Science Day Symposium: Marine Geoengineering

International Maritime Organization

London April 23rd 2015

Strategies for Increasing Ocean Reflectance.

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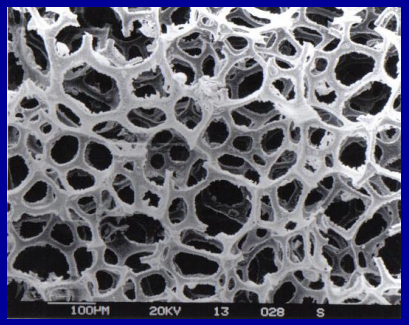
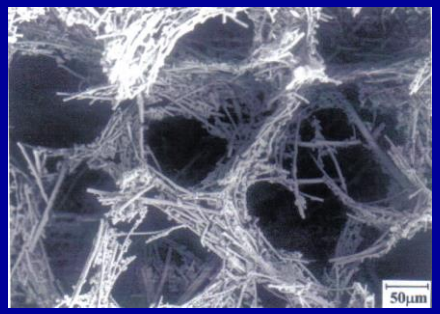
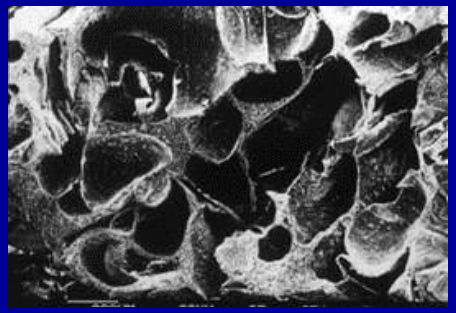


Sintered reticulated titania foam

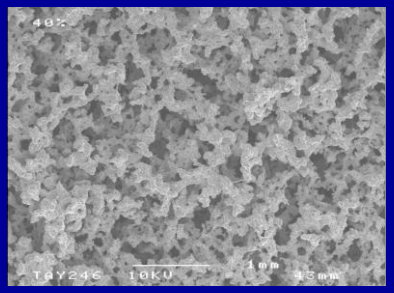


3D array of alumina fibre for metal matrix composites

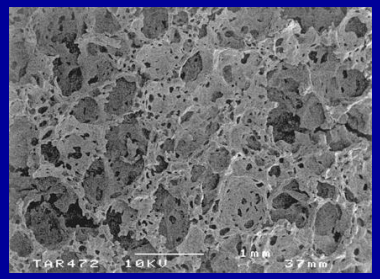
Alumina foam made from egg albumin



Sintered ceramic foam from expansion of cereal starch

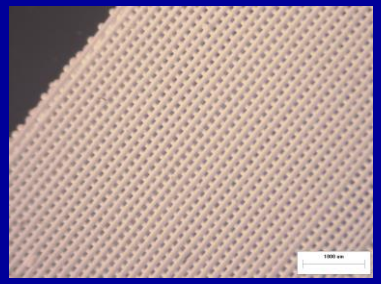


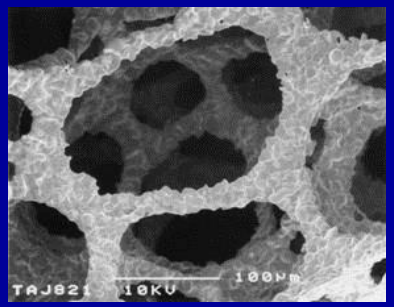
Sintered copper structure of a 91% porosity foam

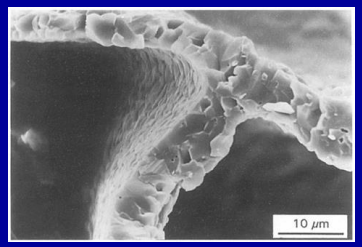


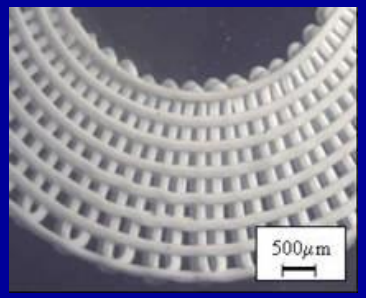
Sintered 92% porous HA foam showing small windows and large connecting passages in the >100 µm region.

