

**Table 2. Stable isotope values on fossil eggshell from abandoned penguin colonies.** The samples are from three major regions of the Antarctic: the Ross Sea, East Antarctica, and the Antarctic Peninsula. It was not possible to extract carbon, oxygen, or nitrogen from all samples. Average age of each sample is provided in cal or  $^{14}\text{C}$  yr BP (only those  $> 26,000$   $^{14}\text{C}$  yr BP) based on radiocarbon dates of bone or other associated material from the same stratigraphic level, or estimated (indicated by an asterisk\*) based on dated material from levels above and below the sampled material. Samples split in half and dated directly are indicated by a dagger ( $\dagger$ ). All dates (lab number provided) except those from the Ross Sea are from previously published papers<sup>3-5</sup>.

Location	Age	Lab Number	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{13}\text{C}_{\text{org}}$	$\delta^{18}\text{O}_{\text{carb}}$	$\delta^{15}\text{N}_{\text{org}}$
<u>Ross Sea</u>						
Adelie Cove Site 3 Level 2-1	515	NZA 20747		-25.9		
Adelie Cove Site 3 Level 2-2	515			-23.5		14.0
Adelie Cove Site 3 Level 2-3	515		-10.3	-27.5	-9.0	13.5
Adelie Cove Site 3 Level 2-4	515		-10.9	-27.5	-8.1	13.8
Adelie Cove Site 3 Level 2-5	515		-9.4	-25.7	-9.8	12.7
Adelie Cove Site 3 Level 3-1	575*		-11.3	-27.7	-8.3	14.8
Adelie Cove Site 3 Level 3-2	575		-11.7	-27.2	-7.9	15.5
Adelie Cove Site 3 Level 3-3	575			-26.3		11.6
Adelie Cove Site 3 Level 3-4	575			-25.0		11.4
Adelie Cove Site 3 Level 3-5	575		-10.5	-26.5	-7.9	13.7
Adelie Cove Site 3 Level 4-2	635	NZA 20748	-11.4		-8.3	
Adelie Cove Site 3 Level 4-3	635		-12.0		-8.4	
Adelie Cove Site 3 Level 4-4	635		-14.0		-6.9	

Table 2 (continued).

Location	Age	Lab Number	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{13}\text{C}_{\text{org}}$	$\delta^{18}\text{O}_{\text{carb}}$	$\delta^{15}\text{N}_{\text{org}}$
Adelie Cove Site 3 Level 4-5	635		-10.5		-8.9	
N. Adelie Cove Site 1 Level 2	5585 <sup>†</sup>	NZA 21107	-8.7	-24.5	-9.7	
N. Adelie Cove Site 1 Level 2-1	5585		-7.4	-25.8	-9.0	
N. Adelie Cove Site 1 Level 2-2	5585		-5.6	-27.7	-9.5	
N. Adelie Cove Site 1 Level 2-3	5585		-8.1	-26.1	-11.5	
N. Adelie Cove Site 1 Level 2-4	5585		-7.8	-25.9	-12.2	
N. Adelie Cove Site 1 Level 2-5	5585		-9.6		-9.7	
N. Adelie Cove Site 1 Level 3	5310 <sup>†</sup>	NZA 21108	-8.0	-25.8	-10.8	
N. Adelie Cove Site 1 Level 3-1	5310		-8.3		-12.7	
N. Adelie Cove Site 1 Level 3-3	5310		-10.8		-11.7	
N. Adelie Cove Site 1 Level 3-4	5310		-10.3		-13.1	
N. Adelie Cove Site 1 Level 3-5	5310		-8.2		-10.2	
N. Adelie Cove Site 1 Level 4-1	6880	NZA 20729	-7.0	-25.7	-9.5	
N. Adelie Cove Site 1 Level 4-2	6880		-7.6	-25.8	-10.5	14.7
N. Adelie Cove Site 1 Level 4-3	6880		-8.8	-25.3	-10.9	13.1
N. Adelie Cove Site 1 Level 4-4	6880		-10.9	-25.9	-11.6	13.9
N. Adelie Cove Site 1 Level 4-5	6880		-7.5	-26.0	-11.0	13.5
N. Adelie Cove Site 1 Level 5-1	6675	NZA 20744	-9.1	-25.7	-12.2	15.0
N. Adelie Cove Site 1 Level 5-2	6675		-8.8	-26.1	-11.1	14.8
N. Adelie Cove Site 1 Level 5-4	6675			-25.6		11.9
N. Adelie Cove Site 1 Level 5-5	6675			-24.6		13.1
N. Adelie Cove Site 1 Level 6-1	6785	NZA 20745	-9.8	-26.0	-9.4	
N. Adelie Cove Site 1 Level 6-3	6785		-9.7		-10.6	

