloride-phosphoric acid mixture onto degassed rhenium filaments. Mass spectrometry was then performed on a IsotopX Isoprobe-T with a dynamic, three cycles routine with 3V target intensity for the 88Sr beam. All data were fractionation-corrected to 86Sr/88Sr = 0.1194 using an exponential law. Four analyses of NBS-987 standard during the analytical session gave a weighted mean of 0.710244 ±7, within uncertainty of the accepted value, so no external correction was applied. More than 90 ratios were collected for each sample and the 2σ analytical uncertainty is reported (Table 1).

Table 1: 87Sr/86Sr isotope data of various fossils and rock samples from the Eastern Cape

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **MIT #ID** | **Sample name** | **87Sr/86Sr** | **% S.E** | **2-sigma S.E.** |
| **Grassridge oyster shells** | | | | |
| *Residues* | | | | |
| OY1A | Oyster #1 | 0.709043 | 0.0008 | 0.000011 |
| OY2A | Oyster #2 | 0.709116 | 0.0017 | 0.000024 |
| OY-3A | Oyster #3A | 0.709136 | 0.0009 | 0.000013 |
| Oy3B | Oyster #3B | 0.709131 | 0.0009 | 0.000013 |
| OY-4B | Oyster #4 | 0.709115 | 0.0013 | 0.000018 |
| OY5A | Oyster #5 | 0.709120 | 0.0009 | 0.000013 |
| GR-OY1R | Oyster #6 | 0.709128 | 0.0006 | 0.000009 |
| *Leaches* | | | | |
| 1AL | Leach; Oyster #1 | 0.709131 | 0.0007 | 0.000010 |
| 2AL | Leach; Oyster #2 | 0.709055 | 0.0006 | 0.000009 |
| 3AL | Leach; Oyster #3A | 0.709144 | 0.0007 | 0.000010 |
| 4AL | Leach; Oyster #4 | 0.709066 | 0.0007 | 0.000010 |
| 5AL | Leach; Oyster #5 | 0.709134 | 0.0006 | 0.000009 |
| GR-OY1 | Leach; Oyster #6 | 0.709116 | 0.0007 | 0.000010 |
| 1M | Matrix material; Oyster #1 | 0.714198 | 0.0034 | 0.000049 |
|  | Matrix material; Oyster #2 | 0.709103 | 0.0012 | 0.000017 |
|  | Matrix material; Oyster #4 | 0.709882 | 0.005 | 0.000071 |
| **Bathurst shark teeth** | | | | |
| Bath01 | Bathurst tooth #1 | 0.707911 | 0.0007 | 0.000010 |
| Bath02 | Bathurst tooth #2 | 0.708131 | 0.0006 | 0.000008 |
| Bath03 | Bathurst tooth #3 | 0.708083 | 0.0005 | 0.000007 |
| Bath04 | Bathurst tooth #4 | 0.707927 | 0.0008 | 0.000011 |
| Bath05 | Bathurst tooth #5 | 0.707867 | 0.0009 | 0.000013 |
| Bath07 | Bathurst tooth #7 | 0.708171 | 0.0006 | 0.000008 |
| Bath09 | Bathurst tooth #9 | 0.708013 | 0.0006 | 0.000008 |
| Bath14 | Bathurst tooth #14 | 0.707925 | 0.0005 | 0.000007 |
| Bath16 | Bathurst tooth #16 | 0.707864 | 0.0008 | 0.000011 |
| Bath18 | Bathurst tooth #18 | 0.708104 | 0.0006 | 0.000008 |
| SA tooth | Bathurst tooth #19 (residue) | 0.707812 | 0.0006 | 0.000008 |
| tooth Hac | Bathurst tooth #19 (leach) | 0.708467 | 0.0005 | 0.000007 |
| **e'Kalikeni corals** | | | | |
|  | Upper small-2 | 0.707805 | 0.0007 | 0.000010 |
|  | Upper large-2 | 0.707822 | 0.0008 | 0.000011 |
|  | Base | 0.707781 | 0.0007 | 0.000010 |
| **Needs Camp bioclastic limestones** | | | | |
| UR1 | Lower Carry, urchin fragments aliquot #1 | 0.708226 | 0.0007 | 0.000010 |
| UR2 | Lower Carry, urchin fragments aliquot #2 | 0.708388 | 0.0006 | 0.000009 |
| UR3 | Lower Carry, urchin fragments aliquot #3 | 0.708374 | 0.0007 | 0.000010 |
| UR4 | Lower Carry, urchin fragments aliquot #4 | 0.708425 | 0.0006 | 0.000009 |
|  | Lower Carry, limestone slab | 0.708342 | 0.0057 | 0.000081 |
|  | Upper Carry, limestone slab | 0.708058 | 0.001 | 0.000014 |
| 2-sigma uncertainties are analytical and do not include external uncertainty | | | | |

* **Oyster shells**

Measured 87Sr/86Sr ratios of the fossil oysters from Grassridge (the Alexandria Formation) are between 0.709043 ±11 and 0.709144 ±10 (Table 1). Their matrix material is more radiogenic and up to ca. 0.7142. All the residues, but one (Oyster#1), have 87Sr/86Sr around ca. 0.7091, and the leaches often show a greater variability (Figure 1). The results reveal Sr compositions that are significantly more radiogenic than those determined from the *in situ* analyses.

* **Shark teeth**

Measured 87Sr/86Sr ratios of the fossil shark teeth from Birbury (the Bathurst Formation) range between 0.707812 ±8 and 0.708171 ±8 (Table 1). The tooth leach is distinctively more radiogenic (ca. 0.708467 ±8; Figure 2). This shows contamination due to variable amounts of dentine and secondary calcite with more radiogenic compositions inadvertently incorporated during the crushing.

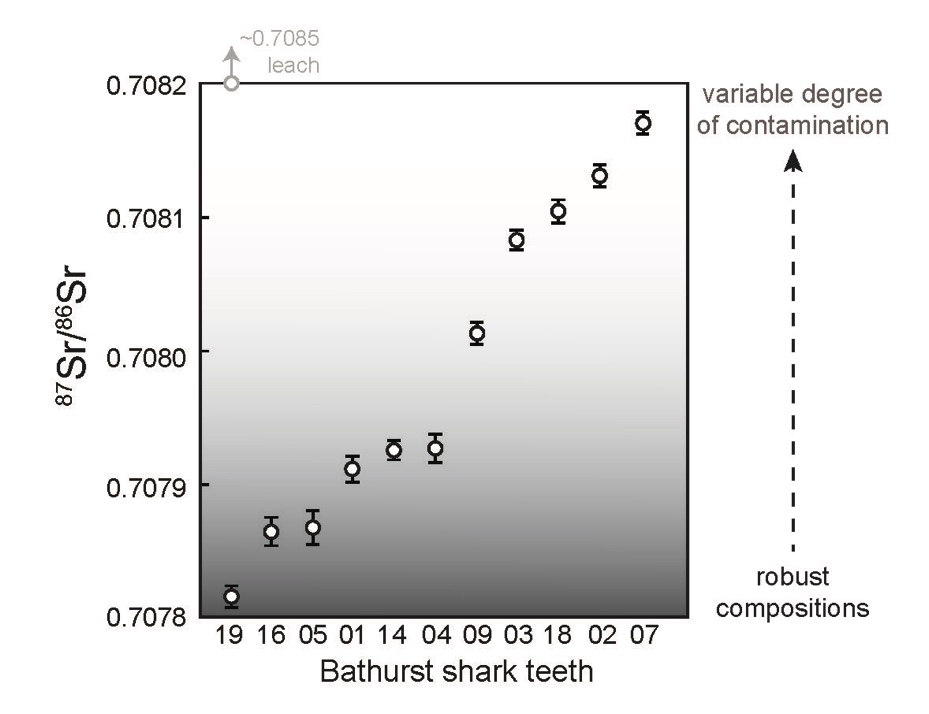


Figure 2: 87Sr/86Sr measurements of eleven shark teeth from Birbury (Bi). The arrow indicates mixing between the unaltered composition of enamel and variable amounts of contamination from incorporation of dentine in the analyses. The leach is significantly more radiogenic.

* **Corals**

Measured 87Sr/86Sr ratios of the corals from e’Kalikeni (the Bathurst Formation) are comprised between 0.707781 ±10 and 0.707822 ±1 (Table 1). This is similar to the shark tooth residue with the least radiogenic composition (Tooth#19), but these may also have residue inside their cavities that may have led to possible contamination.

* **Bioclastic limestones and sea-urchin fragments**

The limestone from the Lower Quarry (Needs Camp) has a 87Sr/86Sr ratio of ca. 0.708342 ±81, and the leaches from sea-urchin fragments extracted from this rock have 87Sr/86Sr ratios between 0.708226 ±10 and 0.708425 ±9 (Table 1). The large variability indicates a significant degree of contamination likely due to sample heterogeneities and post-depositional alteration. The limestone from the Upper Quarry has a lower 87Sr/86Sr ratio of ca. 0.708058 ±14. This may supports a different (younger) Sr composition for this sequence compared to the Lower Quarry, but better-preserved fossils from the two sites need to be analyzed.

