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Penultimate Deglacial Sea-Level Timing from Uranium/Thorium Dating of Tahitian Corals

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Supporting Online Material

Methods

Corals are screened for diagenetic alteration; through visual and thin section inspection and XRD analysis. Screening of corals for alteration with XRD provided a quantitative assessment of the presence of calcite, by comparison to gravimetric mixtures of aragonite and pure calcite. Screening of corals for alteration with XRD provided a quantitative assessment of the presence of calcite. XRD alone, however, cannot detect the presence of secondary aragonite, and therefore thin section analysis of every coral measured was employed to identify secondary aragonite alteration as well as employing XRD.

For U and Th isotope analysis, 0.3 g of coral is spiked with a mixed ^{229}Th : ^{236}U spike and dissolved in HNO_3 , and refluxed in aqua regia to remove all traces of organic matter. Chemical separation of U and Th from the sample matrix follows a procedure adapted from (S1). Measurement of U and Th was performed by a Nu-Instruments MC-ICP-MS. Both U and Th were measured statically, utilising ion counters for the minor beams ^{230}Th and ^{234}U . Machine biases were corrected using sample standard bracketing with CRM-145 for U and an in-house ^{229}Th : ^{230}Th : ^{232}Th standard for Th.

Results are presented in Table S1. Uranium concentrations are within the expected range for modern corals between 2 and 3 ppm, excepting one (310-M0009D-18R-1W-19,28) with a concentration of 5.1ppm. Th concentrations are typically < 1ppb with 7 corals having concentrations higher. All samples measured for U/Th have < 1% calcite, except 310-M0005D-20R-2W-0,21 which has $1.9\% \pm 0.3$ heterogeneity of this calcite diagenesis may explain the spread of ages for repeat measurements of this coral. 310-M0005D-20R-2W-14,21 a more pristine subsample of the same coral produces a much narrower spread of ages.

Detailed morphological analysis of reef structure, to determine whether the corals are in growth position, is not possible for these samples as they are sampled from a drill core rather than a visible outcrop. However, evidence from visual inspection of the cores including: the orientation of the growth axis; the presence of algal encrustations on the upper surface of the coral; partially infilled geopetals; and whether the coral forms part of a continuous framework, are used to demonstrate that the corals are indeed in growth position (Table S1 and Figure S2).

Coral Data used for comparison

Because of the lack of coral data from Tahiti that precedes the last glacial maximum, coral data from other localities must be considered for comparison, in spite of the discrepancies of relative sea level between these “far-field” localities. Coral data used for comparison in Fig. 1, are screened by rejecting samples with initial ($^{234}\text{U}/^{238}\text{U}$) outside 1.137 to 1.151, and are shown as open symbols. The Huon Peninsular corals (blue diamonds) of (S2, 3, 4) are illustrated for MIS 3 (Fig. 1a), while (S5, 6) - including the “Aladdin’s Cave” samples - are shown for the penultimate deglacial. The MIS 5e highstand is represented with corals from, western Australia (purple triangles)(S7, 8, 9), Hawaii (orange circles)(S10), and Barbados (green squares)(S11, 12, 13) .

The paleo-elevations of corals used for comparison are reconstructed using the ages and uplift rates from their original publications. It should be noted though that uplift rates are typically estimated from the ages of last interglacial corals and an assumed sea level at that time. The absolute magnitude of the last interglacial highstand cannot therefore be rigorously constrained from these datasets. This compilation of coral data is therefore used to illustrate the timing of the last interglacial rather than the magnitude of the highstand. The reconstruction of corals from the

Huon Peninsular to lower elevations (Aladdin's Cave and the early highstand) are based on their relative elevation to the interglacial terrace, and therefore provide an estimation of the magnitude of their paleo-elevation relative to the interglacial highstand.

Figures

Figure S1

A Landsat 7 image of Tahiti showing the location of the three areas drilled during IODP Expedition 310. The locations of the drill sites are shown as red circles and the holes that have been samples for this study are shown in pink. The insets showing the details for each site are modified from (S14) contours are spaced at 20 m depth.