Table 2 (continued).

Location	Age	Lab Number	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{13}\text{C}_{\text{org}}$	$\delta^{18}\text{O}_{\text{carb}}$	$\delta^{15}\text{N}_{\text{org}}$
N. Adelie Cove Site 1 Level 6-5	6785		-7.9	-25.3	-10.9	
N. Adelie Cove Site 1 Level 7-1	6890	NZA 20746	-10.0	-25.9	-9.1	12.6
N. Adelie Cove Site 1 Level 7-2	6890		-9.6	-25.9	-9.0	16.0
N. Adelie Cove Site 1 Level 7-3	6890			-26.2		14.2
N. Adelie Cove Site 1 Level 7-4	6890		-8.6	-25.8	-10.0	15.2
N. Adelie Cove Site 1 Level 7-5	6890		-8.5	-26.1	-9.7	16.3
N. Adelie Cove Site 3 Level 2-1	5915	NZA 20728	-11.8	-25.6	-9.5	
N. Adelie Cove Site 3 Level 2-2	5915		-9.3	-24.9	-8.8	13.1
N. Adelie Cove Site 3 Level 2-3	5915		-10.1	-25.7	-7.5	14.6
N. Adelie Cove Site 3 Level 2-4	5915		-8.7		-12.0	
N. Adelie Cove Site 3 Level 2-5	5915		-8.8	-25.2	-8.1	13.7
Campo Icarus Site 2 Level 3-1	3150	NZA 20743	-8.2	-26.1	-8.2	13.8
Campo Icarus Site 2 Level 3-2	3150		-8.1	-26.3	-7.4	
Campo Icarus Site 2 Level 3-3	3150		-7.3	-26.1	-7.1	15.2
Campo Icarus Site 2 Level 3-4	3150		-7.7	-25.9	-7.9	
Campo Icarus Site 2 Level 3-5	3150		-8.5	-25.7	-7.2	14.3
Campo Icarus Site 2 Level 4	2705 <sup>†</sup>	NZA 21106	-7.6	-26.0	-7.5	
Campo Icarus Site 2 Level 4-3	2705		-9.5	-26.5	-8.1	13.3
Campo Icarus Site 2 Level 4-4	2705		-9.4		-8.8	
Campo Icarus Site 2 Level 4-5	2705		-7.3	-25.7	-7.3	14.9
Campo Icarus Site 2 Level 5-1	3675	NZA 20726	-9.5		-9.2	
Campo Icarus Site 2 Level 5-2	3675		-9.1		-8.5	
Campo Icarus Site 2 Level 5-3	3675		-8.3		-7.7	

Table 2 (continued).