Sintered alumina foam mouldings made by the same method as expanded polystyrene.









Porous ceramic for hard tissue scaffolds

Albedo; Ocean ~0.05
Rock~0.01
Grassland 0.15-0.25
Ocean foam 0.4-0.6

Acknowledgements:

Professor Helen Hailes

Professor John Ward

Marianna Devetzoglou

Alex Aziz

Thomas Rowland

Patterns of disease (Disease vector migration)

Extreme weather events

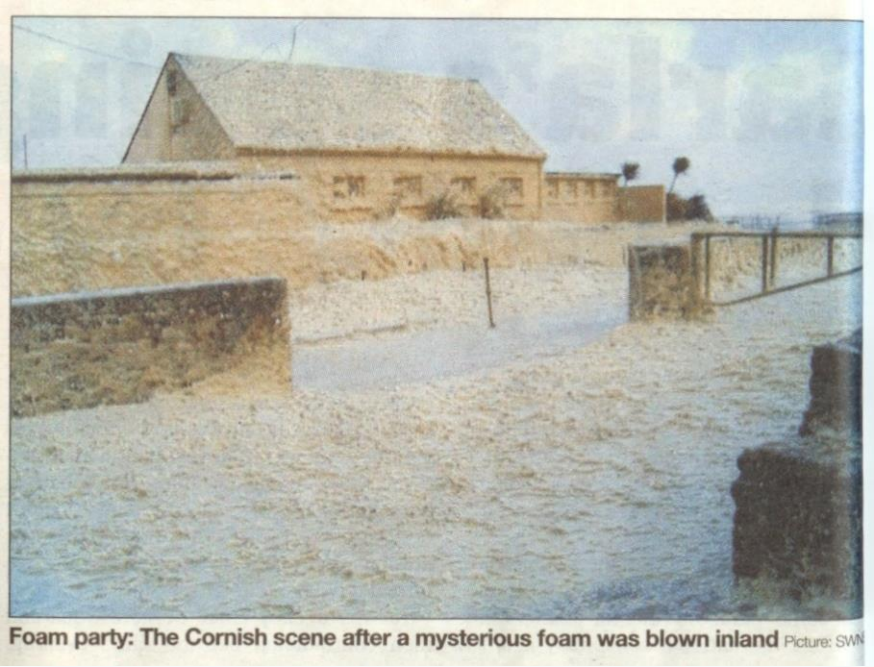
Food insecurity

Water stress and sanitation

Shelter and human settlement

Population and migration

A.Costello and 28 others, Managing the Health Effects of Climate Change, The Lancet 373, (2009), 1693-1733.



Yamba, New South Wales, Australia.