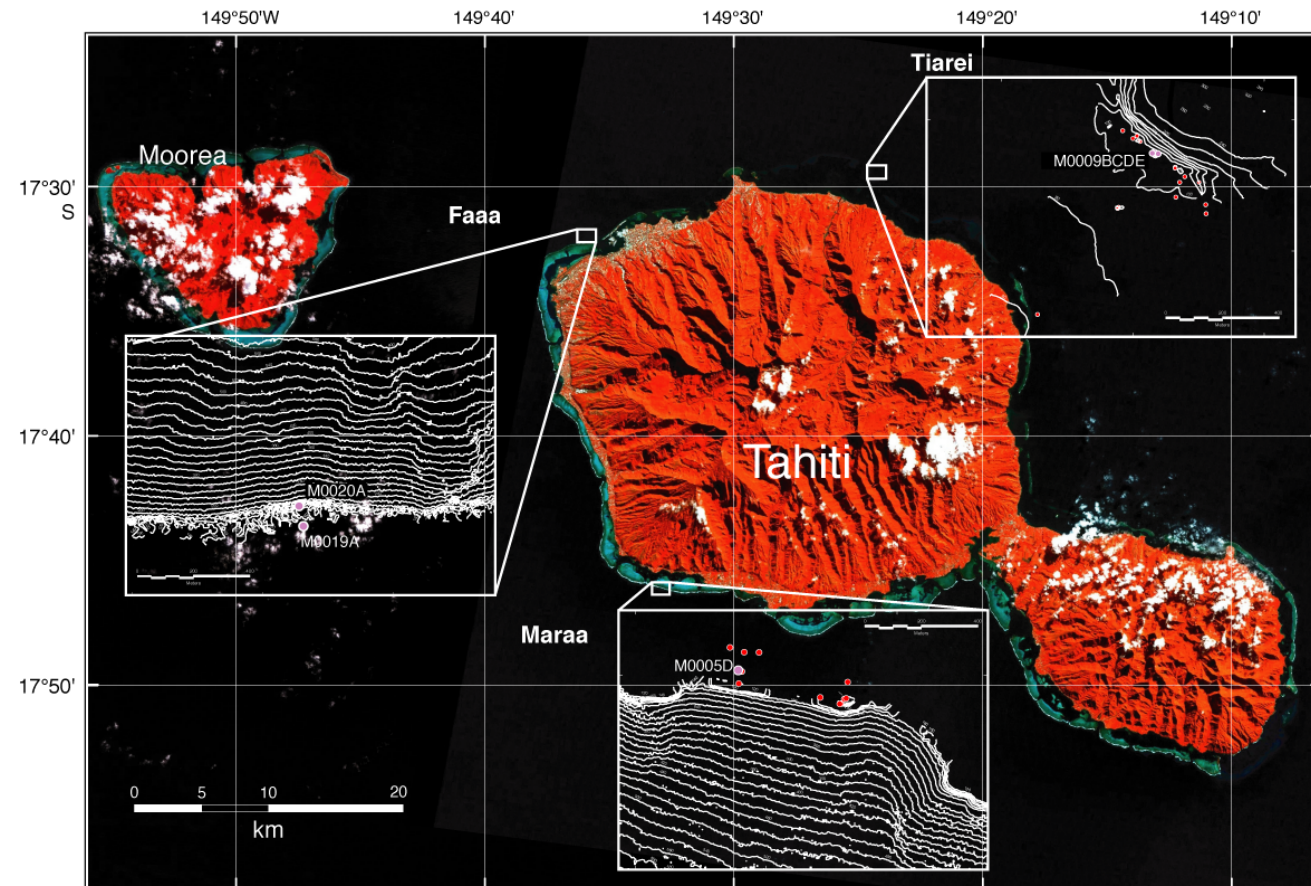


Figure S2: Line-scan of hole M0019A, core 27, section 1, from 65-88 cm (archive half)(S14). Features indicating the corals are in growth position are labelled: coral growth orientation, CO; calcareous algae encrusting the upper surfaces of the corals, CAP; and geopetals, GP, indicating the orientation of the corals hasn't changed since the voids were partially filled. Here the corals also form a continuous framework supportive of them being samples from growth position. Sample 310-M0019A-27R-1W-62,83 was sampled from the working half of this section.