Location	Age	Lab Number	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{13}\text{C}_{\text{org}}$	$\delta^{18}\text{O}_{\text{carb}}$	$\delta^{15}\text{N}_{\text{org}}$
Campo Icarus Site 2 Level 5-4	3675		-9.8		-9.0	
Campo Icarus Site 2 Level 5-5	3675		-8.5		-7.8	
Campo Icarus Site 2 Level 6	3385 <sup>†</sup>	NZA 21057	-9.3	-25.9	-6.8	
Campo Icarus Site 2 Level 6-1	3385		-8.9		-9.3	
Campo Icarus Site 2 Level 6-2	3385		-7.8		-7.9	
Campo Icarus Site 2 Level 6-3	3385		-9.0		-7.2	
Campo Icarus Site 2 Level 7 -1	3680	NZA 20725	-8.5		-8.8	
Campo Icarus Site 2 Level 7 -2	3680		-9.6		-6.9	
Campo Icarus Site 2 Level 7 -3	3680		-9.8		-8.9	
Campo Icarus Site 2 Level 7 -4	3680		-9.6	-25.3	-7.5	
Campo Icarus Site 2 Level 7 -5	3680		-10.3		-8.6	
Campo Icarus Site 2 Level 8	5675 <sup>†</sup>	NZA 20787	-7.9	-26.5	-9.5	
Campo Icarus Site 2 Level 8-1	5675		-9.4		-7.1	
Campo Icarus Site 2 Level 8-2	5675		-9.2		-7.4	
Campo Icarus Site 2 Level 8-3	5675		-7.7		-7.6	
Campo Icarus Site 2 Level 8-4	5675		-9.8		-9.8	
Campo Icarus Site 2 Level 8-5	5675		-10.5		-9.7	
Campo Icarus Site 2 Level 9-1	5740	NZA 21105	-8.6	-26.4	-8.3	
Campo Icarus Site 2 Level 9-2	5740		-9.5	-25.9	-9.0	14.8
Campo Icarus Site 2 Level 9-3	5740		-10.8	-25.6	-9.4	12.9
Campo Icarus Site 2 Level 9-4	5740		-11.7	-26.6	-12.1	
Campo Icarus Site 2 Level 9-5	5740		-8.1	-26.2	-7.9	
Campo Icarus Site 3 Level 4-1	3360	NZA 20727	-14.6	-26.4	-8.1	15.5
Campo Icarus Site 3 Level 4-2	3360		-11.6	-26.4	-10.4	

Table 2 (continued).

Location	Age	Lab Number	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{13}\text{C}_{\text{org}}$	$\delta^{18}\text{O}_{\text{carb}}$	$\delta^{15}\text{N}_{\text{org}}$
Campo Icarus Site 3 Level 4-3	3360		-10.4	-26.3	-9.4	15.1
Campo Icarus Site 3 Level 4-4	3360		-11.6		-7.2	
Campo Icarus Site 3 Level 4-5	3360		-10.6		-8.6	
Cape Hickey Site 1 Level 2-1	3375	NZA 20784	-5.7		-8.0	
Cape Hickey Site 1 Level 2-2	3375	NZA 20785	-8.5		-10.2	
Cape Hickey Site 1 Level 2-3	3375		-5.6		-10.2	
Cape Hickey Site 1 Level 2-4	3375		-6.1		-9.4	
Cape Hickey Site 1 Level 2-5	3375		-6.8		-9.0	
		BETA				
Cape Hickey Site 2 Level 2-1	38230	204544	-7.3		-9.1	
Cape Hickey Site 2 Level 2-2	38230		-11.7		-9.2	
Cape Hickey Site 2 Level 2-3	38230		-9.4		-9.5	
Cape Hickey Site 2 Level 2-4	38230		-9.6		-9.2	
Cape Hickey Site 2 Level 2-5	38230		-10.2		-9.6	
Cape Hickey Site 2 Level 3-1	34220	NZA 20904	-7.9		-4.9	
Cape Hickey Site 2 Level 3-2	34220		-9.7		-9.5	
Cape Hickey Site 2 Level 3-3	34220		-10.7		-9.5	
Cape Hickey Site 2 Level 3-4	34220		-10.6		-10.0	
Cape Hickey Site 2 Level 3-5	34220		-9.3		-9.6	
		BETA				
Cape Hickey Site 2 Level 4-1	31210	204545	-8.9		-8.4	
Cape Hickey Site 2 Level 4-2	31210		-9.5		-9.2	
Cape Hickey Site 2 Level 4-3	31210		-10.9		-8.2	
Cape Hickey Site 2 Level 4-4	31210		-8.2		-10.0	

Table 2 (continued).

