Online Supplementary Information

Appendix A- Accuracy and precision of ICP-MS analyses

Here we present data regarding the accuracy and precision of the ICP-MS analyses. The Finnegan MAT Sector Field ICP-MS was calibrated using a series of multi-element standards selected to cover the range of the values expected for the samples. An additional multi-element standard was analyzed repeatedly in order to assess the overall precision of the measurements. Given the ranges of the values for the measured samples, the re-runs of the calibration standards were within 1.1% for Ca and Mg, within 3% for Sr, and within 12% for Ba (Table A1). One measurement of the most dilute standard was substantially different from its expected value, accounting for the high % difference for Ba standard. The percent variability observed in the repeated measurement of consistency standards was 2.75% for Ca, 2.93% for Mg, 3.28% for Ba, and 5.35% for Sr (Table A2).

Table A1: Calibration standards were each analyzed twice throughout the ICP-MS run in order to monitor the accuracy of the measurements. Standards corresponding to the range of values for the Midauwara samples are marked by italics. Average rsd corresponds to the relative standard deviation produced for each individual (n) measurement.

Analyte	n	average (ppm)	average rsd	expected (ppm)	%difference
Ca	2	0.1226	0.52	0.0231	430.32
Ca	2	0.2702	0.72	0.2312	16.86
Ca	2	0.4847	1.82	0.4623	4.85
Ca	*2*	*2.2870*	*3.11*	*2.3117*	*-1.07*
Ca	*2*	*11.6068*	*0.82*	*11.5586*	*0.42*
Mg	2	0.0021	3.03	0.0046	-54.45
Mg	2	0.0462	0.48	0.0462	0.00

Mg	*2*	*0.0933*	*2.51*	*0.0923*	*1.01*
Mg	*2*	*0.4621*	*2.96*	*0.4617*	*0.09*
Mg	2	2.3088	0.93	2.3086	0.01
Sr	2	0.0038	270.29	0.0046	-18.17
Sr	*2*	*0.0465*	*5.34*	*0.0460*	*1.19*
Sr	*2*	*0.0946*	*5.05*	*0.0920*	*2.85*
Sr	2	0.4606	5.24	0.4600	0.12
Sr	2	2.1001	5.22	2.3000	-8.69
Ba	*2*	*0.0010*	*0.45*	*0.0009*	*12.05*
Ba	*2*	*0.0089*	*0.63*	*0.0090*	*-0.71*
Ba	2	0.0179	1.08	0.0180	-0.21
Ba	2	0.0898	2.28	0.0898	-0.01
Ba	2	0.4459	1.50	0.4489	-0.66

Table A2: Standards composed of a mixture of single element solutions were analyzed eight times over the course of the ICP-MS measurements in order to examine the precision of the measurements. The 1σ stdev corresponds to the 1σ standard deviation for the 8 individual measurements of the consistency standard. The % variability corresponds to the amount of variability in the measured values which is accountable by the 1σ standard deviation. It is likely that the deviation of the analyzed values from the expected values is due to errors in the initial measurement of the consistency standards, given the successful re-runs of the calibration standards within the range of these samples.

Analyte	**n**	**average measured (ppm)**	**average rsd**	**1σ stdev**	**%variability**	**expected (ppm)**	**%difference**
Ca	8	6.2601	2.66	0.1719	2.75	5.6859	10.10
Mg	8	0.2352	2.86	0.0069	2.93	0.2340	0.51
Sr	8	0.0457	3.71	0.0024	5.35	0.0433	5.50
Ba	8	0.0025	1.30	0.0001	3.28	0.0027	-6.79

Online Appendix B: Stable isotope and minor element data for Wadi Midauwara silts and gastropods

Table B1: Stable isotope and minor element data for the silts. Thickness corresponds to the elevation of the sample above the base of the section. The % CaCO corresponds to the insoluble fraction in the carbonate silts.

