

The Ability of Trimethylamine N-oxide (TMAO) to Resist the Chemically Induced Pressurisation of Water by $\text{Mg}(\text{ClO}_4)_2$: Terrestrial Kosmotrope vs Martian Chaotrope – Supporting Information

Pressure as a function of TMAO concentration derivation

The expression for TMAO concentration in molality (mmol of TMAO per kg of wet muscle tissue) is given as:

$$[\text{TMAO}] = 62.1 + 0.0429 \times \text{depth} \quad (1)$$

The concentration in molality must first be converted to a molarity. As molality is defined as the number of moles of a solute per 1000 g of solvent, the mass of a solution in grams m of molality x is therefore:

$$m = xM_s + 1000 \quad (2)$$

M_s = Molar mass of solute = 75.11 g/mol for TMAO

We now assume the density of solution is independent of TMAO concentration and stays fixed at the value for pure water, $\rho = 1000$ g/L. Hence the volume in litres V of the mass m described above is:

$$V = \frac{m}{\rho} = \frac{75.11x + 1000}{1000} \quad (3)$$

The molarity M is now defined as the number of moles of solute, equivalent to x , per unit volume. Hence:

$$M = \frac{x}{V} = \frac{1000x}{75.11x + 1000} \quad (4)$$

Rearranging this to make the concentration in molality x the subject then yields:

$$x = \frac{1000M}{1000 - 75.11M} \quad (5)$$

As the expression (1) for TMAO concentration as a function of depth is given in mmol/kg, the concentration can be substituted for expression (5) multiplied by a factor of 1000.

$$\frac{M \times 10^6}{1000 - 75.11M} = 62.1 + 0.0429 \times \text{depth} \quad (6)$$

We must now convert the depth to an equivalent pressure. It is known that a 10 m increase in ocean depth is equivalent to an increase in pressure P of 1 atm (=1.01325 bar). Hence we can say that at a given depth in meters the pressure in bar is equal to the atmospheric pressure at sea level plus the added pressure associated with the depth:

$$P = 1.01325 + 0.101325 \times \text{depth} \quad (7)$$

Rearranging this expression to make depth the subject means it can be substituted into expression (6).

$$\frac{M \times 10^6}{1000 - 75.11M} = 62.1 + 0.0429 \left[\frac{P - 1.01325}{0.101325} \right] \quad (8)$$

This expression can then be rearranged to make P the subject to yield the expression found in figure 2 of the main text which gives the pressure in bar P as a function of TMAO concentration in molarity M .

$P = \left[\frac{M \times 10^6}{1000 - 75.11M} - 62.1 \right] \left[\frac{0.101325}{0.0429} \right] + 1.01325$	(9)
--	-----

List S1. Samples list with isotopic makeup

- H₂O
- D₂O
- HDO
- H₂O, 1.0 M H-TMAO
- D₂O, 1.0 M H-TMAO
- HDO, 1.0 M H-TMAO
- H₂O, 1.0 M D-TMAO
- D₂O, 1.0 M D-TMAO
- HDO, 1.0 M D-TMAO
- HDO, 1.0 M HD-TMAO
- H₂O, 0.2 M Mg(ClO₄)₂
- D₂O, 0.2 M Mg(ClO₄)₂
- HDO, 0.2 M Mg(ClO₄)₂
- H₂O, 1.0 M H-TMAO, 0.2 M Mg(ClO₄)₂
- D₂O, 1.0 M H-TMAO, 0.2 M Mg(ClO₄)₂
- HDO, 1.0 M H-TMAO, 0.2 M Mg(ClO₄)₂
- H₂O, 1.0 M D-TMAO, 0.2 M Mg(ClO₄)₂
- D₂O, 1.0 M D-TMAO, 0.2 M Mg(ClO₄)₂
- HDO, 1.0 M D-TMAO, 0.2 M Mg(ClO₄)₂
- HDO, 1.0 M HD-TMAO, 0.2 M Mg(ClO₄)₂
- H₂O, 2.7 M Mg(ClO₄)₂
- D₂O, 2.7 M Mg(ClO₄)₂
- HDO, 2.7 M Mg(ClO₄)₂
- H₂O, 1.0 M H-TMAO, 2.7 M Mg(ClO₄)₂
- D₂O, 1.0 M H-TMAO, 2.7 M Mg(ClO₄)₂
- HDO, 1.0 M H-TMAO, 2.7 M Mg(ClO₄)₂
- H₂O, 1.0 M D-TMAO, 2.7 M Mg(ClO₄)₂
- D₂O, 1.0 M D-TMAO, 2.7 M Mg(ClO₄)₂
- HDO, 1.0 M D-TMAO, 2.7 M Mg(ClO₄)₂
- HDO, 1.0 M HD-TMAO, 2.7 M Mg(ClO₄)₂