Location	Age	Lab Number	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{13}\text{C}_{\text{org}}$	$\delta^{18}\text{O}_{\text{carb}}$	$\delta^{15}\text{N}_{\text{org}}$
Cape Hickey Site 2 Level 4-5	31210		-12.8		-11.9	
Edmonson Point Site 2 Level 2-4	1320	NZA 21177	-12.3		-6.6	
Edmonson Point Site 2 Level 2-5	1320		-11.9		-6.1	
Inexpressible Island Site 3 Level 3-1	1990		-9.8		-9.5	
Inexpressible Island Site 3 Level 3-2	1990		-8.6	-25.4	-6.7	
Inexpressible Island Site 3 Level 3-4	1990		-9.0	-27.3	-10.5	
Inexpressible Island Site 3 Level 4-1	3305	NZA 20749	-9.0		-9.6	
Inexpressible Island Site 3 Level 4-2	3305		-9.1		-10.2	
Inexpressible Island Site 3 Level 4-3	3305		-9.6		-10.2	
Inexpressible Island Site 3 Level 4-4	3305		-9.5		-9.2	
Inexpressible Island Site 3 Level 5	3325*		-9.5	-26.1	-11.5	
Inexpressible Island Site 3 Level 5-2	3325		-10.3		-10.0	
Inexpressible Island Site 3 Level 5-3	3325		-10.0		-9.4	
Inexpressible Island Site 3 Level 5-4	3325		-10.3		-9.9	
Inexpressible Island Site 3 Level 5-5	3325		-9.8		-10.9	
Inexpressible Island Site 3 Level 6-1	3340	NZA 20750	-10.4		-10.1	
Inexpressible Island Site 3 Level 6-2	3340		-10.8		-10.6	
Inexpressible Island Site 3 Level 6-3	3340		-10.6		-9.6	
Inexpressible Island Site 3 Level 6-4	3340		-10.5		-10.3	
Inexpressible Island Site 3 Level 6-5	3340		-9.1		-10.6	
Inexpressible Island Site 3 Level 7-1	2840	NZA 21156	-9.6		-11.4	
Inexpressible Island Site 3 Level 7-2	2840		-11.6		-11.0	
Inexpressible Island Site 3 Level 7-3	2840		-8.8		-7.0	
Inexpressible Island Site 3 Level 7-4	2840		-10.4		-10.4	

Table 2 (continued)

Location	Age	Lab Number	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{13}\text{C}_{\text{org}}$	$\delta^{18}\text{O}_{\text{carb}}$	$\delta^{15}\text{N}_{\text{org}}$
Inexpressible Island Site 3 Level 7-5	2840		-9.3		-10.2	
Prior Island Site 1 Level 3-1	3450	NZA 20958				12.8
Prior Island Site 1 Level 3-2	3450		-9.6	-26.3	-9.8	12.3
Prior Island Site 1 Level 3-3	3450			-25.1		13.2
Prior Island Site 1 Level 3-4	3450			-26.1		11.2
Prior Island Site 1 Level 3-5	3450			-25.4		12.5
<u>East Antarctica</u>						
Casey Site 15 Level 2	3155	NZA 18075	-11.9	-28.0	-4.6	12.2
Casey Site 15 Level 2	3155		-12.6	-27.4	-4.3	10.9
Casey Site 15 Level 6	3365 <sup>†</sup>	NZA 17711	-12.4		-5.2	
Casey Site 15 Level 6	3365		-12.8		-5.1	
Casey Site 15 Level 9	8925 <sup>†</sup>	NZA 17710	-12.4		-5.2	
Casey Site 15 Level 9	8925		-9.4	-26.1	-5.1	
Casey Site 17 Level 2	3075	NZA 18076	-10.4	-26.6	-6.5	11.8
Casey Site 17 Level 2	3075		-12.2	-28.0	-6.4	13.0
Casey Site 17 Level 3	3140	NZA 18035	-11.4	-26.6	-6.6	11.0
Casey Site 17 Level 3	3140		-11.4	-26.7	-6.8	12.2
Casey Site 17 Level 7	8690 <sup>†</sup>	NZA 17712	-10.5		-7.2	
Casey Site 17 Level 7	8690		-10.6	-28.2	-7.6	
Casey Site 30 Level 6	8290 <sup>†</sup>	NZA 17696	-10.6		-6.9	
Casey Site 30 Level 9	8715 <sup>†</sup>	NZA 17695	-12.0	-27.73	-6.6	
Casey Site 30 Level 10	8915 <sup>†</sup>	NZA 17694	-11.0		-5.7	
Casey Site 30 Level 10	8915		-10.0		-6.9	
Casey Site 35 Level 2	6540	NZA 17802	-12.4	-27.4	-6.5	

Table 2 (continued).