Thickness (cm)	**$\delta^{18}O$**	**stdev**	**$\delta^{13}C$**	**stdev**	**Mg/Ca**	**Mg/Ca err**	**Sr/Ca**	**Sr/Ca err**	**Ba/Ca**	**Ba/Ca err**	**%$CaCO_3$**
530	-9.9	0.24	-1.5	0.02	0.021245	0.001577	0.004589	0.000516	0.000429	2.29E-05	91.71
520	-8.5	0.03	-1.0	0.06	0.022864	0.000863	0.004657	0.000102	0.000373	8.19E-06	89.19
510	-8.9	0.02	-0.9	0.02	0.02169	0.000408	0.004045	0.000195	0.000389	1.28E-05	89.20
500	-9.7	0.30	-0.2	0.15	0.024608	0.001303	0.004948	0.000271	0.000361	1.33E-05	97.56
490	-8.4	0.02	-0.4	-0.30	0.023861	0.000945	0.005251	0.000158	0.000405	1.13E-05	92.45
480	-9.4	0.27	-0.8	0.09	0.022322	0.001017	0.004557	0.000313	0.000393	1.23E-05	96.29
470	-9.5	0.14	-0.9	0.19	0.022085	0.00084	0.004881	0.000229	0.00038	1.03E-05	92.06
460	-9.9	0.03	-0.7	0.07	0.023114	0.000535	0.005202	0.00017	0.000399	7.31E-06	93.96
450	-8.7	0.24	-0.3	0.15	0.023564	0.000641	0.00596	0.000205	0.0004	7.97E-06	97.08
440	-8.4	0.06	-0.7	0.12	0.021502	0.000864	0.004915	0.00015	0.000368	1.11E-05	96.10
430	-8.7	0.32	-0.8	0.26	0.020936	0.00023	0.004589	0.000217	0.000352	2.59E-06	95.26
420	-9.1	-9.12	-0.6	0.01	0.022898	0.000586	0.005319	0.000139	0.000368	7.01E-06	96.79
410	-10.3	0.17	-0.7	0.09	0.022647	0.00043	0.004628	0.000164	0.000399	6.87E-06	95.94
390	-9.2	0.06	-0.8	0.05	0.023437	0.00188	0.004715	0.000445	0.000357	2.04E-05	97.32
380	-10.1	0.01	-0.7	0.04	0.023437	0.00054	0.004715	0.000388	0.000357	7.68E-06	97.32
370	-9.1	0.16	-0.5	0.10	0.023704	0.001092	0.004864	0.000395	0.000324	1.01E-05	95.34
360	-9.6	0.02	-0.8	0.10	0.021883	0.000349	0.004717	0.00023	0.000363	3.95E-06	
350	-9.2	0.10	-1.0	0.08	0.020187	0.000201	0.004864	0.000195	0.000318	2.94E-06	95.42
340	-8.9	0.05	-0.7	0.02	0.021763	0.000923	0.004549	0.000292	0.000412	1.21E-05	95.56
330	-9.6	0.09	-0.7	0.04	0.025126	0.000401	0.004968	0.000265	0.00033	4.45E-06	93.64
320	-8.1	0.02	-1.1	0.02	0.025126	0.00057	0.005179	0.000486	0.000385	7.32E-06	92.70
310	-8.9	0.13	-0.7	0.04	0.02608	0.000508	0.005645	0.000425	0.000314	5.98E-06	95.36
300	-9.9	0.08	-0.5	0.14	0.024725	0.001116	0.006231	0.000238	0.000326	9.1E-06	94.98
290	-9.9	0.02	-0.2	0.10	0.027288	0.001812	0.006017	0.000463	0.000306	1.65E-05	97.14