Atomic species	ϵ (kJ/mol)	σ (Å)	Charge (e)
O _w	0.65	3.166	-0.8476
H _w	0.00	0.00	0.4238
C1	0.39	3.70	-0.2600
H1	0.065	1.80	0.1100
N1	0.711	3.25	0.4400
O1	0.585	3.08	-0.6500
Mg	0.4593	0.90	2.0000
Cl _p	0.566	4.19	2.3904
O _p	0.65	3.166	-0.8476

Table S1. Lennard-Jones and Coulomb parameters for atomic species present in simulation. W subscript indicates water atoms, 1 indicates TMAO, p indicates perchlorate ion

Sample	Water Molecules	TMAO Molecules	Mg ²⁺ ions	ClO ₄ ⁻ ions	Box dimension (Å)
H ₂ O	1000	-	-	-	31.0723
1.0 M TMAO	4104	80	-	-	51.0434
0.2 M Mg(ClO ₄) ₂	4104	-	16	32	49.9840
1.0 M TMAO, 0.2 M Mg(ClO ₄) ₂	4104	80	16	32	51.2654
2.7 M Mg(ClO ₄) ₂	4224	-	260	520	54.4902
1.0 M TMAO, 2.7 M Mg(ClO ₄) ₂	4224	80	260	520	55.5774

Table S2. Number of molecules used in each simulation box and length of cubic box

