

**Oman corals suggest that a stronger winter shamal season caused the Akkadian Empire (Mesopotamia) collapse**

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### **Analytical method**

We analyzed  $\delta^{18}\text{O}_{\text{coral}}$  in fossil corals with 20–40 µg coral skeletons using stable isotope ratio mass spectrometry (MAT253) and an automated carbonate preparation device (KIEL IV). The analytical precision of  $\delta^{18}\text{O}_{\text{coral}}$  was 0.05‰. We measured Sr/Ca using an inductively coupled plasma optical emission spectrophotometer (iCAP6200). The fossil coral powders weighed in *ca.* 150 µg were dissolved with 25% HNO<sub>3</sub>. Sample solutions for Sr/Ca measurement were diluted to Ca concentrations of 15 ppm. The analytical precision of Sr/Ca was less than 0.06 mmol/mol ( $1\sigma$ ). We estimated  $\delta^{18}\text{O}_{\text{SW}}$  by subtracting the SST contribution inferred from Sr/Ca from  $\delta^{18}\text{O}_{\text{coral}}$  following Ren et al. (2003). We used the SST dependency of Sr/Ca calculated from our modern coral (-0.044 mmol/mol × °C<sup>-1</sup>: Watanabe et al., 2017) and the published  $\delta^{18}\text{O}_{\text{coral}}\text{-SST}$  slope (-0.18‰<sub>VPDB</sub> × °C<sup>-1</sup>: Gagan et al., 1998) for estimations of  $\delta^{18}\text{O}_{\text{SW}}$ . The error of  $\delta^{18}\text{O}_{\text{SW}}$  ( $1\sigma$ ) was 0.12‰<sub>VSMOW</sub>, calculated following Nurhati et al. (2011).

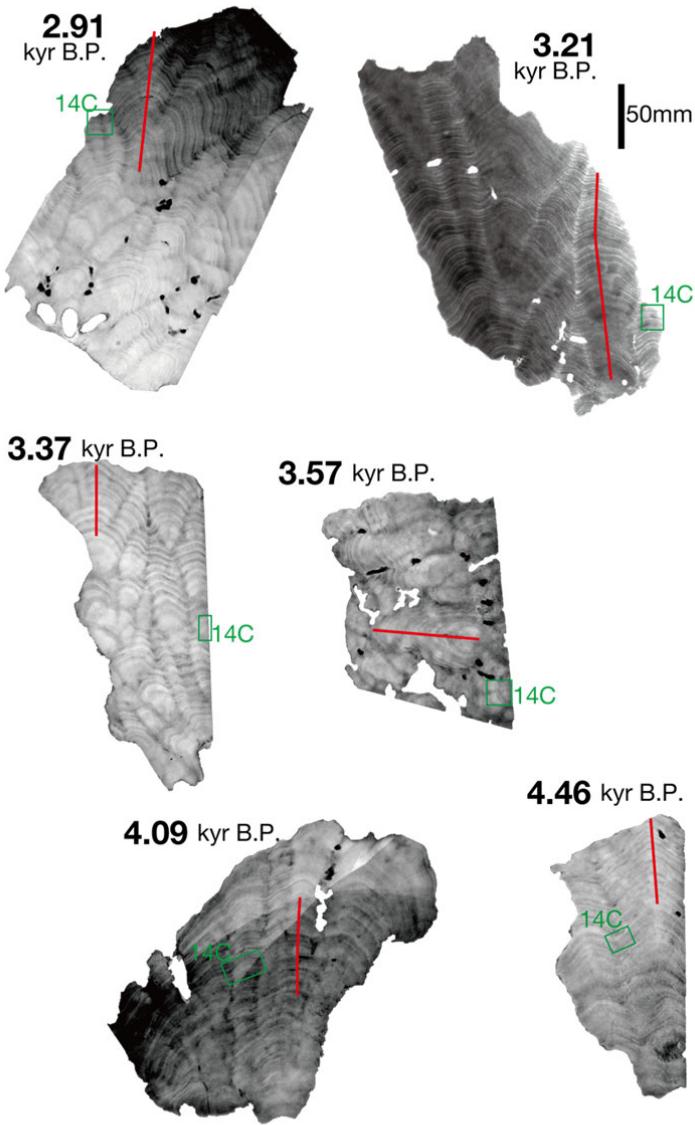


Figure DR1

X-ray image of Omani fossil corals. Age results of fossil corals are showed on TableDR2.