Thickness (cm)	$\delta^{18}O$	stdev	$\delta^{13}C$	stdev	Mg/Ca	Mg/Ca error	Sr/Ca	Sr/Ca error	Ba/Ca	Ba/Ca error	$\%CaCO_3$
280	-10.1	0.09	-0.3	0.12	0.02729	0.000712	0.005882	0.00017	0.000324	5.31E-06	96.90
270	-8.9	0.05	0.1	0.06	0.028221	0.002413	0.006494	0.000683		1.93E-05	98.58
260	-10.0	0.03	-0.1	0.04	0.028216	0.001018	0.006343	0.000471	0.000329	8.09E-06	95.72
250	-9.7	0.13	-0.2	0.03	0.027247	0.001389	0.006327	0.000269	0.000298	1.09E-05	98.81
240	-10.2	0.02	-0.2	0.09	0.030431	0.001873	0.007381	0.000552	0.00033	1.39E-05	99.00
230	-9.6	0.06	-0.4	0.07	0.029887	0.002084	0.008882	0.000479	0.000334	1.58E-05	97.11
220	-10.1	0.08	-0.1	0.12	0.028818	0.000561	0.007605	0.0003	0.000306	6.81E-06	94.65
210	-10.2	0.16	-0.5	0.05	0.030165	0.001974	0.007692	0.00076	0.000307	1.39E-05	96.30
200					0.008333	0.000323	0.000294	8.53E-05	0.000294	4.06E-06	97.98
190	-10.8	0.05	-0.3	0.04	0.03197	0.000215	0.008401	0.00019	0.000273	3.51E-06	96.23
180	-10.8	0.08	-0.3	0.05	0.033336	0.000313	0.008458	0.000153	0.000275	2.91E-06	96.33
170	-10.6	0.05	-0.3	0.02	0.03163	0.00036	0.00819	7.32E-05	0.000279	3.18E-06	95.63
160	-10.6	0.08	-0.1	-0.12	0.033336	0.000313	0.008458	0.000153	0.000275	2.91E-06	96.24
150	-10.7	0.04	-0.4	0.03	0.033454	0.000526	0.008123	0.000164	0.00028	3.84E-06	96.41
140	-10.8	0.02	-0.7	0.09	0.033275	0.000641	0.008052	0.000152	0.000268	3.83E-06	96.37
130	-10.9	0.02	-0.5	0.10	0.032049	0.000345	0.008297	0.00023	0.00028	4.07E-06	97.15
120	-10.8	0.20	-1.0	0.18	0.033105	0.000327	0.007899	0.00018	0.000273	4.55E-06	96.50
110	-10.4	0.04	-0.5	0.09	0.032164	0.000522	0.007548	7.47E-05	0.00024	3.15E-06	96.80
100	-10.7	0.02	-0.1	0.21	0.033403	0.00025	0.008242	0.000101	0.000256	2.43E-06	96.81
90	-11.3	0.20	0.1	0.05	0.034467	0.000577	0.008276	0.000127	0.000253	2.51E-06	96.11
80	-11.0	0.06	-0.7	0.02	0.033471	0.000449	0.007833	0.000194	0.000252	4.21E-06	94.52
70	-10.5	0.13	-0.2	0.03	0.030853	0.000567	0.00756	0.000167	0.000249	4.18E-06	97.61
60	-10.8	0.06	-0.6	0.08	0.03331	0.000229	0.007752	0.000145	0.000245	1.73E-06	95.09
50					0.033739	4.29E-05	0.007732	9.38E-05	0.000225	1.25E-06	95.02
40	-10.9	0.07	-0.5	0.02	0.033174	0.00028	0.009371	0.000148	0.00026	3.26E-06	96.74
30	-10.9	0.16	-0.3	0.30	0.030815	0.000848	0.007099	0.000154	0.000324	6.97E-06	88.44
20	-11.0	0.32	-0.7	0.39	0.030913	0.000737	0.007497	0.000146	0.000306	5.63E-06	92.77
0	-10.9	0.16	-0.2	0.01	0.030754	0.000461	0.0078	0.000135	0.000325	4.09E-06	98.07

Table B2: Stable isotope and minor element data for gastropod shells from Wadi Midauwara silts.