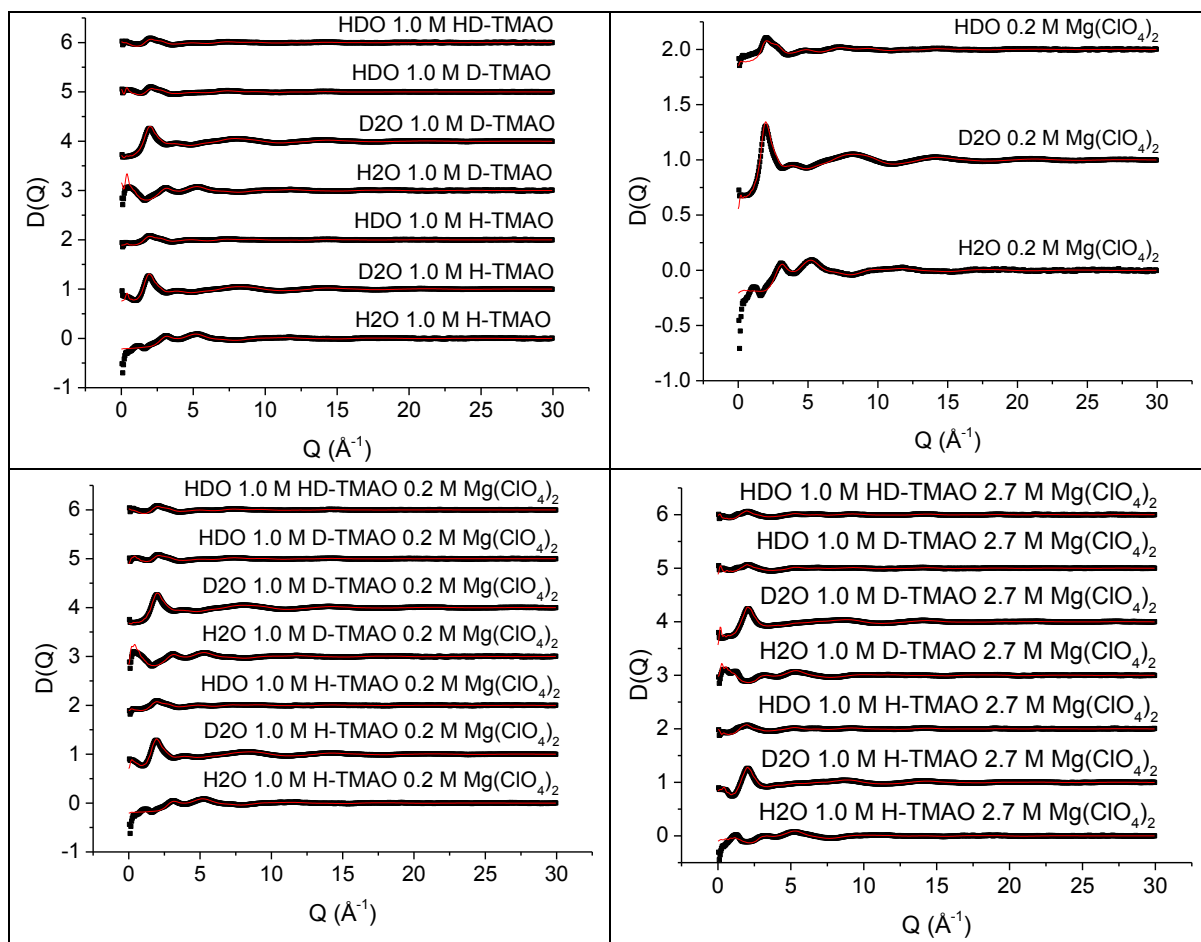


Figure S1. EPSR fits (red lines) to corrected diffraction data (black points) for 1.0 M TMAO (top left), 0.2 M $\text{Mg}(\text{ClO}_4)_2$ (top right), 1.0 M TMAO + 0.2 M $\text{Mg}(\text{ClO}_4)_2$ (bottom left), 1.0 M TMAO + 2.7 M $\text{Mg}(\text{ClO}_4)_2$ (bottom right). Other two samples EPSR fits found in main text.