Appendix 3: Electron Microprobe Analysis (EPMA)

Table 1: Measured elemental compositions along three profiles of an oyster shell (GR samples)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Profile 1 | | | | | Profile 2 | | | | | Profile 3 | | | | |
| **SrO** | **CaO** | **MnO** | **MgO** | **Total** | **SrO** | **CaO** | **MnO** | **MgO** | **Total** | **SrO** | **CaO** | **MnO** | **MgO** | **Total** |
| 0.12 | 55.48 | 0.05 | 0.47 | 56.11 | 0.10 | 55.00 | 0.01 | 0.40 | 55.51 | 0.07 | 54.94 | 0.06 | 0.57 | 55.64 |
| 0.09 | 54.84 | 0.00 | 0.42 | 55.36 | 0.07 | 55.01 | 0.03 | 0.38 | 55.49 | 0.06 | 55.39 | 0.00 | 0.48 | 55.93 |
| 0.10 | 55.11 | 0.01 | 0.45 | 55.67 | 0.09 | 55.24 | 0.00 | 0.37 | 55.70 | 0.07 | 54.82 | 0.04 | 0.51 | 55.45 |
| 0.09 | 54.83 | 0.05 | 0.43 | 55.40 | 0.05 | 55.31 | 0.00 | 0.35 | 55.71 | 0.05 | 55.32 | 0.00 | 0.47 | 55.84 |
| 0.06 | 55.04 | 0.05 | 0.46 | 55.61 | 0.09 | 54.98 | 0.01 | 0.33 | 55.40 | 0.05 | 54.78 | 0.02 | 0.51 | 55.36 |
| 0.08 | 54.51 | 0.00 | 0.49 | 55.08 | 0.09 | 54.97 | 0.02 | 0.37 | 55.45 | 0.09 | 54.95 | 0.00 | 0.51 | 55.55 |
| 0.07 | 55.09 | 0.02 | 0.49 | 55.68 | 0.10 | 55.05 | 0.00 | 0.40 | 55.54 | 0.05 | 55.06 | 0.02 | 0.47 | 55.60 |
| 0.11 | 55.40 | 0.00 | 0.47 | 55.98 | 0.10 | 55.17 | 0.00 | 0.32 | 55.59 | 0.06 | 54.72 | 0.01 | 0.44 | 55.22 |
| 0.06 | 54.64 | 0.03 | 0.47 | 55.20 | 0.07 | 54.93 | 0.03 | 0.40 | 55.43 | 0.04 | 55.29 | 0.02 | 0.48 | 55.83 |
| 0.09 | 54.85 | 0.00 | 0.38 | 55.32 | 0.05 | 55.18 | 0.03 | 0.36 | 55.61 | 0.04 | 54.68 | 0.02 | 0.53 | 55.27 |
| 0.10 | 55.00 | 0.00 | 0.39 | 55.49 | 0.11 | 55.03 | 0.00 | 0.40 | 55.54 | 0.06 | 55.28 | 0.03 | 0.47 | 55.84 |
| 0.08 | 54.98 | 0.02 | 0.39 | 55.46 | 0.05 | 55.06 | 0.00 | 0.40 | 55.51 | 0.07 | 54.54 | 0.01 | 0.45 | 55.07 |
| 0.08 | 55.04 | 0.03 | 0.39 | 55.54 | 0.02 | 54.88 | 0.00 | 0.37 | 55.27 | 0.05 | 55.04 | 0.02 | 0.54 | 55.65 |
| 0.13 | 55.09 | 0.03 | 0.32 | 55.56 | 0.06 | 54.51 | 0.05 | 0.35 | 54.97 | 0.03 | 55.01 | 0.05 | 0.49 | 55.58 |
| 0.10 | 54.28 | 0.02 | 0.42 | 54.81 | 0.10 | 55.14 | 0.05 | 0.37 | 55.66 | 0.07 | 54.98 | 0.01 | 0.48 | 55.54 |
| 0.09 | 55.60 | 0.00 | 0.41 | 56.09 | 0.10 | 55.42 | 0.02 | 0.42 | 55.96 | 0.05 | 55.20 | 0.04 | 0.50 | 55.79 |
| 0.09 | 55.13 | 0.03 | 0.48 | 55.72 | 0.09 | 55.09 | 0.01 | 0.36 | 55.55 | 0.08 | 54.95 | 0.04 | 0.55 | 55.62 |
| 0.06 | 54.73 | 0.05 | 0.36 | 55.20 | 0.08 | 55.33 | 0.00 | 0.35 | 55.76 | 0.06 | 54.86 | 0.02 | 0.55 | 55.49 |
| 0.11 | 55.04 | 0.00 | 0.45 | 55.60 | 0.06 | 54.60 | 0.04 | 0.38 | 55.08 | 0.08 | 55.00 | 0.02 | 0.48 | 55.58 |
| 0.11 | 54.58 | 0.02 | 0.45 | 55.17 | 0.05 | 55.61 | 0.03 | 0.34 | 56.04 | 0.05 | 54.63 | 0.05 | 0.51 | 55.24 |
| 0.10 | 55.35 | 0.01 | 0.38 | 55.83 | 0.03 | 55.27 | 0.00 | 0.36 | 55.67 | 0.13 | 55.27 | 0.07 | 0.44 | 55.91 |
| 0.06 | 55.07 | 0.00 | 0.33 | 55.46 | 0.02 | 55.19 | 0.02 | 0.36 | 55.59 | 0.03 | 54.80 | 0.00 | 0.45 | 55.28 |
| 0.08 | 54.83 | 0.02 | 0.34 | 55.27 | 0.10 | 54.51 | 0.01 | 0.43 | 55.04 | 0.02 | 54.94 | 0.01 | 0.46 | 55.43 |
| 0.05 | 54.92 | 0.01 | 0.34 | 55.32 | 0.05 | 54.46 | 0.05 | 0.45 | 55.02 | 0.03 | 54.89 | 0.01 | 0.57 | 55.50 |
| 0.06 | 54.64 | 0.03 | 0.28 | 55.00 | 0.07 | 54.67 | 0.00 | 0.45 | 55.19 | 0.03 | 54.78 | 0.06 | 0.55 | 55.41 |
| 0.10 | 55.39 | 0.01 | 0.30 | 55.80 | 0.07 | 54.37 | 0.04 | 0.48 | 54.96 | 0.07 | 54.70 | 0.05 | 0.54 | 55.36 |
| 0.07 | 54.60 | 0.04 | 0.34 | 55.05 | 0.06 | 54.95 | 0.02 | 0.52 | 55.54 | 0.03 | 54.96 | 0.00 | 0.53 | 55.52 |
| 0.10 | 54.95 | 0.00 | 0.29 | 55.34 | 0.08 | 54.31 | 0.02 | 0.62 | 55.03 | 0.09 | 55.09 | 0.02 | 0.53 | 55.73 |
| 0.06 | 54.70 | 0.06 | 0.39 | 55.20 | 0.15 | 55.01 | 0.05 | 0.64 | 55.84 | 0.04 | 54.68 | 0.00 | 0.51 | 55.23 |
| 0.08 | 54.67 | 0.08 | 0.36 | 55.18 | 0.07 | 54.56 | 0.05 | 0.67 | 55.36 | 0.07 | 53.55 | 0.00 | 0.48 | 54.09 |
| 0.11 | 54.78 | 0.00 | 0.35 | 55.24 | 0.09 | 54.58 | 0.02 | 0.63 | 55.31 | 0.07 | 54.27 | 0.04 | 0.57 | 54.94 |
| 0.06 | 55.07 | 0.02 | 0.38 | 55.53 | 0.13 | 54.89 | 0.01 | 0.70 | 55.72 | 0.04 | 54.21 | 0.00 | 0.51 | 54.76 |
| 0.06 | 54.96 | 0.02 | 0.40 | 55.45 | 0.05 | 54.75 | 0.06 | 0.64 | 55.50 | 0.06 | 53.97 | 0.00 | 0.49 | 54.53 |
| 0.07 | 54.68 | 0.00 | 0.38 | 55.13 | 0.07 | 54.40 | 0.05 | 0.67 | 55.19 | 0.06 | 54.10 | 0.02 | 0.50 | 54.68 |
| 0.08 | 54.86 | 0.00 | 0.42 | 55.36 | 0.09 | 54.94 | 0.02 | 0.63 | 55.68 | 0.07 | 54.53 | 0.07 | 0.50 | 55.16 |
| 0.03 | 55.29 | 0.01 | 0.45 | 55.78 | 0.12 | 54.51 | 0.02 | 0.65 | 55.29 | 0.04 | 54.63 | 0.00 | 0.50 | 55.17 |
| 0.09 | 54.85 | 0.00 | 0.40 | 55.34 | 0.15 | 54.09 | 0.00 | 0.64 | 54.88 | 0.09 | 54.36 | 0.06 | 0.49 | 55.01 |
| 0.08 | 55.21 | 0.02 | 0.40 | 55.71 | 0.11 | 54.90 | 0.04 | 0.66 | 55.71 | 0.00 | 54.61 | 0.01 | 0.54 | 55.16 |
| 0.09 | 54.70 | 0.01 | 0.40 | 55.20 | 0.11 | 54.51 | 0.04 | 0.64 | 55.30 | 0.03 | 54.52 | 0.01 | 0.49 | 55.04 |
| 0.04 | 55.16 | 0.00 | 0.42 | 55.62 | 0.14 | 54.66 | 0.03 | 0.64 | 55.47 | 0.11 | 55.15 | 0.05 | 0.47 | 55.77 |
| 0.08 | 54.82 | 0.02 | 0.39 | 55.30 | 0.08 | 54.76 | 0.02 | 0.61 | 55.47 | 0.08 | 54.79 | 0.01 | 0.48 | 55.36 |
| 0.08 | 55.36 | 0.05 | 0.34 | 55.83 | 0.09 | 54.48 | 0.00 | 0.61 | 55.18 | 0.09 | 54.85 | 0.02 | 0.52 | 55.48 |
| 0.05 | 54.48 | 0.06 | 0.39 | 54.98 | 0.06 | 54.60 | 0.00 | 0.61 | 55.27 | 0.05 | 54.83 | 0.01 | 0.46 | 55.35 |
| 0.10 | 54.81 | 0.02 | 0.47 | 55.40 | 0.08 | 54.25 | 0.03 | 0.59 | 54.95 | 0.11 | 54.89 | 0.00 | 0.49 | 55.49 |
| 0.07 | 55.71 | 0.00 | 0.36 | 56.14 | 0.11 | 55.12 | 0.03 | 0.52 | 55.77 | 0.10 | 54.80 | 0.07 | 0.50 | 55.48 |
| 0.10 | 55.14 | 0.00 | 0.35 | 55.59 | 0.10 | 55.81 | 0.03 | 0.62 | 56.56 | 0.05 | 55.35 | 0.01 | 0.51 | 55.92 |
| 0.12 | 55.16 | 0.00 | 0.31 | 55.60 | 0.10 | 54.27 | 0.03 | 0.57 | 54.96 | 0.03 | 55.10 | 0.04 | 0.46 | 55.63 |
| 0.07 | 54.94 | 0.05 | 0.39 | 55.45 | 0.11 | 55.00 | 0.04 | 0.59 | 55.74 | 0.10 | 55.33 | 0.00 | 0.51 | 55.94 |