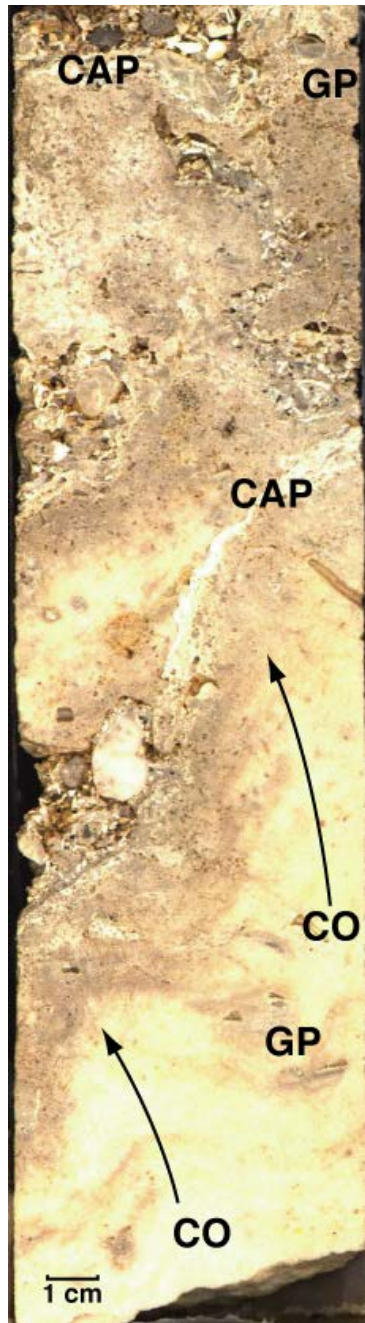


Figure S3

Line scans of core sections 27-1 – 29-1 from Hole M0019A with lithological descriptions adapted from (S14) and water depth interpretations based on the criteria of (S15). Ages are in ka BP (Table S1), values in bold are replicates that are isochronous and have $(^{234}\text{U}/^{238}\text{U})_i$ within 5‰ of modern seawater, ages in italic have $(^{234}\text{U}/^{238}\text{U})_i$ outside of the rejection criteria and are not considered to be reliable.