Location	Age	Lab Number	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{18}\text{O}_{\text{carb}}$	$\delta^{15}\text{N}_{\text{org}}$	
Casey Site 35 Level 3a	6810*		-10.0	-26.4	-7.2	
Casey Site 35 Level 3b	6810		-11.3	-26.3	-6.7	
Casey Site 35 Level 4	7080	NZA 17699	-10.7	-26.7	-6.2	
Casey Site 35 Level 4	7080		-12.4	-25.9	-7.6	
Casey Site 35 Level 5	7660 <sup>†</sup>	NZA 17690	-12.5		-6.5	
Casey Site 35 Level 5	7660		-11.8	-27.7	-6.6	
Casey Site 35 Level 6a	7575*		-12.9	-26.6	-7.1	
Casey Site 35 Level 6b	7575		-11.8	-28.3	-7.4	13.6
Casey Site 35 Level 7	7500 <sup>†</sup>	NZA 17692	-12.0		-6.4	
Casey Site 35 Level 7	7500		-12.9	-27.8	-7.0	
Casey Site 35 Level 8	8025 <sup>†</sup>	NZA 17691	-11.3	-28.5	-7.6	14.1
Casey Site 44 Level 2	6855	NZA 17805	-11.8	-25.7	-6.3	
Casey Site 44 Level 2	6855		-11.4	-26.7	-5.7	
Casey Site 44 Level 4	7460 <sup>†</sup>	NZA 17709	-11.5	-29.5	-7.9	
Casey Site 44 Level 7	7640 <sup>†</sup>	NZA 17708	-12.7		-7.2	
Casey Site 44 Level 7	7640		-12.7	-26.9	-6.9	
Casey Site 44 Level 8	8790	NZA 17697	-11.8		-6.7	
Casey Site 44 Level 8	8790		-10.7	-26.4	-6.3	
Casey Site 61 Level 3	7490 <sup>†</sup>	NZA 17689	-11.0		-7.6	
Casey Site 61 Level 3	7490		-10.7	-26.3	-5.2	
Casey Site 61 Level 4	7025 <sup>†</sup>	NZA 17688	-10.9		-7.5	
Casey Site 61 Level 4	7025		-10.3	-26.6	-5.5	12.1
Casey Site 61 Level 5a	7340*		-12.0		-5.5	



Table 2 (continued).