| 0.06 | 54.94 | 0.00 | 0.37 | 55.37 | 0.10 | 55.01 | 0.01 | 0.53 | 55.65 | 0.06 | 54.86 | 0.03 | 0.54 | 55.49 |
| 0.08 | 54.95 | 0.02 | 0.40 | 55.45 | 0.12 | 53.91 | 0.01 | 0.55 | 54.59 | 0.10 | 55.18 | 0.01 | 0.50 | 55.78 |
| 0.05 | 54.92 | 0.01 | 0.34 | 55.31 | 0.08 | 54.74 | 0.04 | 0.54 | 55.40 | 0.08 | 54.87 | 0.00 | 0.55 | 55.50 |
| 0.09 | 55.06 | 0.04 | 0.36 | 55.55 | 0.12 | 54.90 | 0.00 | 0.64 | 55.66 | 0.04 | 54.55 | 0.00 | 0.45 | 55.04 |
| 0.09 | 55.17 | 0.03 | 0.30 | 55.60 | 0.10 | 54.83 | 0.01 | 0.52 | 55.46 | 0.04 | 55.27 | 0.01 | 0.44 | 55.76 |
| 0.07 | 55.56 | 0.01 | 0.31 | 55.94 | 0.09 | 54.62 | 0.03 | 0.51 | 55.25 | 0.06 | 55.07 | 0.00 | 0.47 | 55.60 |
| 0.08 | 55.17 | 0.00 | 0.29 | 55.55 | 0.07 | 55.09 | 0.01 | 0.50 | 55.67 | 0.09 | 55.22 | 0.00 | 0.48 | 55.79 |
| 0.09 | 54.87 | 0.02 | 0.32 | 55.30 | 0.07 | 54.81 | 0.04 | 0.51 | 55.43 | 0.08 | 54.93 | 0.01 | 0.51 | 55.54 |
| 0.09 | 54.69 | 0.02 | 0.29 | 55.08 | 0.11 | 55.61 | 0.06 | 0.53 | 56.30 | 0.05 | 54.90 | 0.02 | 0.48 | 55.45 |
| 0.08 | 54.89 | 0.03 | 0.41 | 55.41 | 0.11 | 54.68 | 0.04 | 0.53 | 55.35 | 0.09 | 54.98 | 0.04 | 0.48 | 55.59 |
| 0.09 | 54.64 | 0.05 | 0.40 | 55.18 | 0.07 | 54.65 | 0.01 | 0.54 | 55.27 | 0.08 | 54.82 | 0.00 | 0.51 | 55.42 |
| 0.08 | 55.51 | 0.06 | 0.40 | 56.05 | 0.13 | 54.93 | 0.03 | 0.48 | 55.57 | 0.05 | 54.88 | 0.04 | 0.49 | 55.46 |
| 0.08 | 55.00 | 0.06 | 0.44 | 55.58 | 0.12 | 54.74 | 0.03 | 0.58 | 55.48 | 0.04 | 55.05 | 0.00 | 0.50 | 55.59 |
| 0.12 | 54.87 | 0.01 | 0.37 | 55.37 | 0.07 | 54.75 | 0.04 | 0.51 | 55.37 | 0.07 | 54.78 | 0.00 | 0.50 | 55.35 |
| 0.08 | 54.86 | 0.03 | 0.28 | 55.25 | 0.11 | 54.90 | 0.00 | 0.49 | 55.50 | 0.06 | 54.70 | 0.03 | 0.50 | 55.29 |
| 0.08 | 55.28 | 0.02 | 0.30 | 55.67 | 0.08 | 54.81 | 0.00 | 0.53 | 55.43 | 0.07 | 54.90 | 0.03 | 0.50 | 55.50 |
| 0.06 | 55.13 | 0.00 | 0.34 | 55.54 | 0.13 | 54.42 | 0.05 | 0.54 | 55.14 | 0.07 | 54.77 | 0.03 | 0.44 | 55.30 |
| 0.09 | 55.42 | 0.06 | 0.33 | 55.89 | 0.06 | 54.67 | 0.00 | 0.67 | 55.40 | 0.05 | 54.79 | 0.04 | 0.48 | 55.36 |
| 0.08 | 55.47 | 0.00 | 0.36 | 55.91 | 0.08 | 55.17 | 0.04 | 0.56 | 55.85 | 0.06 | 54.86 | 0.00 | 0.52 | 55.44 |
| 0.12 | 54.66 | 0.02 | 0.35 | 55.14 | 0.07 | 54.58 | 0.03 | 0.48 | 55.15 | 0.10 | 54.96 | 0.05 | 0.49 | 55.60 |
| 0.09 | 55.41 | 0.07 | 0.44 | 56.01 | 0.10 | 54.93 | 0.00 | 0.60 | 55.62 | 0.07 | 54.66 | 0.00 | 0.51 | 55.24 |
| 0.08 | 55.62 | 0.05 | 0.42 | 56.16 | 0.11 | 54.64 | 0.00 | 0.58 | 55.34 | 0.06 | 55.03 | 0.01 | 0.47 | 55.57 |
| 0.11 | 55.31 | 0.01 | 0.36 | 55.78 | 0.07 | 54.75 | 0.08 | 0.56 | 55.47 | 0.13 | 54.89 | 0.08 | 0.48 | 55.58 |
| 0.07 | 54.83 | 0.03 | 0.43 | 55.36 | 0.09 | 55.00 | 0.02 | 0.57 | 55.68 | 0.05 | 54.73 | 0.01 | 0.48 | 55.27 |
| 0.07 | 54.66 | 0.01 | 0.41 | 55.15 | 0.14 | 54.74 | 0.00 | 0.57 | 55.45 | 0.08 | 54.87 | 0.03 | 0.50 | 55.48 |
| 0.08 | 54.73 | 0.00 | 0.39 | 55.21 | 0.11 | 54.86 | 0.00 | 0.46 | 55.42 | 0.08 | 54.95 | 0.00 | 0.44 | 55.47 |
| 0.09 | 54.62 | 0.03 | 0.36 | 55.10 | 0.07 | 54.67 | 0.03 | 0.58 | 55.35 | 0.05 | 54.49 | 0.00 | 0.48 | 55.02 |
| 0.04 | 55.86 | 0.00 | 0.23 | 56.13 | 0.10 | 54.89 | 0.00 | 0.57 | 55.57 | 0.08 | 55.66 | 0.01 | 0.44 | 56.19 |
| 0.11 | 55.43 | 0.02 | 0.29 | 55.84 | 0.08 | 54.66 | 0.05 | 0.61 | 55.40 | 0.07 | 54.94 | 0.04 | 0.49 | 55.54 |
| 0.09 | 55.12 | 0.02 | 0.21 | 55.45 | 0.09 | 54.64 | 0.03 | 0.51 | 55.26 | 0.08 | 55.14 | 0.00 | 0.47 | 55.69 |
| 0.06 | 54.76 | 0.00 | 0.22 | 55.04 | 0.13 | 54.87 | 0.00 | 0.56 | 55.56 | 0.09 | 54.42 | 0.05 | 0.50 | 55.06 |
| 0.08 | 55.06 | 0.04 | 0.19 | 55.37 | 0.11 | 54.46 | 0.01 | 0.53 | 55.12 | 0.07 | 54.53 | 0.00 | 0.49 | 55.09 |
| 0.06 | 54.98 | 0.00 | 0.18 | 55.23 | 0.05 | 54.32 | 0.02 | 0.54 | 54.93 | 0.06 | 54.79 | 0.03 | 0.56 | 55.43 |
| 0.07 | 55.54 | 0.00 | 0.24 | 55.86 | 0.11 | 54.68 | 0.05 | 0.64 | 55.49 | 0.09 | 54.94 | 0.00 | 0.59 | 55.63 |
| 0.08 | 55.36 | 0.00 | 0.23 | 55.66 | 0.11 | 54.74 | 0.00 | 0.54 | 55.39 | 0.04 | 54.93 | 0.00 | 0.49 | 55.46 |
| 0.11 | 55.51 | 0.08 | 0.28 | 55.98 | 0.10 | 54.67 | 0.00 | 0.55 | 55.32 | 0.08 | 54.64 | 0.00 | 0.58 | 55.30 |
| 0.09 | 55.08 | 0.00 | 0.22 | 55.39 | 0.09 | 54.98 | 0.05 | 0.60 | 55.71 | 0.09 | 55.43 | 0.02 | 0.54 | 56.08 |
| 0.07 | 55.47 | 0.01 | 0.24 | 55.80 | 0.06 | 54.80 | 0.01 | 0.58 | 55.44 | 0.13 | 54.97 | 0.00 | 0.48 | 55.58 |
| 0.05 | 54.75 | 0.00 | 0.24 | 55.03 | 0.12 | 55.18 | 0.03 | 0.65 | 55.97 | 0.06 | 54.65 | 0.03 | 0.56 | 55.30 |
| 0.07 | 54.84 | 0.01 | 0.29 | 55.21 | 0.12 | 54.85 | 0.00 | 0.52 | 55.49 | 0.10 | 55.28 | 0.01 | 0.54 | 55.94 |
| 0.08 | 54.91 | 0.03 | 0.28 | 55.29 | 0.10 | 54.54 | 0.02 | 0.57 | 55.24 | 0.07 | 54.84 | 0.00 | 0.48 | 55.39 |
| 0.08 | 54.84 | 0.00 | 0.26 | 55.18 | 0.12 | 55.24 | 0.04 | 0.56 | 55.95 | 0.06 | 54.47 | 0.01 | 0.48 | 55.03 |
| 0.05 | 55.29 | 0.04 | 0.25 | 55.62 | 0.14 | 54.57 | 0.06 | 0.57 | 55.34 | 0.08 | 55.01 | 0.03 | 0.55 | 55.67 |
| 0.09 | 55.25 | 0.00 | 0.33 | 55.66 | 0.13 | 54.65 | 0.02 | 0.57 | 55.37 | 0.05 | 54.77 | 0.02 | 0.50 | 55.34 |
| 0.06 | 55.13 | 0.00 | 0.32 | 55.52 | 0.07 | 54.86 | 0.04 | 0.54 | 55.52 | 0.06 | 55.05 | 0.04 | 0.51 | 55.66 |
| 0.09 | 54.89 | 0.00 | 0.19 | 55.17 | 0.06 | 54.38 | 0.03 | 0.55 | 55.03 | 0.08 | 54.95 | 0.03 | 0.55 | 55.60 |
| 0.10 | 55.06 | 0.01 | 0.23 | 55.40 | 0.09 | 54.83 | 0.01 | 0.52 | 55.45 | 0.05 | 54.95 | 0.00 | 0.55 | 55.55 |
| 0.11 | 55.09 | 0.00 | 0.25 | 55.45 | 0.08 | 55.00 | 0.04 | 0.59 | 55.70 | 0.06 | 54.85 | 0.00 | 0.57 | 55.48 |
| 0.08 | 54.89 | 0.03 | 0.25 | 55.24 | 0.09 | 54.87 | 0.01 | 0.54 | 55.50 | 0.07 | 54.83 | 0.05 | 0.50 | 55.45 |
| 0.05 | 54.81 | 0.01 | 0.24 | 55.12 | 0.10 | 54.70 | 0.03 | 0.54 | 55.36 | 0.07 | 55.06 | 0.00 | 0.53 | 55.67 |
| 0.11 | 54.89 | 0.03 | 0.20 | 55.24 | 0.12 | 54.91 | 0.00 | 0.57 | 55.59 | 0.03 | 54.87 | 0.00 | 0.55 | 55.45 |
| 0.09 | 55.03 | 0.01 | 0.20 | 55.33 | 0.14 | 54.56 | 0.00 | 0.57 | 55.27 | 0.09 | 54.79 | 0.03 | 0.53 | 55.45 |
| Step distance is 30 µm | | | | | | | | | | | | | | |