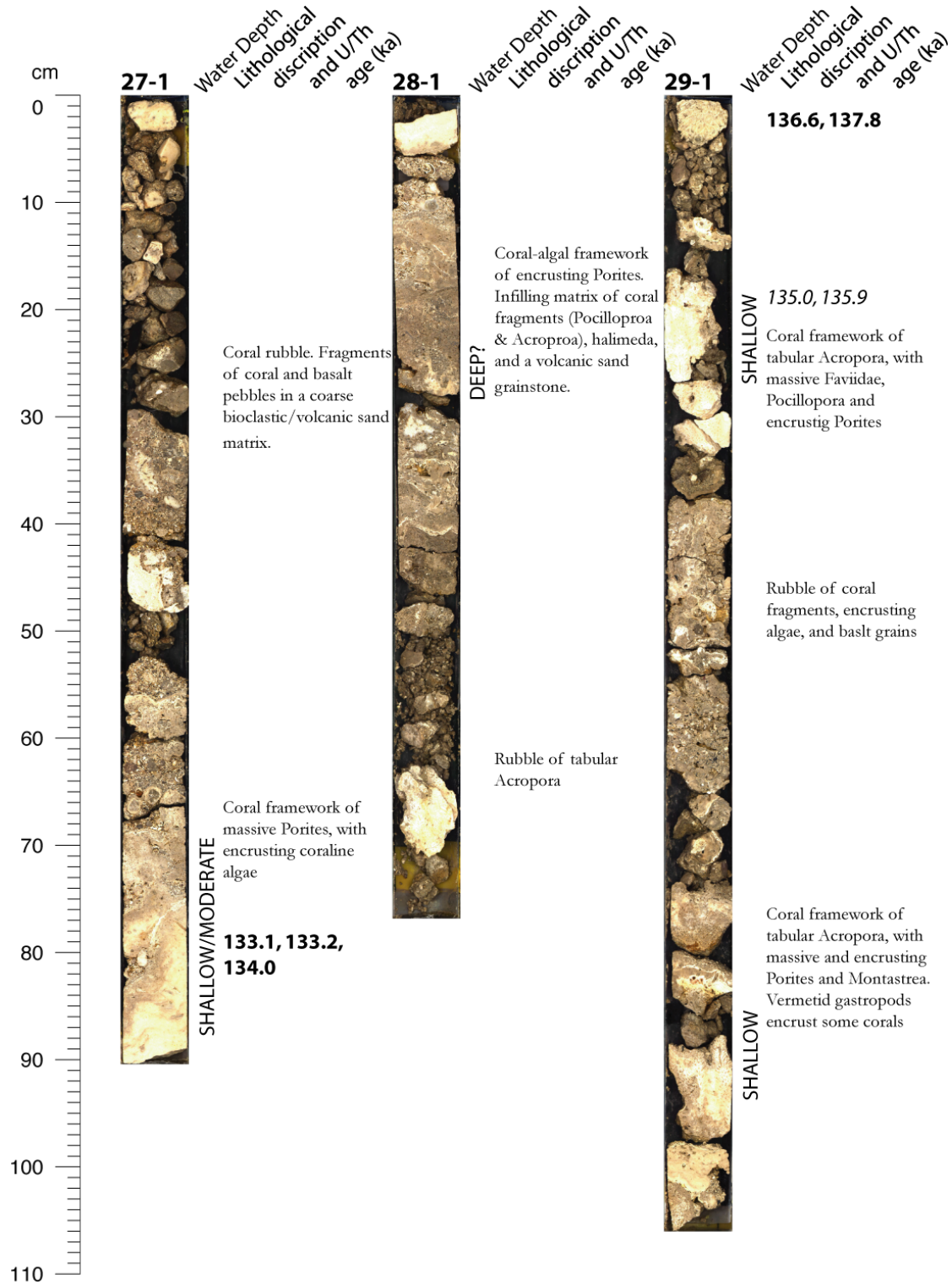


Table S1

U and Th isotopes. () indicates activity ratio. All ratios are presented as at the time of measurement, except $(^{234}\text{U}/^{238}\text{U})_i$ which is calculated as the ratio at the time when the coral grew, using the U/Th age. The age is calculated assuming a closed system, using the Isoplot software (S16) using the half lives of (S17). Initial ^{230}Th is accounted for assuming it is scavenged from seawater with a $^{232}\text{Th}/^{230}\text{Th}$ of 20000 (S18). Ages are presented in years before 1950 AD. Coral types are: mp, massive Porites sp.; rbp, robust branching Pocillopora sp.; ta, tabular Acropora sp.; mf massive Favia sp.; ep, encrusting Porites sp.; ba, branching Acropora sp.; em, encrusting Montipora sp.; and fp, foliaceous Pachyseris. Features indicating the coral is in growth position are: co, the orientation of the coral; cap, the positioning of an algal crust on the upper surface of the coral; gp, the orientation of partially filled geopetals within the coral; and cf, whether the coral forms part of a continuous framework.