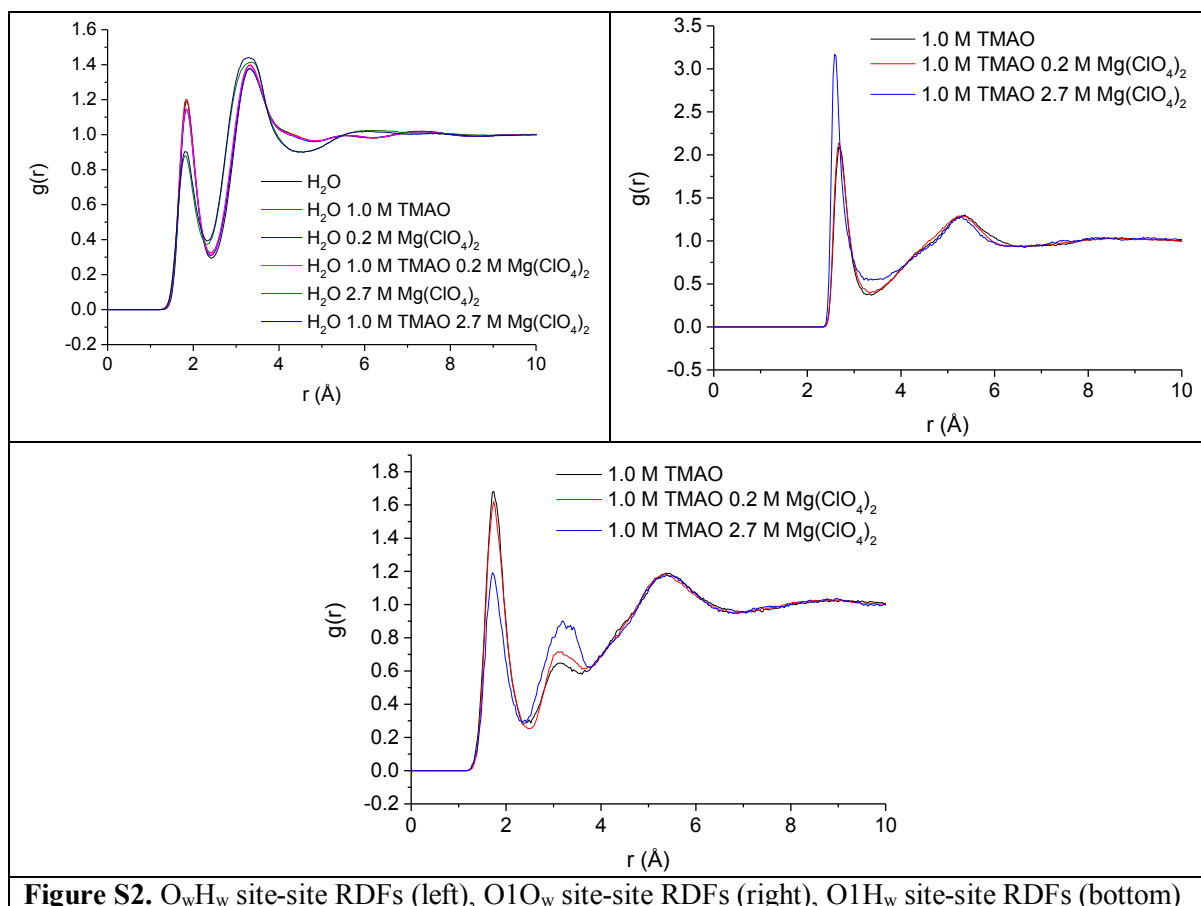


Figure S2. O_wH_w site-site RDFs (left), $O1O_w$ site-site RDFs (right), $O1H_w$ site-site RDFs (bottom)

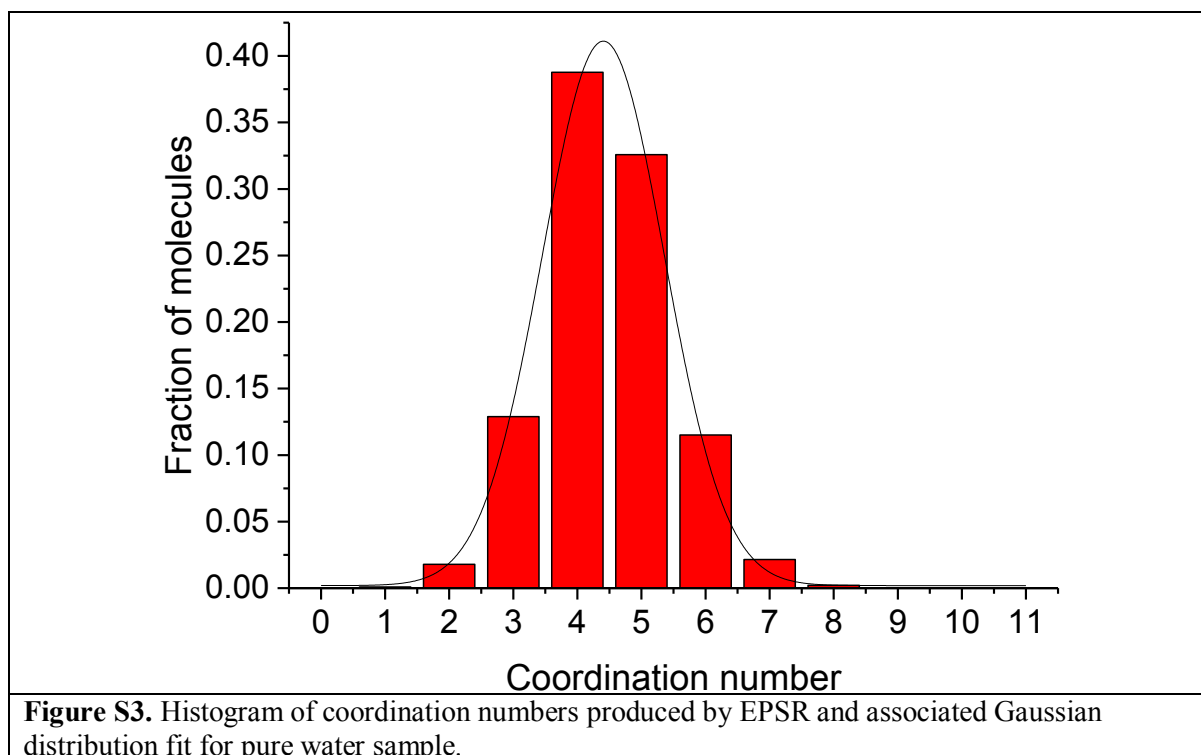


Figure S3. Histogram of coordination numbers produced by EPSR and associated Gaussian distribution fit for pure water sample.