Appendix 4: Secondary Ion Mass Spectrometry (SIMS)

Table 1: Measured 18O/16O ratios across one oyster shell section (GR samples)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sample** | **nA** | **16O (cps)** | **Measured 18O/16O** | **Uncertainty 1sd (per mil)** | **DT-Fax (bits)** | **DT-Fay (bits)** | **IMF corrected 18O/16O** | **d18O VSMOW** |
| 1 | 0.5865663 | 1608757000 | 0.002059 | 0.097428 | -5 | -23 | 0.002083 | 28.778967 |
| 2 | 0.5761638 | 1600705000 | 0.002061 | 0.127315 | 5 | 13 | 0.002085 | 29.749689 |
| 3 | 0.5779084 | 1594820000 | 0.002058 | 0.159749 | 2 | 3 | 0.002083 | 28.421253 |
| 4 | 0.581543 | 1598823000 | 0.002059 | 0.100597 | 2 | -26 | 0.002083 | 28.550650 |
| 5 | 0.5815634 | 1602823000 | 0.002059 | 0.117662 | -9 | -18 | 0.002083 | 28.452728 |
| 6 | 0.5800527 | 1617598000 | 0.002058 | 0.115926 | -6 | -4 | 0.002082 | 27.953628 |
| 7 | 0.5834566 | 1602944000 | 0.002057 | 0.112006 | 0 | -25 | 0.002081 | 27.553449 |
| 8 | 0.5770017 | 1607162000 | 0.002059 | 0.108185 | -6 | -2 | 0.002083 | 28.727008 |
| 9 | 0.5723422 | 1599922000 | 0.002059 | 0.140284 | -3 | 6 | 0.002083 | 28.611601 |
| 10 | 0.5783864 | 1598922000 | 0.002061 | 0.103947 | -2 | -25 | 0.002085 | 29.826127 |
| 11 | 0.5722139 | 1601413000 | 0.002059 | 0.143719 | -12 | -15 | 0.002083 | 28.792456 |
| 12 | 0.5661745 | 1584710000 | 0.002059 | 0.111004 | 4 | -8 | 0.002083 | 28.870893 |
| 13 | 0.5630233 | 1585032000 | 0.002061 | 0.098274 | 2 | 0 | 0.002085 | 29.720212 |
| 14 | 0.5614485 | 1591000000 | 0.002059 | 0.093814 | -6 | -2 | 0.002083 | 28.799950 |
| 15 | 0.5612623 | 1582169000 | 0.002058 | 0.116049 | 4 | -6 | 0.002082 | 28.101510 |
| 16 | 0.5559168 | 1581908000 | 0.002059 | 0.128371 | 3 | 10 | 0.002083 | 28.494694 |
| 17 | 0.5600865 | 1570288000 | 0.002060 | 0.094021 | 4 | -24 | 0.002084 | 29.131684 |
| 18 | 0.5533226 | 1579807000 | 0.002058 | 0.090250 | -6 | 1 | 0.002082 | 28.332325 |
| 19 | 0.5530997 | 1575647000 | 0.002060 | 0.103789 | -6 | -3 | 0.002084 | 29.238598 |
| 20 | 0.5547535 | 1564744000 | 0.002059 | 0.131837 | 5 | -24 | 0.002083 | 28.435242 |
| 21 | 0.5483268 | 1574877000 | 0.002058 | 0.105489 | 3 | -2 | 0.002082 | 28.209423 |
| 22 | 0.5451654 | 1564194000 | 0.002059 | 0.114756 | 4 | 5 | 0.002083 | 28.441237 |
| 23 | 0.553296 | 1571804000 | 0.002060 | 0.130850 | -2 | -24 | 0.002084 | 29.335021 |
| 24 | 0.5437182 | 1570843000 | 0.002057 | 0.084225 | -3 | 9 | 0.002081 | 27.589420 |
| 25 | 0.544822 | 1564045000 | 0.002057 | 0.087279 | 3 | -4 | 0.002081 | 27.856206 |
| 26 | 0.5397307 | 1570819000 | 0.002058 | 0.128503 | -5 | 3 | 0.002082 | 28.176949 |
| 27 | 0.5475492 | 1554799000 | 0.002059 | 0.124189 | 5 | -26 | 0.002083 | 28.797452 |
| 28 | 0.5372797 | 1555817000 | 0.002059 | 0.108194 | -5 | -5 | 0.002083 | 28.605606 |
| 29 | 0.5324505 | 1556052000 | 0.002059 | 0.090117 | -2 | 13 | 0.002083 | 28.693035 |
| 30 | 0.5373024 | 1556342000 | 0.002059 | 0.075149 | 5 | -8 | 0.002083 | 28.706525 |
| **IAEA-603 standard** | |  |  |  |  |  |  |  |
| 1 | 0.5874644 | 1604841000 | 0.002058 | 0.125241 | -2 | -7 |  |  |
| 2 | 0.5876881 | 1605953000 | 0.002059 | 0.136917 | -2 | -6 |  |  |
| 3 | 0.5861869 | 1595139000 | 0.002058 | 0.077333 | -2 | -7 |  |  |
| 4 | 0.5700563 | 1598588000 | 0.002059 | 0.120851 | -2 | -6 |  |  |
| 5 | 0.5693202 | 1588797000 | 0.002059 | 0.113742 | -2 | -5 |  |  |
| 6 | 0.5592205 | 1576795000 | 0.002059 | 0.115867 | -2 | -7 |  |  |
| 7 | 0.5502247 | 1572857000 | 0.002059 | 0.083282 | -1 | -6 |  |  |
| 8 | 0.5471118 | 1570419000 | 0.002058 | 0.109175 | -1 | -6 |  |  |
| 9 | 0.5371006 | 1551150000 | 0.002059 | 0.118385 | 0 | -5 |  |  |
| (Absolute 18O/16O atomic IAEA 603= 0.002083) | | | | |  |  |  |  |

Appendix 5: Carbonate Clumped Isotope Thermometry

Table 1: Analytical results of laboratory standards used for clumped isotope analysis

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Thermo Mat 253** | | | | | | | | **Nu Carb 1** | | | | | | | | **Nu Carb 2** | | | | | | | |
| **Standard** | n | δ13C | 1s.e. | δ18O | 1s.e. | Δ47 | 1s.e. | n | | δ13C | 1s.e. | δ18O | 1s.e. | Δ47 | 1s.e. | n | | δ13C | 1s.e. | δ18O | 1s.e. | Δ47 | 1 s.e. |
| Carmel Chalk | 30 | -2.2 | 0.0 | -3.9 | 0.0 | 0.671 | 0.004 | 12 | | -2.2 | 0.0 | -3.9 | 0.0 | 0.680 | 0.011 | 27 | | -2.18 | 0.008 | -3.98 | 0.013 | 0.663 | 0.007 |
| Cararra Marble | 8 | 2.0 | 0.0 | -1.5 | 0.0 | 0.377 | 0.008 | - | | - | - | - | - | - | - | - | | - | - | - | - | - | - |
| CM Tile | 35 | 2.0 | 0.0 | -1.5 | 0.0 | 0.380 | 0.003 | 16 | | 2.0 | 0.0 | -1.6 | 0.0 | 0.389 | 0.008 | 27 | | 2.0 | 0.005 | -1.51 | 0.008 | 0.382 | 0.008 |
| ETH 1 | 46 | 2.0 | 0.0 | -2.2 | 0.0 | 0.267 | 0.003 | 16 | | 2.0 | 0.0 | -2.2 | 0.0 | 0.260 | 0.005 | 50 | | 2.0 | 0.004 | -2.2 | 0.007 | 0.263 | 0.005 |
| ETH 2 | 37 | -10.2 | 0.0 | -18.7 | 0.0 | 0.261 | 0.004 | 9 | | -10.2 | 0.0 | -18.7 | 0.0 | 0.254 | 0.003 | 47 | | -10.2 | 0.004 | -18.7 | 0.007 | 0.262 | 0.006 |
| ETH 3 | 28 | 1.7 | 0.0 | -1.8 | 0.0 | 0.697 | 0.004 | 12 | | 1.7 | 0.0 | -1.7 | 0.0 | 0.684 | 0.008 | 22 | | 1.7 | 0.006 | -1.71 | 0.007 | 0.677 | 0.008 |
| ETH 4 | 35 | -10.2 | 0.0 | -18.8 | 0.0 | 0.518 | 0.003 | 5 | | -10.2 | 0.0 | -18.8 | 0.0 | 0.517 | 0.018 | 13 | | -10.2 | 0.008 | -18.9 | 0.015 | 0.491 | 0.009 |
| IAEA-C1 | 6 | 2.4 | 0.0 | -2.3 | 0.0 | 0.358 | 0.005 | - | | - | - | - | - | - | - | - | | - | - | - | - | - | - |
| IAEA-C2 | 7 | -8.2 | 0.0 | -8.8 | 0.0 | 0.716 | 0.007 | - | | - | - | - | - | - | - | - | | - | - | - | - | - | - |
| Merck | 3 | -42.0 | 0.0 | -15.7 | 0.0 | 0.611 | 0.009 | - | | - | - | - | - | - | - | 4 | | -42.1 | 0.027 | -15.7 | 0.025 | 0.582 | 0.014 |
| Veinstrom | 32 | -6.2 | 0.0 | -12.6 | 0.0 | 0.710 | 0.004 | 11 | | -6.2 | 0.0 | -12.6 | 0.0 | 0.710 | 0.011 | 26 | | -6.2 | 0.014 | -12.6 | 0.013 | 0.728 | 0.009 |

Table 2: Clumped isotope results for all measured sample replicates (Rn) and calculated averages (in bold) excluding highlighted values with anomalous δ18O and/or Δ48, or with high internal errors for Δ47