Location	IODP Sample ID	Coral	Growth Position	mbsl	²³⁸ U ppm	2s	²³² Th ppb	2s	(²³⁰ Th / ²³⁸ U)	2s	(²³⁴ U / ²³⁸ U)	2s	(²³² Th/ ²³⁸ U)	2s	Age Ka BP	2s	(²³⁴ U / ²³⁸ U) _i	2s	% calcite	2s	
Maraa																					
	310-M0005D-20R-2W-0,21	mp	co, gp	117.52	3.1263	0.0039	0.194	0.003	0.7866	0.0028	1.1024	0.0008	0.0000204	0.0000004	132.4	0.9	1.149	0.001	1.9%	0.3%	
	310-M0005D-20R-2W-0,21	mp	co, gp	117.52	2.9457	0.0004	0.2445	0.0004	0.8020	0.0009	1.1007	0.0008	0.00002717	0.00000004	137.9	0.4	1.149	0.001			
	310-M0005D-20R-2W-14,21	mp	co, gp	117.66	2.7359	0.0042	0.216	0.004	0.7949	0.0029	1.1081	0.0008	0.0000259	0.00000005	133.6	1.0	1.158	0.001	0.3%	0.2%	
	310-M0005D-20R-2W-14,21	mp	co, gp	117.66	2.5690	0.0008	0.0849	0.0001	0.7902	0.0009	1.1016	0.0008	0.00001082	0.00000002	133.7	0.4	1.148	0.001			
Faaa																					
	310-M0020A-21R-2W-13,20	rbp		113.16	2.9434	0.0038	17.6	0.3	0.3813	0.0014	1.1396	0.0008	0.0019591	0.0000347	44.1	0.2	1.158	0.001	0.1%	0.2%	
	310-M0020A-25R-3W-11,13	mp		124.28	3.0016	0.0037	2.45	0.04	0.5037	0.0018	1.1175	0.0008	0.0002668	0.0000047	64.6	0.3	1.141	0.001	0.6%	0.2%	
	310-M0019A-27R-1W-62,83	mp	co, gp, cap, cf	115.24	2.4738	0.0003	0.232	0.004	0.7903	0.0027	1.1038	0.0010	0.0000311	0.0000005	133.2	0.9	1.151	0.001			
	310-M0019A-27R-1W-62,83	mp	co, gp, cap, cf	115.24	2.4799	0.0008	0.205	0.0003	0.7896	0.0009	1.1030	0.0008	0.0000270	0.00000005	133.1	0.4	1.150	0.001			
	310-M0019A-27R-1W-62,83	mp	co, gp, cap, cf	115.24	2.4889	0.0003	0.207	0.0003	0.7919	0.0009	1.1025	0.0008	0.0000272	0.00000004	134.0	0.4	1.150	0.001			
	310-M0019A-29R-1W-0,4	mf	co	117.61	2.6539	0.0004	2.302	0.037	0.7996	0.0027	1.1024	0.0010	0.0002801	0.0000044	136.6	0.9	1.151	0.001			
	310-M0019A-29R-1W-0,4	mf	co	117.61	2.6539	0.0004	2.250	0.004	0.8030	0.0009	1.1021	0.0008	0.0002776	0.0000005	137.8	0.4	1.151	0.001			
	310-M0019A-29R-1W-16,24	ta	co, cap	117.77	3.1345	0.0005	0.170	0.003	0.8063	0.0027	1.1163	0.0010	0.0000191	0.0000003	135.0	0.9	1.170	0.001			
	310-M0019A-29R-1W-16,24	ta	co, cap	117.77	3.1198	0.0004	0.154	0.0003	0.8092	0.0009	1.1164	0.0008	0.0000162	0.00000003	135.9	0.4	1.171	0.001			
	310-M0019A-32R-1W-0,4	rbp	co?, cf?	119.61	2.5717	0.0003	0.603	0.010	0.7979	0.0027	1.1065	0.0011	0.0000788	0.0000013	134.9	0.9	1.156	0.002			
	310-M0019A-32R-1W-0,4	rbp	co?, cf?	119.61	2.5899	0.0005	0.258	0.0004	0.8034	0.0009	1.1055	0.0008	0.0000326	0.0000001	137.0	0.4	1.155	0.001			
Tierci																					
	310-M0009B-16R-	mp	co	124.43	3.2753	0.0002	0.387	0.003	0.2694	0.0008	1.1277	0.0008	0.0000386	0.0000003	29.59	0.10	1.139	0.001	0.2%	0.2%	