Shell (ID)	$\delta^{18}O$	$\delta^{13}C$	Mg/Ca	Mg/Ca(err)	Sr/Ca	Sr/Ca (err)	Ba/Ca	Ba/Ca (err)
A1	-10.3	-3.3	0.000430	1.1088E-05	0.005776	9.8693E-05	0.000422	7.5994E-06
A2	-10.4	-3.6	0.000449	0.00	0.005715	2.7515E-04	0.000379	1.6622E-05
A3	-10.2	-3.8	0.000831	4.3337E-05	0.005904	1.7107E-04	0.000449	1.0905E-05
A4	-10.4	-3.5	0.001161	4.9659E-05	0.005961	1.7639E-04	0.000514	1.0285E-05
A5	-10.3	-3.9	0.000696	2.2457E-05	0.006114	1.4862E-04	0.000476	7.3914E-06
A6			0.001472	9.9595E-05	0.006177	1.0848E-04	0.000465	1.0544E-05
A7	-10.4	-4.0	0.000582	0.00	0.006065	1.9447E-04	0.000370	1.0519E-05
A8	-10.4	-3.9	0.000542	1.0065E-04	0.006171	1.9913E-04	0.000437	9.6037E-06
A9	-10.7	-4.1	0.000986	1.7054E-04	0.006222	3.1386E-04	0.000427	1.2804E-05
A10	-10.8	-4.0	0.000346	0.00	0.006030	1.5761E-04	0.000472	1.2306E-05
A11			0.000420	2.8615E-05	0.005561	2.6951E-04	0.000513	1.7065E-05
B1	-11.1	-3.0	0.000963	7.4429E-06	0.004429	1.2303E-04	0.000168	1.5949E-06
B2	-11.0	-2.8	0.000761	5.1470E-06	0.004605	9.0597E-05	0.000256	2.9411E-06
B3	-11.1	-3.1	0.001171	4.2185E-05	0.004504	1.9593E-04	0.000307	1.0546E-05
B4	-11.1	-3.4	0.001024	1.3500E-05	0.004256	9.6489E-05	0.000174	2.8929E-06
B5			0.001440	2.6703E-05	0.005084	2.8256E-04	0.000233	1.1444E-05
B6	-11.6	-3.9	0.003230	2.7153E-05	0.005299	1.3630E-04	0.000259	4.7918E-06
B7	-11.3	-3.7	0.002063	7.0571E-06	0.004998	6.1033E-05	0.000243	2.0163E-06
B8			0.000483	1.2624E-05	0.005252	1.1508E-04	0.000270	2.0163E-06
C1	-10.8	-3.1	0.004874	9.4881E-05	0.004450	5.7838E-05	0.000212	2.7542E-06
C2	-10.5	-2.9	0.002002	9.2252E-05	0.004881	2.0727E-04	0.000250	8.4732E-06
C3	-10.6	-3.0	0.000845	1.3771E-05	0.004829	7.8689E-05	0.000241	3.9344E-06
C4	-11.1	-3.0	0.000834	1.2234E-05	0.005004	1.3536E-04	0.000265	3.8928E-06
C5			0.002029	2.0857E-05	0.004648	8.1038E-05	0.000262	2.6912E-06
C6	-10.6	-3.1	0.000392	2.9220E-06	0.004608	3.4333E-05	0.000196	1.4610E-06

Shell (ID)	$\delta^{18}O$	$\delta^{13}C$	Mg/Ca	Mg/Ca(err)	Sr/Ca	Sr/Ca (err)	Ba/Ca	Ba/Ca (err)
C7*	-8.3	-1.4	0.000613	6.2850E-06	0.005054	5.1852E-05	0.000306	3.1425E-06
C8*	-7.2	-0.2	0.000717	2.9569E-06	0.004661	1.9220E-05	0.000179	7.3922E-07
D1	-9.3	-4.0	0.000722	6.4173E-06	0.002677	4.8700E-05	0.000510	4.5298E-06
D2			0.000771	5.9369E-06	0.002825	2.1769E-05	0.000449	3.4632E-06
D3	-10.3	-4.6	0.000533	4.4705E-06	0.002438	2.0437E-05	0.000305	2.5546E-06
D4	-9.8	-4.2	0.000422	7.9586E-06	0.002952	7.6697E-05	0.000422	7.9586E-06
D5	-10.6	-5.2	0.000400	7.8185E-06	0.002868	8.7104E-05	0.000333	6.5155E-06
D6	-10.4	-4.9	0.001469	1.2412E-04	0.002570	3.6172E-05	0.000245	3.4449E-06
D7	-10.5	-5.3	0.000448	6.3759E-06	0.002975	4.2313E-05	0.000367	5.2166E-06
D8	-10.3	-5.4	0.001833	9.6608E-06	0.002902	4.1139E-05	0.000496	2.6165E-06
D9	-10.2	-5.4	0.000428	6.8420E-06	0.002737	9.6099E-05	0.000342	5.4736E-06
D10	-10.3	-5.8	0.000675	6.9422E-06	0.002551	2.6226E-05	0.000375	3.8568E-06
D11	-10.4	-5.9	0.000610	3.6969E-06	0.002659	1.6108E-05	0.000436	2.6407E-06
E1	-10.8	-4.1	0.001580	5.3254E-05	0.003364	5.6776E-05	0.000213	1.3656E-06
E2	-10.7	-4.4	0.003959	1.2587E-04	0.003335	1.2415E-04	0.000257	7.7456E-06
E3			0.000572	3.3681E-06	0.002626	6.5925E-05	0.000191	1.2630E-06
E4	-10.9	-5.0	0.000455	9.9579E-07	0.002848	6.9706E-06	0.000218	5.9748E-07
E5	-11.2	-5.1	0.000837	1.3102E-05	0.002910	5.6366E-05	0.000289	2.1379E-06
E6	-11.1	-5.1	0.000329	4.1969E-06	0.003452	2.3245E-05	0.000222	1.6142E-06
E7	-11.0	-5.1	0.000177	1.6290E-05	0.002508	4.2762E-05	0.000243	4.0726E-06
E8	-10.8	-5.0	0.000572	2.9363E-06	0.002374	1.0277E-05	0.000172	7.3406E-07
E9	-10.8	-5.0	0.000427	5.0163E-06	0.002642	2.6196E-05	0.000171	1.6721E-06
E10	-10.8	-4.9	0.000372	5.2493E-06	0.002646	4.3289E-05	0.000168	1.9685E-06
E11			0.000722	5.2844E-06	0.002757	1.7028E-05	0.000193	1.1743E-06
E12	-10.7	-5.1	0.000490	1.4864E-05	0.002615	8.0456E-05	0.000169	4.2467E-06
E13	-10.6	-5.0	0.000356	1.7442E-06	0.002606	4.2676E-05	0.000156	6.3426E-07