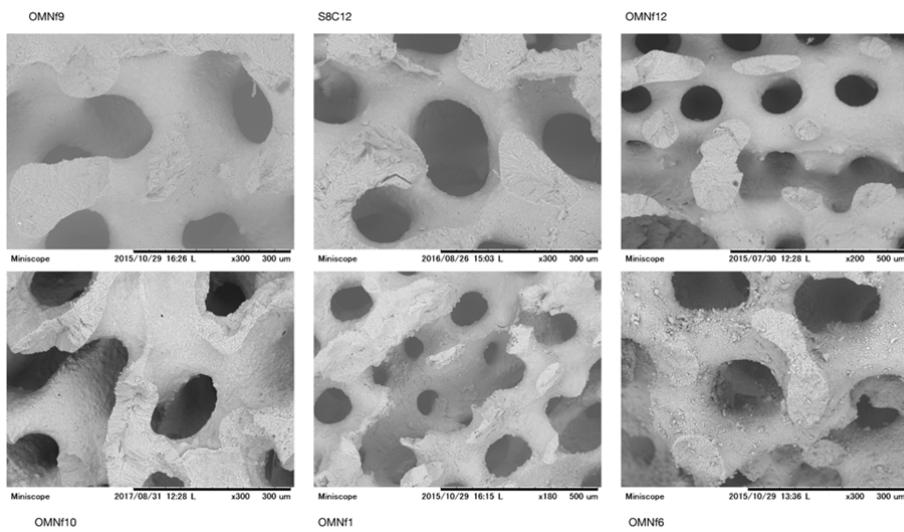


Figure DR2

SEM figures of fossil corals from Oman. Black bar shows scale.

**Table DR1-** Descriptions and sampling intervals of modern and fossil corals from Oman.

	Age (kyr B.P.)	Number of annual cycles	Diagenetic condition <sup>a</sup>	Sampling resolution (mm/sample)
OMN130221	0	26	-	0.5
OMNf-9	2.91	5	excellent	0.4
S8C12	3.21	8	excellent	0.2
OMNf-12	3.37	6	excellent	0.4
OMNf-10	3.57	4	good	0.4
OMNf-1	4.09	4	fair	0.9
OMNf-6	4.46	6	fair	0.4

a: Diagenetic condition assessed using SEM photos of fossil corals, following the Cobb et al. (2013). Guidelines: 'excellent' = little to no evidence of diagenetic alteration, 'good' = pervasive evidence of minor alteration, 'fair' = isolated evidence of major alteration.

**Table DR2-** Radiocarbon results in fossil corals from Oman.

Sample	Raw <sup>14</sup> C age (kyr B.P.)	Std Dev. (kyr B.P.)	Local reservoir corrected (kyr B.P.) <sup>a</sup>	Calendar age (kyr B.P.) <sup>b</sup>	Std Dev. (kyr B.P.)
OMNf9	3.70	0.02	3.14	2.91	0.04
S8C12	3.92	0.02	3.36	3.21	0.05
OMNf12	4.05	0.02	3.49	3.37	0.03
OMN10	4.22	0.02	3.66	3.57	0.04
OMNf1	4.61	0.02	4.05	4.09	0.05
OMNf6	4.89	0.02	4.33	4.46	0.04

a: Local reservoir effect was corrected by following Cullen et al. (2000). b: Calendar age were determined following to Marine13 program using OxCal software.

**Table DR3-** Analytical results of coral proxy

	$\delta^{18}\text{O}_{\text{coral}}$ anomaly ( $\text{\textperthousand}_{\text{VPDB}}$ )			Sr/Ca anomaly (mmol/mol)			$\delta^{18}\text{O}_{\text{sw}}$ anomaly ( $\text{\textperthousand}_{\text{VSMOW}}$ )		
	Max.	min	Seasonal amplitude	Max.	Min.	Seasonal amplitude	Max.	Min.	Seasonal amplitude
<b>OMN130221</b>	0.408	0.383	0.791	0.147	-0.127	0.274	0.18	-0.10	0.28
<b>OMNf-9</b>	0.346	-0.435	0.781	0.186	-0.120	0.306	0.27	-0.27	0.53
<b>S8C12</b>	0.452	-0.450	0.902	0.207	-0.106	0.313	0.13	-0.19	0.32
<b>OMNf-12</b>	0.374	-0.359	0.733	0.187	-0.104	0.291	0.18	-0.25	0.43
<b>OMNf-10</b>	0.384	-0.263	0.647	0.201	-0.103	0.304	0.19	-0.29	0.48
<b>OMNf-1</b>	0.777	-0.656	1.433	0.313	-0.215	0.528	0.96	-1.03	1.99
<b>OMNf-6</b>	0.466	-0.411	0.877	0.218	-0.130	0.348	0.29	-0.36	0.65

**Table DR4** Results of one-way analysis of variance on coral proxies among before, during and after 4.09 kyr B.P. \*\* symbol shows  $P$  value  $< 0.01$ .

	Degrees of freedom	Sums of squares	Means square	F value	P value
Sr/Ca	Factor	2	0.21	0.11	5.61 <b>0.005**</b>
	Error	98	1.86	0.02	
	Total	100	2.08		
$\delta^{18}\text{O}_{\text{c}}$	Factor	2	0.13	0.07	0.80 0.451
	Error	98	7.98	0.08	
	Total	102	8.11		
$\delta^{18}\text{O}_{\text{sw}}$	Factor	2	2.48	1.24	5.81 <b>0.004**</b>
	Error	98	20.87	0.21	
	Total	100	23.34		

**Table DR5-** Results of regression analysis between winter modern coral records and wind speed or Shamal days (days with over 8.75 m/second wind speed).

	$\delta^{18}\text{O}_{\text{coral}}$	Sr/Ca	$\delta^{18}\text{O}_{\text{sw}}$
<b>Shamal days</b>	0.707**	0.777**	-0.562**

Correlation coefficient ( $r$ ) was shown on the table. The combinations with \* symbol and \*\*symbol shows P-value  $< 0.05$  and  $< 0.01$  respectively.

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