Sample	r_0 (Å)	r_1 (Å)	Coordination number
H ₂ O	2.00	3.33	4.41 ± 0.02
1.0 M TMAO	2.00	3.36	4.35 ± 0.02
0.2 M Mg(ClO ₄) ₂	2.00	3.32	4.39 ± 0.01
1.0 M TMAO, 0.2 M Mg(ClO ₄) ₂	2.00	3.40	4.48 ± 0.02
2.7 M Mg(ClO ₄) ₂	2.00	3.73	5.752 ± 0.009
1.0 M TMAO, 2.7 M Mg(ClO ₄) ₂	2.00	3.83	5.89 ± 0.01

Table S3. Distances used to calculate O_wO_w coordination numbers where r_0 corresponds to a finite distance before the first peak begins and r_1 corresponds to the location of the first minima. Uncertainties on coordination number are statistical uncertainties associated with fitting a Gaussian peak to the coordination number distribution calculated by EPSR.

Sample	r_0 (Å)	r_1 (Å)	Coordination number
H ₂ O	1.00	2.44	2.50 ± 0.04
1.0 M TMAO	1.00	2.41	2.42 ± 0.02
0.2 M Mg(ClO ₄) ₂	1.00	2.43	2.46 ± 0.01
1.0 M TMAO, 0.2 M Mg(ClO ₄) ₂	1.00	2.42	2.35 ± 0.01
2.7 M Mg(ClO ₄) ₂	1.00	2.32	1.69 ± 0.01
1.0 M TMAO, 2.7 M Mg(ClO ₄) ₂	1.00	2.33	1.72 ± 0.01

Table S4. Distances used to calculate O_wH_w coordination numbers where r_0 corresponds to a finite distance before the first peak begins and r_1 corresponds to the location of the first minima. Uncertainties on coordination number are statistical uncertainties associated with fitting a Gaussian peak to the coordination number distribution calculated by EPSR.

Sample	r_0 (Å)	r_1 (Å)	Coordination number
1.0 M TMAO	2.00	3.32	2.60 ± 0.01
1.0 M TMAO, 0.2 M Mg(ClO ₄) ₂	2.00	3.39	2.811 ± 0.009
1.0 M TMAO, 2.7 M Mg(ClO ₄) ₂	2.00	3.52	3.03 ± 0.03

Table S5. Distances used to calculate O₁O_w coordination numbers where r_0 corresponds to a finite distance before the first peak begins and r_1 corresponds to the location of the first minima. Uncertainties on coordination number are statistical uncertainties associated with fitting a Gaussian peak to the coordination number distribution calculated by EPSR.

Sample	r_0 (Å)	r_1 (Å)	Coordination number
1.0 M TMAO	1.00	2.39	2.3186 ± 0.0005
1.0 M TMAO, 0.2 M Mg(ClO ₄) ₂	1.00	2.47	2.44 ± 0.01
1.0 M TMAO, 2.7 M Mg(ClO ₄) ₂	1.00	2.35	1.0 ± 0.3

Table S6. Distances used to calculate O₁H_w coordination numbers where r_0 corresponds to a finite distance before the first peak begins and r_1 corresponds to the location of the first minima. Uncertainties on coordination number are statistical uncertainties associated with fitting a Gaussian peak to the coordination number distribution calculated by EPSR.

Sample	Average Number of Water Molecules Hydrogen Bonded to a Central Water Molecule
Pure H ₂ O	3.412 ± 0.004
1.0 M TMAO	3.232 ± 0.005
2.7 M Mg(ClO ₄) ₂	2.005 ± 0.002
1.0 M TMAO, 2.7 M Mg(ClO ₄) ₂	2.052 ± 0.002
0.2 M Mg(ClO ₄) ₂	3.321 ± 0.004
1.0 M TMAO, 0.2 M Mg(ClO ₄) ₂	3.330 ± 0.002

Table S7. Average number of water molecules hydrogen bonded to a central molecule

Sample	Average Number of Water Molecules Hydrogen Bonded to a Central TMAO Oxygen
1.0 M TMAO	2.191 ± 0.008
1.0 M TMAO, 0.2 M Mg(ClO ₄) ₂	2.014 ± 0.007
1.0 M TMAO, 2.7 M Mg(ClO ₄) ₂	1.33 ± 0.01

Table S8. Average number of water molecules donating a hydrogen bond to a central TMAO oxygen as calculated using the hydrogen bonding analysis code for all samples.