Shell (ID)	**$\delta^{18}O$**	**$\delta^{13}C$**	**Mg/Ca**	**Mg/Ca(err)**	**Sr/Ca**	**Sr/Ca (err)**	**Ba/Ca**	**Ba/Ca (err)**
F1	-10.8	-3.0	0.000608	6.8084E-06	0.004937	5.5254E-05	0.000261	2.9192E-06
F2	-10.9	-3.1	0.000912	2.6815E-06	0.004743	1.3944E-05	0.000280	8.2466E-07
F3	-10.8	-3.3	0.000679	9.1024E-06	0.004760	6.3808E-05	0.000249	3.3347E-06
F4	-10.6	-2.8	0.000276	4.2978E-07	0.005225	8.1483E-06	0.000237	3.6901E-07
F5	-10.3	-3.0	0.000778	4.9254E-06	0.004487	2.8406E-05	0.000276	1.7466E-06
F6	-10.5	-3.4	0.000688	7.3681E-06	0.005761	6.1699E-05	0.000340	3.6415E-06
F7	-10.8	-3.1	0.000892	1.0921E-05	0.005655	6.9193E-05	0.000361	4.4159E-06
F8	-10.6	-3.1	0.000355	2.5351E-07	0.005442	3.8833E-06	0.000255	1.8181E-07

Appendix C: Rayleigh evaporation model

The isotopic enrichment of an evaporating pan of water can be modeled by Rayleigh distillation. As presented in Criss (1999), a useful, integrated form of the Rayleigh equation is used in this study:

$$\left(\frac{R_w - R_w^s}{R_w^i - R_w^s}\right) = f^u \qquad [1]$$

where R_w is the isotopic ratio of the water at any point in the evaporation process, R_w^i is the initial isotopic ratio, and R_w^s is isotope ratio at evaporative completion (Stewart, 1975; Criss, 1999). The exponent u in the above equation is:

$$u = \frac{1 - \alpha_{evap}^{0}(1-h)}{\alpha_{evap}^{0}(1-h)} \qquad [2]$$

The term R_w^s is a constant for any given atmospheric condition and is equal to:

$$R_w^s = \frac{\alpha_{eq} h R_v}{1 - \alpha_{evap}^{0}(1-h)} \qquad [3]$$

In the above expressions, α_{evap}^{0} is the nonequilibrium (kinetic) isotopic fractionation factor for water evaporating into air at zero humidity and R_v is the isotopic ratio of the ambient water vapor (Stewart, 1975; Criss, 1999). R-values can be converted to δ-values by substituting the value (1000+δ) for each R-value in the equations above.

At 24°C, the value for α_{eq} is 1.00945, using the temperature dependent relationship of Majoube (1970). We made the assumption that the R_v was in equilibrium with the initial water composition (presumably representative of local precipitation). The initial $\delta^{18}O$ of the water was assumed to be -9.1‰$_{SMOW}$, equivalent to water in equilibrium with the lightest carbonate $\delta^{18}O$ values (-11.3‰$_{PDB}$ at 24°C). The value for the kinetic fractionation for $^{18}O/^{16}O$ recommended by Criss (1999) is that of Stewart (1975), which is 1.0278.

References

Criss, R. E., 1999. Principles of stable isotope distribution. Oxford University Press, New York.

Majoube, M., 1971. Fractionnement en oxygene 18 et deuterium entre l'eu et sa vapeur. Journal of Chemical Physics 68, 1425-1436

Stewart, M. K., 1975. Stable Isotope Fractionation due to Evaporation and Isotopic Exchange of Falling Waterdrops: Applications to Atmospheric Processes and Evaporation of Lakes. Journal of Geophysical Research 80, 1133-1146.