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sample** | **Type** | **Mass Spectrometer** | **δ13C ‰ VPDB** | **1 sd** | **δ18O ‰ VPDB** | **1 sd** | **Δ47 ‰** | **1 SE** | **Δ48 ‰** | **1 SE** | **Average Temperature  [°C]** | **1 SE** | **δ18O water ‰ VSMOW** | **1 sd** |
| **15 NEEDSCAMP** | |  | **-5.6** | **0.1** | **-3.6** | **0.0** | **0.688** | **0.007** | **0.139** | **0.039** | **20.4** | **1.8** | **-2.2** | **0.8** |
| R1 | Carb. | Thermo | -5.5 |  | -3.6 |  | 0.681 |  | 0.041 |  | 22.4 |  | -1.7 |  |
| R2 | Carb. | Thermo | -5.7 |  | -3.6 |  | 0.688 |  | 0.233 |  | 20.4 |  | -2.2 |  |
| R3 | Carb. | Thermo | -5.6 |  | -3.6 |  | 0.707 |  | 0.134 |  | 15.2 |  | -3.3 |  |
| R4 | Carb. | Thermo | -5.7 |  | -3.7 |  | 0.677 |  | 0.149 |  | 23.6 |  | -1.6 |  |
| **17 BIRBURRY** | |  | **-6.8** | **0.0** | **-3.3** | **0.0** | **0.690** | **0.008** | **0.145** | **0.027** | **19.8** | **2.3** | **-2.0** | **0.8** |
| R1 | Carb. | Thermo | -6.8 |  | -3.3 |  | 0.702 |  | 0.184 |  | 16.5 |  | -2.6 |  |
| R2 | Carb. | Thermo | -6.8 |  | -3.3 |  | 0.675 |  | 0.093 |  | 24.1 |  | -1.1 |  |
| R3 | Carb. | Thermo | -6.9 |  | -3.3 |  | 0.694 |  | 0.158 |  | 18.7 |  | -2.2 |  |
| **B1A** |  |  | **-7.1** | **0.2** | **-5.0** | **0.2** | **0.692** | **0.007** | **0.219** | **0.050** | **19.5** | **2.1** | **-3.8** | **0.9** |
| R1 | Carb. | Thermo | -7.2 |  | -5.0 |  | 0.676 |  | 0.243 |  | 23.9 |  | -2.8 |  |
| R2 | Carb. | Thermo | -7.4 |  | -5.4 |  | 0.694 |  | 0.185 |  | 18.7 |  | -4.3 |  |
| R3 | Carb. | Thermo | -7.0 |  | -4.8 |  | 0.711 |  | 0.105 |  | 14.1 |  | -4.7 |  |
| R4 | Carb. | Thermo | -6.9 |  | -4.9 |  | 0.685 |  | 0.341 |  | 21.3 |  | -3.3 |  |
| **B2A** |  |  | **-6.3** | **0.0** | **-5.1** | **0.0** | **0.695** | **0.010** | **0.239** | **0.039** | **18.7** | **2.9** | **-4.0** | **1.2** |
| R1 | Carb. | Thermo | -6.3 |  | -5.1 |  | 0.691 |  | 0.273 |  | 19.6 |  | -3.8 |  |
| R2 | Carb. | Thermo | -6.3 |  | -5.1 |  | 0.708 |  | 0.302 |  | 14.9 |  | -4.8 |  |
| R3 | Carb. | Thermo | -6.3 |  | -5.1 |  | 0.713 |  | 0.256 |  | 13.6 |  | -5.1 |  |
| R4 | Carb. | Thermo | -6.3 |  | -5.1 |  | 0.667 |  | 0.126 |  | 26.5 |  | -2.4 |  |
| **B2B** |  |  | **-6.7** | **0.4** | **-5.1** | **0.0** | **0.686** | **0.008** | **0.149** | **0.046** | **21.1** | **2.3** | **-3.5** | **1.0** |
| R1 | Carb. | Thermo | -6.5 |  | -5.1 |  | 0.676 |  | 0.181 |  | 23.9 |  | -2.9 |  |
| R2 | Carb. | Thermo | -6.5 |  | -5.1 |  | 0.680 |  | 0.157 |  | 22.7 |  | -3.2 |  |
| R3 | Carb. | Thermo | -7.3 |  | -5.2 |  | 0.676 |  | 0.021 |  | 23.9 |  | -3.0 |  |
| R4 | Carb. | Thermo | -6.5 |  | -5.1 |  | 0.711 |  | 0.236 |  | 14.1 |  | -5.0 |  |
| **B3A** |  |  | **-7.0** | **0.3** | **-5.2** | **0.1** | **0.685** | **0.008** | **0.173** | **0.027** | **21.4** | **2.2** | **-3.6** | **1.0** |
| R1 | Carb. | Thermo | -7.1 |  | -5.3 |  | 0.706 |  | 0.120 |  | 15.5 |  | -4.9 |  |
| R2 | Carb. | Thermo | -7.1 |  | -5.4 |  | 0.680 |  | 0.133 |  | 22.7 |  | -3.5 |  |
| R3 | Carb. | Thermo | -6.5 |  | -5.1 |  | 0.669 |  | 0.212 |  | 25.9 |  | -2.5 |  |
| R4 | Carb. | Thermo | -7.3 |  | -5.1 |  | 0.684 |  | 0.226 |  | 21.5 |  | -3.5 |  |
| **DA3** |  |  | **-6.2** | **0.0** | **-4.9** | **0.0** | **0.668** | **0.006** | **0.131** | **0.043** | **26.2** | **1.9** | **-2.2** | **0.8** |
| R1 | Carb. | Thermo | -6.1 |  | -4.8 |  | 0.679 |  | 0.169 |  | 23.0 |  | -2.9 |  |
| R2 | Carb. | Thermo | -6.2 |  | -4.9 |  | 0.655 |  | 0.028 |  | 30.2 |  | -1.4 |  |
| R3 | Carb. | Thermo | -6.2 |  | -4.9 |  | 0.660 |  | 0.101 |  | 28.6 |  | -1.8 |  |
| R4 | Carb. | Thermo | -6.1 |  | -4.9 |  | 0.679 |  | 0.225 |  | 23.0 |  | -2.9 |  |
| **DH1A** |  |  | **-0.8** | **0.0** | **0.7** | **0.0** | **0.681** | **0.009** | **0.231** | **0.032** | **22.6** | **2.6** | **2.6** | **1.0** |
| R1 | Chalky | NuCarb1 | -0.9 |  | 0.7 |  | 0.699 |  | 0.295 |  | 17.4 |  | 1.5 |  |
| R2 | Chalky | NuCarb1 | -0.9 |  | 0.7 |  | 0.670 |  | 0.203 |  | 25.6 |  | 3.3 |  |
| R3 | Chalky | NuCarb1 | -0.8 |  | 0.7 |  | 0.673 |  | 0.196 |  | 24.7 |  | 3.1 |  |
| R4 | Chalky | NuCarb2 | -0.8 |  | 0.4 |  | 0.837 |  | 0.547 |  | -14.3 |  | -6.4 |  |
| **DH1B** |  |  | **-0.5** | **0.1** | **0.3** | **0.2** | **0.683** | **0.011** | **0.212** | **0.009** | **21.8** | **3.1** | **2.0** | **1.0** |
| R1 | Fibrous | NuCarb1 | -0.3 |  | 1.0 |  | 0.724 |  | 0.277 |  | 10.8 |  | 0.4 |  |
| R2 | Fibrous | NuCarb1 | -0.5 |  | 0.4 |  | 0.705 |  | 0.201 |  | 15.7 |  | 0.9 |  |