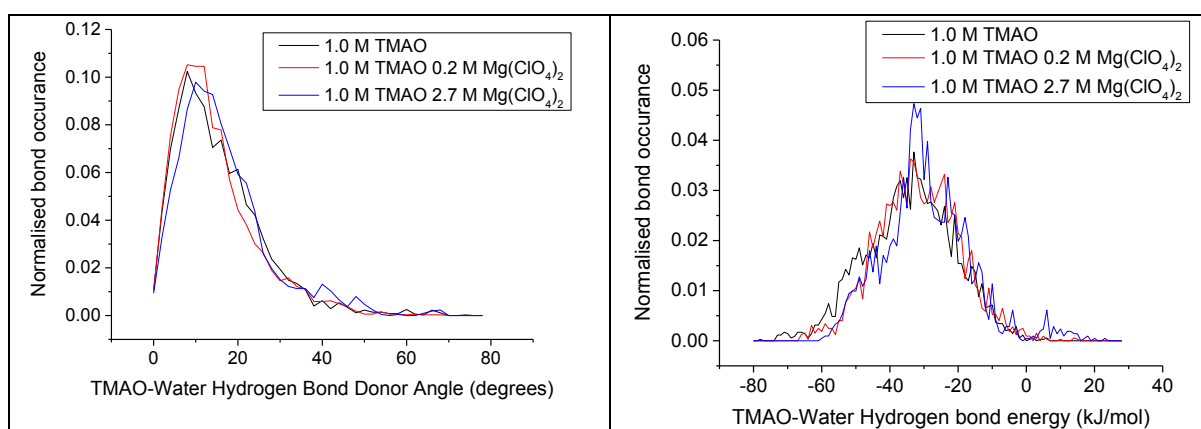
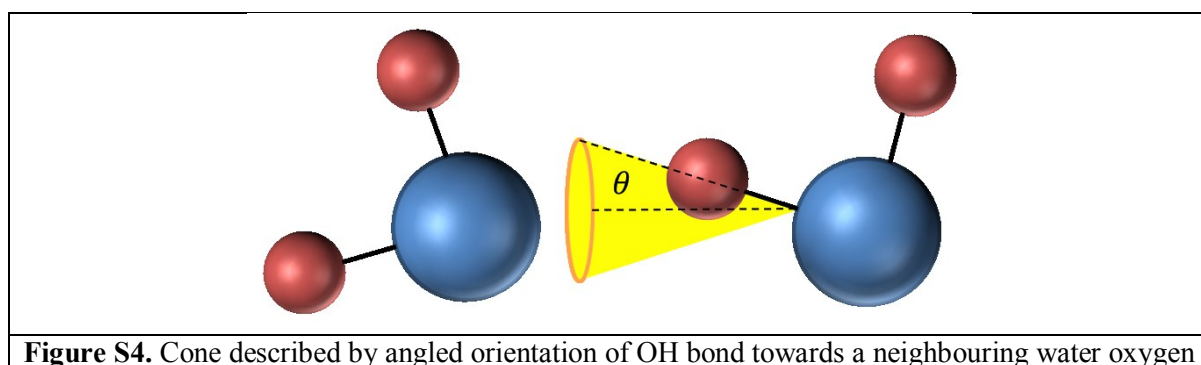


Figure S5. TMAO-water hydrogen bond angle distribution (left) and hydrogen bond energy distribution (right). It can be seen here that as the number of TMAO molecules in the simulation box is much smaller than the number of water molecules the angle and energy distributions are much noisier.