Location	IODP Sample ID	Coral	Growth Position	mbsl	²³⁸ U ppm	2s	²³² Th ppb	2s	(²³⁰ Th / ²³⁸ U)	2s	(²³⁴ U / ²³⁸ U)	2s	(²³² Th/ ²³⁸ U)	2s	Age Ka BP	2s	(²³⁴ U / ²³⁸ U) _i	2s	% calcite	2s
	2W-13,17																			
	310-M0009B-16R-2W-13,17	mp	co	124.43	3.1816	0.0005	0.362	0.008	0.2694	0.0006	1.1269	0.0008	0.0000373	0.0000008	29.61	0.08	1.138	0.001		
	310-M0009B-17R-1W-5,10	mp	co, cap	124.48	3.4967	0.0005	0.355	0.001	0.2712	0.0005	1.1278	0.0005	0.0000333	0.0000001	29.81	0.07	1.139	0.001	0.5%	0.2%
	310-M0009B-17R-1W-5,10	mp	co, cap	124.48	3.3945	0.0011	0.304	0.007	0.2713	0.0006	1.1274	0.0008	0.0000293	0.0000006	29.84	0.08	1.139	0.001		
	310-M0009B-17R-1W-70,80	ba	co, cap	125.13	3.5654	0.0003	0.678	0.005	0.2693	0.0008	1.1296	0.0008	0.0000622	0.0000005	29.52	0.10	1.141	0.001	0.1%	0.2%
	310-M0009B-17R-1W-70,80	ba	co, cap	125.13	3.5320	0.0005	0.717	0.003	0.2709	0.0005	1.1315	0.0005	0.0000665	0.0000002	29.66	0.07	1.143	0.001		
	310-M0009C-18R-1W-80,87	em	co, gp, cap, cf	121.45	3.9956	0.0006	4.04	0.01	0.2853	0.0006	1.1262	0.0005	0.0003311	0.0000012	31.66	0.08	1.138	0.001	0.6%	0.2%
	310-M0009C-18R-1W-80,87	em	co, gp, cap, cf	121.45	3.8925	0.0014	3.79	0.08	0.2871	0.0006	1.1263	0.0008	0.0003184	0.0000069	31.89	0.09	1.138	0.001		
	310-M0009D-18R-1W-19,28	fp	co, gp, cap, cf	132.09	2.6619	0.0007	0.914	0.007	0.2742	0.0008	1.1283	0.0008	0.0001124	0.0000008	30.18	0.10	1.140	0.001	0.0%	0.2%
	310-M0009D-18R-1W-19,28	fp	co, gp, cap, cf	132.09	5.1113	0.0006	2.408	0.018	0.2713	0.0008	1.1281	0.0008	0.0001542	0.0000012	29.82	0.10	1.139	0.001	0.2%	0.2%
	310-M0009D-18R-1W-19,28	fp	co, gp, cap, cf	132.09	5.1951	0.0070	2.829	0.010	0.2737	0.0007	1.1276	0.0005	0.0001783	0.0000007	30.14	0.09	1.139	0.001		
	310-M0009D-20R-2W-0,5	ba		137.80	3.3250	0.0006	1.474	0.005	0.2799	0.0006	1.1321	0.0005	0.0001452	0.0000005	30.78	0.07	1.144	0.001	0.5%	0.2%
	310-M0009D-20R-2W-0,5	ba		137.80	3.2898	0.0016	1.395	0.030	0.2818	0.0006	1.1325	0.0008	0.000139	0.0000003	31.00	0.08	1.145	0.001		
	310-M0009D-25R-1W-64,70	mp	co, gp, cap, cf	145.82	2.8052	0.0008	0.228	0.002	0.8263	0.0024	1.0952	0.0008	0.0000266	0.0000002	148.1	0.9	1.145	0.001	0.1%	0.2%
	310-M0009D-25R-1W-95,102	ta	co, gp, cap, cf	146.13	3.5084	0.0010	0.605	0.005	0.8315	0.0024	1.1090	0.0008	0.0000565	0.0000004	145.6	0.9	1.165	0.001	0.1%	0.2%
	310-M0009D-25R-2W-41,49	mp	co, gp, cap	146.95	2.6787	0.0004	0.879	0.003	0.8364	0.0017	1.0930	0.0005	0.0001075	0.0000004	152.7	0.7	1.143	0.001	0.1%	0.2%
	310-M0009D-25R-2W-41,49	mp	co, gp, cap	146.95	2.6901	0.0003	0.798	0.001	0.8376	0.0010	1.0937	0.0008	0.0000971	0.0000002	152.9	0.5	1.144	0.001		
	310-M0009D-25R-2W-52,55	mp	co, gp, cap	147.06	2.7078	0.0004	0.563	0.002	0.8388	0.0017	1.0940	0.0005	0.0000681	0.0000003	153.2	0.7	1.145	0.001	0.1%	0.2%
	310-M0009D-	mp	co, gp,	147.06	2.7063	0.0006	0.564	0.001	0.8388	0.0010	1.0936	0.0008	0.0000682	0.0000001	153.4	0.5	1.144	0.001		

Location	IODP Sample ID	Coral	Growth Position	mbsl	²³⁸ U ppm	2s	²³² Th ppb	2s	(²³⁰ Th / ²³⁸ U)	2s	(²³⁴ U/ ²³⁸ U)	2s	(²³² Th/ ²³⁸ U)	2s	Age Ka BP	2s	(²³⁴ U/ ²³⁸ U) _i	2s	% calcite	2s
	25R-2W-52,55		cap																	
	310-M0009E-12R- 2W-86,107	mp	co, gp, cap, cf	113.56	3.2507	0.0004	1.744	0.013	0.2952	0.0008	1.1263	0.0008	0.0001756	0.0000013	32.94	0.11	1.139	0.001	0.4%	0.2%
	310-M0009E-12R- 2W-86,107	mp	co, gp, cap, cf	113.56	3.1999	0.0004	1.824	0.007	0.2955 28747	0.0005 9882	1.1261	0.0005	0.0001866	0.0000007	32.98	0.08	1.138	0.001	0.1%	0.2%

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