| R3 | Fibrous | NuCarb1 | -0.5 |  | 0.4 |  | 0.676 |  | 0.231 |  | 23.9 |  | 2.6 |  |
| R4 | Fibrous | NuCarb2 | -0.6 |  | 0.1 |  | 0.669 |  | 0.205 |  | 25.9 |  | 2.6 |  |
| **DH1C** |  |  | **-0.4** | **0.1** | **0.7** | **0.2** | **0.684** | **0.024** | **0.310** | **0.034** | **22.1** | **6.6** | **2.4** | **2.6** |
| R1 | Chalky | NuCarb1 | -0.5 |  | 0.5 |  | 0.730 |  | 0.264 |  | 9.3 |  | -0.5 |  |
| R2 | Chalky | NuCarb1 | -0.4 |  | 0.8 |  | 0.651 |  | 0.290 |  | 31.4 |  | 4.5 |  |
| R3 | Chalky | NuCarb1 | -0.4 |  | 0.8 |  | 0.670 |  | 0.377 |  | 25.6 |  | 3.3 |  |
| R4 | Chalky | NuCarb2 | -0.4 |  | 0.5 |  | 0.716 |  | 0.325 |  | 12.8 |  | 0.3 |  |
| R5 | Chalky | NuCarb2 | -0.4 |  | 0.4 |  | 0.788 |  | 0.421 |  | -4.3 |  | -3.7 |  |
| **DH1D** |  |  | **-1.5** | **0.2** | **-2.0** | **0.1** | **0.671** | **0.018** | **0.275** | **0.039** | **25.8** | **5.4** | **0.5** | **2.1** |
| R1 | Fibrous | NuCarb2 | -1.6 |  | -1.9 |  | 0.660 |  | 0.209 |  | 28.6 |  | 1.2 |  |
| R2 | Fibrous | NuCarb2 | -1.6 |  | -2.0 |  | 0.720 |  | 0.385 |  | 11.8 |  | -2.4 |  |
| R3 | Fibrous | NuCarb2 | -1.6 |  | -2.0 |  | 0.672 |  | 0.270 |  | 25.0 |  | 0.4 |  |
| R4 | Fibrous | NuCarb2 | -1.2 |  | -2.1 |  | 0.632 |  | 0.235 |  | 37.6 |  | 2.8 |  |
| **DH3A** |  |  | **-0.4** | **0.0** | **0.6** | **0.0** | **0.699** | **0.008** | **0.194** | **0.036** | **17.4** | **2.3** | **1.4** | **0.8** |
| R1 | Chalky | NuCarb1 | -0.4 |  | 0.6 |  | 0.710 |  | 0.260 |  | 14.4 |  | 0.7 |  |
| R2 | Chalky | NuCarb1 | -0.4 |  | 0.6 |  | 0.704 |  | 0.185 |  | 16.0 |  | 1.1 |  |
| R3 | Chalky | NuCarb1 | -0.4 |  | 0.5 |  | 0.683 |  | 0.138 |  | 21.8 |  | 2.3 |  |
| R4 | Chalky | NuCarb2 | -0.5 |  | 0.1 |  | 0.809 |  | 0.608 |  | -8.7 |  | -5.2 |  |
| **DH3B** |  |  | **-1.4** | **0.1** | **-0.2** | **0.0** | **0.665** | **0.037** | **0.227** | **0.056** | **28.3** | **10.6** | **2.7** | **3.8** |
| R1 | Chalky | NuCarb2 | -1.3 |  | -0.2 |  | 0.739 |  | 0.338 |  | 7.0 |  | -1.7 |  |
| R2 | Chalky | NuCarb2 | -1.5 |  | -0.3 |  | 0.626 |  | 0.185 |  | 39.6 |  | 5.0 |  |
| R3 | Chalky | NuCarb2 | -1.4 |  | -0.2 |  | 0.692 |  | 0.278 |  | 19.3 |  | 1.0 |  |
| R4 | Chalky | NuCarb2 | -1.4 |  | -0.2 |  | 0.630 |  | 0.159 |  | 38.3 |  | 4.8 |  |
| **DH91A** |  |  | **-2.0** | **0.1** | **-1.5** | **0.1** | **0.652** | **0.023** | **0.200** | **0.044** | **31.5** | **7.1** | **2.1** | **2.3** |
| R1 | Fibrous | NuCarb2 | -2.0 |  | -1.6 |  | 0.616 |  | 0.215 |  | 43.1 |  | 4.3 |  |
| R2 | Fibrous | NuCarb2 | -2.0 |  | -1.5 |  | 0.647 |  | 0.117 |  | 32.7 |  | 2.4 |  |
| R3 | Fibrous | NuCarb2 | -2.0 |  | -1.5 |  | 0.701 |  | 0.244 |  | 16.8 |  | -0.8 |  |
| R4 | Fibrous | NuCarb2 | -1.9 |  | -1.4 |  | 0.694 |  | 0.268 |  | 18.7 |  | -0.3 |  |
| **DH92A** |  |  | **-0.6** | **0.0** | **0.6** | **0.2** | **0.686** | **0.011** | **0.249** | **0.017** | **21.1** | **3.1** | **2.2** | **1.3** |
| R1 | Chalky | NuCarb1 | -0.6 |  | 0.8 |  | 0.693 |  | 0.201 |  | 19.0 |  | 1.9 |  |
| R2 | Chalky | NuCarb1 | -0.7 |  | 0.8 |  | 0.657 |  | 0.274 |  | 29.6 |  | 4.1 |  |
| R3 | Chalky | NuCarb1 | -0.6 |  | 0.7 |  | 0.708 |  | 0.270 |  | 14.9 |  | 0.9 |  |
| R4 | Chalky | NuCarb2 | -0.6 |  | 0.4 |  | 0.687 |  | 0.251 |  | 20.7 |  | 1.9 |  |
| **DH92B** |  |  | **-2.0** | **0.0** | **-1.5** | **0.0** | **0.684** | **0.013** | **0.258** | **0.023** | **21.8** | **3.8** | **0.2** | **1.3** |
| R1 | Fibrous | NuCarb2 | -2.0 |  | -1.5 |  | 0.693 |  | 0.289 |  | 19.0 |  | -0.3 |  |
| R2 | Fibrous | NuCarb2 | -2.0 |  | -1.5 |  | 0.658 |  | 0.271 |  | 29.3 |  | 1.7 |  |
| R3 | Fibrous | NuCarb2 | -2.0 |  | -1.5 |  | 0.700 |  | 0.214 |  | 17.1 |  | -0.8 |  |
| R4 | Fibrous | NuCarb2 | -2.1 |  | -1.5 |  | 0.537 |  | 0.114 |  | 75.2 |  | 9.7 |  |
| **GR3A** |  |  | **-3.9** | **0.0** | **-1.5** | **0.1** | **0.716** | **0.020** | **0.314** | **0.060** | **13.3** | **5.2** | **-1.6** | **2.4** |
| R1 | Chalky | NuCarb1 | -3.9 |  | -1.3 |  | 0.674 |  | 0.226 |  | 24.4 |  | 1.0 |  |
| R2 | Chalky | NuCarb1 | -3.9 |  | -1.4 |  | 0.690 |  | 0.302 |  | 19.9 |  | -0.1 |  |
| R3 | Chalky | NuCarb2 | -3.9 |  | -1.6 |  | 0.755 |  | 0.488 |  | 3.2 |  | -4.0 |  |
| R4 | Chalky | NuCarb2 | -3.9 |  | -1.5 |  | 0.745 |  | 0.240 |  | 5.6 |  | -3.3 |  |
| **GR3B** |  |  | **-4.2** | **0.0** | **-1.5** | **0.2** | **0.685** | **0.020** | **0.257** | **0.017** | **21.7** | **5.6** | **0.1** | **2.5** |
| R1 | Chalky | NuCarb1 | -4.2 |  | -1.5 |  | 0.694 |  | 0.223 |  | 18.7 |  | -0.4 |  |
| R2 | Chalky | NuCarb1 | -4.2 |  | -1.5 |  | 0.660 |  | 0.267 |  | 28.6 |  | 1.6 |  |