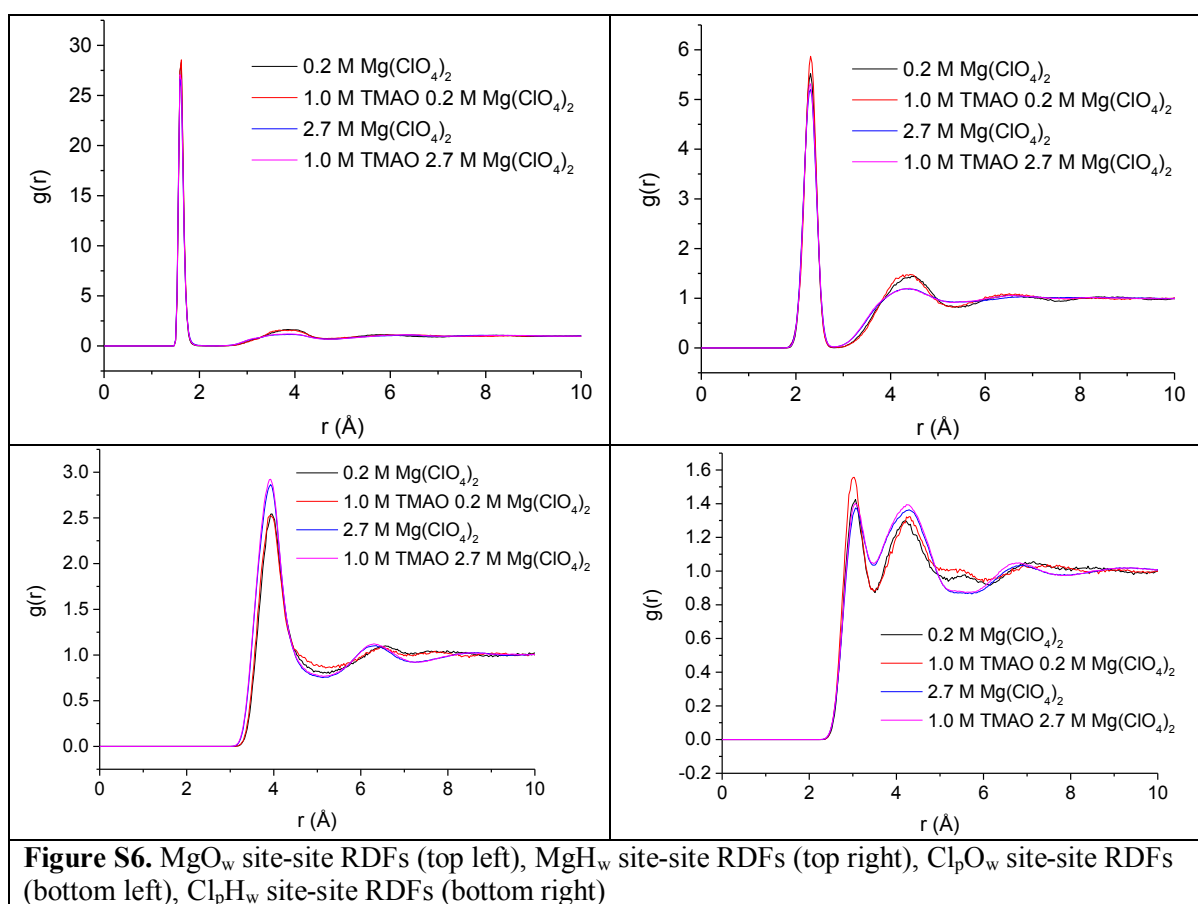


Figure S6. MgO_w site-site RDFs (top left), MgH_w site-site RDFs (top right), Cl_pO_w site-site RDFs (bottom left), Cl_pH_w site-site RDFs (bottom right)

Sample	Peak location (x_c) (degrees)	Peak width (w) (degrees)
Pure H_2O	11.87 ± 0.08	8.0 ± 0.1
1.0 M TMAO	11.61 ± 0.07	8.10 ± 0.09
2.7 M $\text{Mg}(\text{ClO}_4)_2$	13.2 ± 0.1	9.7 ± 0.1
1.0 M TMAO, 2.7 M $\text{Mg}(\text{ClO}_4)_2$	13.1 ± 0.1	9.9 ± 0.2
0.2 M $\text{Mg}(\text{ClO}_4)_2$	11.75 ± 0.07	8.27 ± 0.09
1.0 M TMAO, 0.2 M $\text{Mg}(\text{ClO}_4)_2$	11.46 ± 0.06	7.81 ± 0.07

Table S9. Fitting parameters to water-water hydrogen bond donor angle distributions predicted by equation 2 in main text

Sample	Peak location (x_c)	Peak width (w)
1.0 M TMAO	9.9 ± 0.2	7.6 ± 0.3
1.0 M TMAO, 0.2 M $\text{Mg}(\text{ClO}_4)_2$	9.3 ± 0.1	6.6 ± 0.2
1.0 M TMAO, 2.7 M $\text{Mg}(\text{ClO}_4)_2$	11.2 ± 0.1	7.4 ± 0.2

Table S10. Fitting parameters to TMAO-water hydrogen bond donor angle distributions predicted by equation 2 in main text