Location	Age	Lab Number	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{13}\text{C}_{\text{org}}$	$\delta^{18}\text{O}_{\text{carb}}$	$\delta^{15}\text{N}_{\text{org}}$
Casey Site 61 Level 5b	7340		-8.6	-26.7	-5.4	
Casey Site 61 Level 6a	7340*		-11.9	-26.8	-6.4	12.6
Casey Site 61 Level 6b	7340		-11.4	-27.2	-5.7	
Casey Site 61 Level 7	7660 <sup>†</sup>	NZA 17687	-11.6		-7.3	
Casey Site 61 Level 8	7635 <sup>†</sup>	NZA 17686	-13.4	-27.0	-6.0	
Casey Site 61 Level 8	7635		-11.5		-7.4	
Casey Site 66 Level 4	2060	NZA 18037	-7.0	-27.0	-7.8	
Casey Site 66 Level 4	2060		-9.1	-25.3	-5.6	
Casey Site 66 Level 5	2095	NZA 18078	-11.6	-27.8	-7.4	
Casey Site 66 Level 5	2095		-9.5	-27.3	-7.6	
Casey Site 69 Level 4	5555		-11.3	-27.8	-6.5	
Casey Site 69 Level 5	7235	NZA 17804	-12.2		-6.6	
Casey Site 75 Level 5	5890	NZA 17803	-10.5	-25.6	-6.6	
Casey Site 78 Level 1	4385	NZA 17682	-11.3	-27.7	-4.7	11.6
Casey Site 78 Level 3	4440	NZA 17683	-12.1	-27.6	-4.6	
Casey Site 78 Level 5	4435	NZA 17698	-11.4	-27.1	-5.0	
Casey Site 78 Level 6	5460	NZA 17684	-11.7		-5.8	
Casey Site 80 Level 2	4060	NZA 18036	-12.1	-27.0	-6.0	
Casey Site 80 Level 3	3850	NZA 18077	-12.9	-27.1	-5.0	
Casey Site 80 Level 3	3850		-12.2	-27.4	-6.6	
Casey Site 80 Level 4	4405 <sup>†</sup>	NZA 17713	-12.3		-7.2	
Casey Site 80 Level 4	4405		-13.9	-27.2	-6.1	
Peterson Site 1 Level 4	265	NZA 18038	-11.5		-5.4	-26.3
Peterson Site 3 Level 8	1315	NZA 18080	-11.4		-7.7	-28.0

Table 2 (continued).

Location	Age	Lab Number	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{13}\text{C}_{\text{org}}$	$\delta^{18}\text{O}_{\text{carb}}$	$\delta^{15}\text{N}_{\text{org}}$
<u>Antarctic Peninsula</u>						
King George Island Site 2 Level 3-1	410	NZA 15290	-13.2		-4.3	
King George Island Site 2 Level 3-2	410		-13.2		-3.5	
King George Island Site 2 Level 3-3	410		-12.6		-2.7	
King George Island Site 2 Level 3-4	410		-12.6		-3.6	
King George Island Site 2 Level 3-5	410		-12.9		-1.7	
King George Island Site 3 Level 3-1	385	NZA 15295	-12.1		-3.2	
King George Island Site 3 Level 3-2	385		-14.8		-4.0	
King George Island Site 3 Level 3-3	385		-12.6		-3.4	
King George Island Site 3 Level 3-4	385		-12.2		-3.2	
King George Island Site 3 Level 3-5	385		-12.7		-4.9	
		BETA				
Lagoon Island Site 2 Level 2-1	770	141907	-10.0		-6.9	
Lagoon Island Site 2 Level 2-2	770		-10.0		-5.4	
Lagoon Island Site 2 Level 2-3	770		-8.7		-5.9	
Lagoon Island Site 2 Level 2-4	770		-10.2		-7.2	
Lagoon Island Site 2 Level 2-5	770		-9.1		-6.2	
		BETA				
Lagoon Island Site 2 Level 4-1	3615	141909	-9.3		-4.2	
Lagoon Island Site 2 Level 4-3	3615		-9.0		-5.9	
Lagoon Island Site 2 Level 4-4	3615		-9.9		-6.1	
		BETA				
Lagoon Island Site 3 Level 5-1	5745	141916	-10.2		-3.8	

Table 2 (continued).

Location	Age	Lab Number	$\delta^{13}\text{C}_{\text{carb}}$	$\delta^{13}\text{C}_{\text{org}}$	$\delta^{18}\text{O}_{\text{carb}}$	$\delta^{15}\text{N}_{\text{org}}$
Lagoon Island Site 3 Level 5-2	5745		-8.8		-4.8	
Lagoon Island Site 3 Level 5-3	5745		-9.4		-5.7	
Lagoon Island Site 3 Level 5-5	5745		-10.0		-6.1	
BETA						
Ginger Island TP1 Level 4-1	510	141905	-16.0		-6.8	
Ginger Island TP1 Level 4-2	510		-13.8		-5.3	
Ginger Island TP1 Level 4-3	510		-11.5		-4.7	
Ginger Island TP1 Level 4-4	510		-17.4		-5.7	
Ginger Island TP1 Level 4-5	510		-11.8		-4.4	