| R3 | Chalky | NuCarb1 | -4.2 |  | -1.5 |  | 0.649 |  | 0.301 |  | 32.1 |  | 2.4 |  |
| R4 | Chalky | NuCarb2 | -4.1 |  | -1.8 |  | 0.738 |  | 0.236 |  | 7.3 |  | -3.2 |  |
| **GR3C** |  |  | **-3.7** | **0.0** | **-1.4** | **0.2** | **0.686** | **0.019** | **0.247** | **0.012** | **21.5** | **5.5** | **0.1** | **2.7** |
| R1 | Chalky | NuCarb1 | -3.7 |  | -1.2 |  | 0.625 |  | 0.268 |  | 40.0 |  | 4.1 |  |
| R2 | Chalky | NuCarb1 | -3.7 |  | -1.4 |  | 0.694 |  | 0.233 |  | 18.7 |  | -0.3 |  |
| R3 | Chalky | NuCarb1 | -3.7 |  | -1.4 |  | 0.665 |  | 0.228 |  | 27.1 |  | 1.4 |  |
| R4 | Chalky | NuCarb2 | -3.7 |  | -1.6 |  | 0.723 |  | 0.223 |  | 11.0 |  | -2.2 |  |
| R5 | Chalky | NuCarb2 | -3.6 |  | -1.6 |  | 0.725 |  | 0.283 |  | 10.5 |  | -2.3 |  |
| **GR5A** |  |  | **-4.0** | **0.0** | **-3.2** | **0.0** | **0.716** | **0.005** | **0.196** | **0.016** | **13.0** | **1.2** | **-3.3** | **0.4** |
| R1 | Chalky | NuCarb1 | -4.0 |  | -3.1 |  | 0.711 |  | 0.212 |  | 14.1 |  | -3.0 |  |
| R2 | Chalky | NuCarb1 | -4.0 |  | -3.2 |  | 0.720 |  | 0.180 |  | 11.8 |  | -3.6 |  |
| R3 | Chalky | NuCarb1 | -3.1 |  | -0.9 |  | 0.664 |  | 0.268 |  | 27.4 |  | 2.0 |  |
| R4 | Chalky | NuCarb1 | -4.3 |  | -2.0 |  | 0.737 |  | 0.284 |  | 7.5 |  | -2.8 |  |
| R5 | Chalky | NuCarb2 | -3.1 |  | -1.4 |  | 2.020 |  | 3.770 |  | -117.5 |  | -53.5 |  |
| **GR5B** |  |  | **-4.7** | **0.1** | **-2.2** | **0.2** | **0.724** | **0.021** | **0.264** | **0.030** | **11.0** | **5.2** | **-2.8** | **1.8** |
| R1 | Chalky | NuCarb1 | -5.5 |  | -3.9 |  | 0.707 |  | 0.230 |  | 15.2 |  | -3.6 |  |
| R2 | Chalky | NuCarb1 | -4.8 |  | -2.0 |  | 0.703 |  | 0.234 |  | 16.3 |  | -1.5 |  |
| R3 | Chalky | NuCarb2 | -4.7 |  | -2.3 |  | 0.760 |  | 0.479 |  | 2.0 |  | -4.9 |  |
| R4 | Chalky | NuCarb2 | -4.7 |  | -2.3 |  | 0.744 |  | 0.293 |  | 5.8 |  | -4.1 |  |
| **GR5C** |  |  | **-4.4** | **0.0** | **-1.8** | **0.2** | **0.665** | **0.015** | **0.237** | **0.036** | **27.3** | **4.4** | **1.0** | **1.8** |
| R1 | Chalky | NuCarb1 | -4.4 |  | -1.7 |  | 0.658 |  | 0.220 |  | 29.3 |  | 1.5 |  |
| R2 | Chalky | NuCarb1 | -4.5 |  | -1.7 |  | 0.644 |  | 0.252 |  | 33.7 |  | 2.4 |  |
| R3 | Chalky | NuCarb1 | -4.4 |  | -1.7 |  | 0.710 |  | 0.324 |  | 14.4 |  | -1.5 |  |
| R4 | Chalky | NuCarb2 | -4.4 |  | -2.1 |  | 0.649 |  | 0.150 |  | 32.1 |  | 1.7 |  |
| **GR6A** |  |  | **-4.4** | **0.0** | **-1.7** | **0.0** | **0.676** | **0.014** | **0.259** | **0.017** | **24.1** | **3.9** | **0.5** | **1.4** |
| R1 | Chalky | NuCarb1 | -4.3 |  | -1.7 |  | 0.657 |  | 0.226 |  | 29.6 |  | 1.6 |  |
| R2 | Chalky | NuCarb1 | -4.4 |  | -1.7 |  | 0.702 |  | 0.268 |  | 16.5 |  | -1.1 |  |
| R3 | Chalky | NuCarb1 | -4.4 |  | -1.7 |  | 0.668 |  | 0.284 |  | 26.2 |  | 1.0 |  |
| R4 | Chalky | NuCarb2 | -4.4 |  | -2.0 |  | 0.586 |  | 0.051 |  | 54.2 |  | 5.8 |  |
| **GR7A** |  |  | **-4.2** | **0.0** | **-1.4** | **0.0** | **0.676** | **0.011** | **0.273** | **0.021** | **23.9** | **3.1** | **0.7** | **1.3** |
| R1 | Chalky | NuCarb1 | -4.2 |  | -1.5 |  | 0.703 |  | 0.278 |  | 16.3 |  | -0.9 |  |
| R2 | Chalky | NuCarb1 | -4.2 |  | -1.4 |  | 0.668 |  | 0.275 |  | 26.2 |  | 1.2 |  |
| R3 | Chalky | NuCarb1 | -4.1 |  | -1.4 |  | 0.652 |  | 0.218 |  | 31.1 |  | 2.2 |  |
| R4 | Chalky | NuCarb1 | -4.2 |  | -1.4 |  | 0.682 |  | 0.321 |  | 22.1 |  | 0.4 |  |
| **GR7B** |  |  | **-3.2** | **0.1** | **-1.1** | **0.1** | **0.680** | **0.010** | **0.215** | **0.038** | **22.8** | **2.9** | **0.8** | **1.2** |
| R1 | Chalky | NuCarb1 | -3.2 |  | -1.0 |  | 0.692 |  | 0.296 |  | 19.3 |  | 0.2 |  |
| R2 | Chalky | NuCarb1 | -3.2 |  | -1.0 |  | 0.676 |  | 0.205 |  | 23.9 |  | 1.2 |  |
| R3 | Chalky | NuCarb1 | -3.2 |  | -1.2 |  | 0.654 |  | 0.243 |  | 30.5 |  | 2.3 |  |
| R4 | Chalky | NuCarb2 | -3.1 |  | -1.3 |  | 0.699 |  | 0.117 |  | 17.4 |  | -0.5 |  |
| **GR91A** |  |  | **-3.2** | **0.0** | **-1.1** | **0.2** | **0.677** | **0.007** | **0.226** | **0.034** | **23.8** | **2.2** | **1.0** | **1.0** |
| R1 | Chalky | NuCarb1 | -3.2 |  | -1.0 |  | 0.655 |  | 0.304 |  | 30.2 |  | 2.5 |  |
| R2 | Chalky | NuCarb1 | -3.3 |  | -1.0 |  | 0.678 |  | 0.159 |  | 23.3 |  | 1.0 |  |
| R3 | Chalky | NuCarb1 | -3.2 |  | -1.1 |  | 0.686 |  | 0.260 |  | 21.0 |  | 0.5 |  |
| R4 | Chalky | NuCarb2 | -3.2 |  | -1.4 |  | 0.687 |  | 0.179 |  | 20.7 |  | 0.1 |  |
| Note: Sample replicates with anomalous δ18O and/or Δ48, and with a high internal error for Δ47 are highlighted | | | | | | | | | | | | | | |

Appendix 6: Laser Ablation MC-ICPMS Analysis

Table 1: Analytical results of laboratory standards used for the laser ablation analysis

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sample** | **Laser Freq** | **Laser Power** | **Laser Diam** | **Notes** | **87Sr/86Sr** | **1SE** |
| SCSC standard | | | | | | |
| std1 | 10 | 65 | 30 | ~300 micron line ~5J/cm2 | 0.709071 | 0.000039 |
| std2 | 10 | 65 | 30 | ~300 micron line ~5J/cm2 | 0.709032 | 0.000027 |
| std3 | 10 | 65 | 30 | ~300 micron line ~5J/cm2 | 0.709120 | 0.000032 |
| std4 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709048 | 0.000033 |
| std5 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709094 | 0.000028 |
| std6 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709082 | 0.000033 |
| std7 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709083 | 0.000034 |
| std8 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709061 | 0.000041 |
| std9 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709154 | 0.000032 |
| std10 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709148 | 0.000038 |
| std11 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709120 | 0.000038 |
| std12 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709114 | 0.000039 |
| std13 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709206 | 0.000021 |
| std14 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709271 | 0.000025 |
| std15 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709269 | 0.000031 |
| std16 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709203 | 0.000030 |
| std17 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709167 | 0.000027 |
| std18 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709183 | 0.000029 |
| std19 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709216 | 0.000031 |
| std20 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709214 | 0.000028 |
| std21 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709230 | 0.000033 |
| std22 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709163 | 0.000029 |
| std23 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709239 | 0.000029 |
| std24 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709198 | 0.000028 |
| std25 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709177 | 0.000026 |
| std26 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709207 | 0.000027 |
| std27 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709281 | 0.000028 |
| std28 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709124 | 0.000032 |
| std29 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709206 | 0.000029 |
| std30 | 10 | 65 | 30 | ~300 micron line ~4J/cm2 | 0.709252 | 0.000031 |
|  |  |  |  | **Average:** | **0.709164** | **0.000031** |
| SBO standard | | | | | | |
| std1 | 10 | 60 | 40 | ~300 micron line ~5J/cm2 | 0.709068 | 0.000025 |
| std2 | 10 | 60 | 40 | ~300 micron line ~5J/cm2 | 0.709027 | 0.000019 |
| std3 | 10 | 60 | 40 | ~300 micron line ~5J/cm2 | 0.709097 | 0.000022 |
| std4 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709076 | 0.000030 |
| std5 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709126 | 0.000030 |
| std6 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709192 | 0.000050 |
| std7 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709163 | 0.000024 |
| std8 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709124 | 0.000030 |
| std9 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709148 | 0.000019 |
| std10 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709121 | 0.000024 |
| std11 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709172 | 0.000034 |
| std12 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709069 | 0.000032 |
| std13 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709163 | 0.000029 |
| std14 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709114 | 0.000041 |
| std15 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.709220 | 0.000015 |
| std16 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.709200 | 0.000024 |
| std17 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.709224 | 0.000030 |
| std18 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.709149 | 0.000030 |
| std19 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.709241 | 0.000039 |
| std20 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.709190 | 0.000038 |
| std21 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709183 | 0.000028 |
| std22 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709204 | 0.000039 |
| std23 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709243 | 0.000028 |
| std24 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709191 | 0.000097 |
| std25 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709141 | 0.000018 |
| std26 | 10 | 65 | 40 | ~300 micron line ~4J/cm2 | 0.709198 | 0.000016 |
| std27 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709194 | 0.000033 |
| std28 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709231 | 0.000027 |
| std29 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709236 | 0.000023 |
| std30 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709204 | 0.000035 |
| std31 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709187 | 0.000024 |
| std32 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709213 | 0.000034 |
| std33 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709268 | 0.000026 |
| std34 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709111 | 0.000047 |
| std35 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709213 | 0.000027 |
| std36 | 10 | 60 | 40 | ~300 micron line ~4J/cm2 | 0.709240 | 0.000025 |
|  |  |  |  | **Average:** | **0.709171** | **0.000031** |
| MACS 3 USGS standard | | | | | | |
| std1 | 10 | 53 | 30 | ~300 micron line ~5J/cm2 | 0.707581 | 0.000348 |
| std2 | 10 | 50 | 30 | ~300 micron line ~2J/cm2 | 0.707576 | 0.000051 |
| std3 | 10 | 50 | 30 | ~300 micron line ~2J/cm2 | 0.707520 | 0.000045 |
| std4 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.707539 | 0.000042 |
| std5 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.707590 | 0.000043 |
| std6 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.707704 | 0.000129 |
| std7 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.707860 | 0.000040 |
| std8 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.707589 | 0.000048 |
| std9 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.707802 | 0.000041 |
| std10 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.707692 | 0.000048 |
| std11 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.707615 | 0.000075 |
| std12 | 10 | 50 | 30 | ~300 micron line ~4J/cm2 | 0.707695 | 0.000059 |
|  |  |  |  | **Average:** | **0.707647** | **0.000081** |