The result of an algal bloom in 2007

Porthtowan, Cornwall, UK, 2010

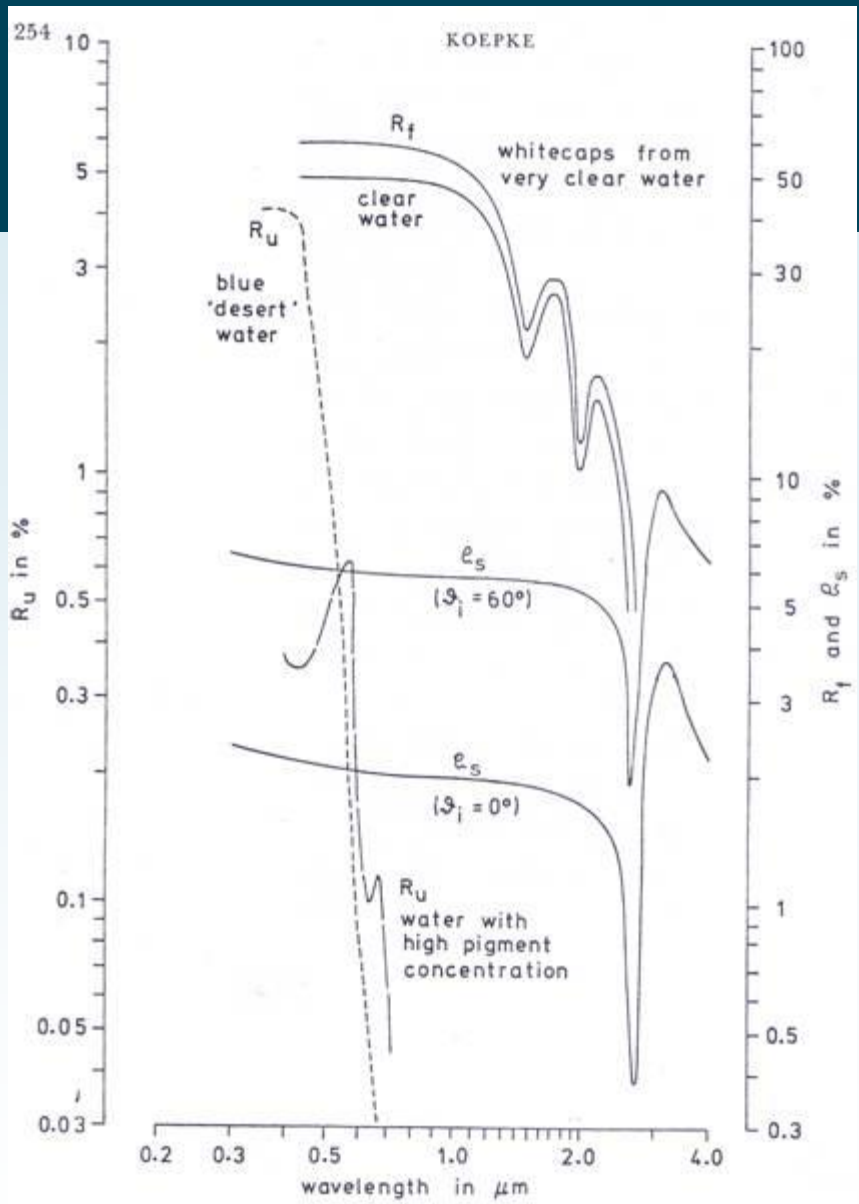
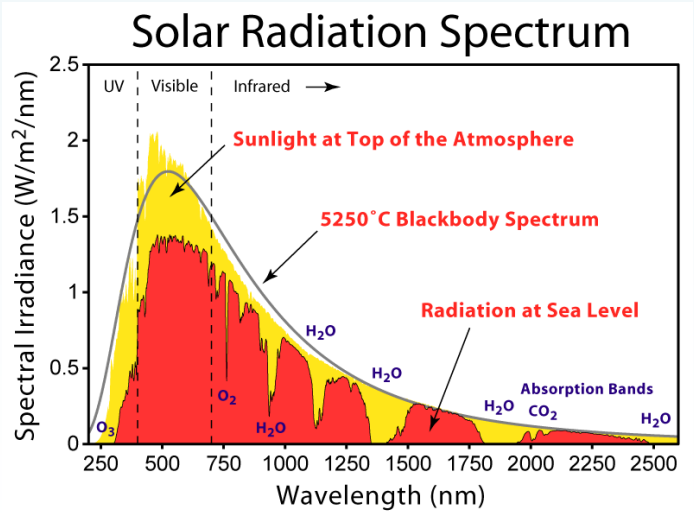


Fig. 2. Spectral reflectance of the components of an ocean surface hemispherical reflectance factor for directional incidence ρ_s of a flat surface, calculated with the Fresnel formula from the refractive index (Irvine and Pollack, 1968), reflectance of foam R_f from clear and very clear water measured by Whitlock (1982) (both right ordinate); and reflectance R_u just above the ocean surface due to underlight for two different water types measured by Morel (1980) (left ordinate).

Reflectance of whitecaps = 0.5-0.6 in the visible falling below 0.1 in the IR

P.Koepke, Remote sensing signalling signatures of whitecaps, Ocean Whitecaps (E.C.Monahan and G.Mac Niocailli (Eds) D.Reidel Publ. 1986, pp. 251-260.



$$W = P_1 V_1 \frac{\gamma}{\gamma - 1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{(\gamma-1)}{\gamma}} - 1\right]$$

Energy needed:

Consider a patch of ocean 1 km x 1 km (10^6 m ^{2}) with foam thickness 10mm. Volume is 10^4 m$^{3.}$
Air is pumped at 34 kPa (5 psi). Energy required 303 MJ or **303 Jm^{-2}**. (30.3 kJm^{-3} of air)

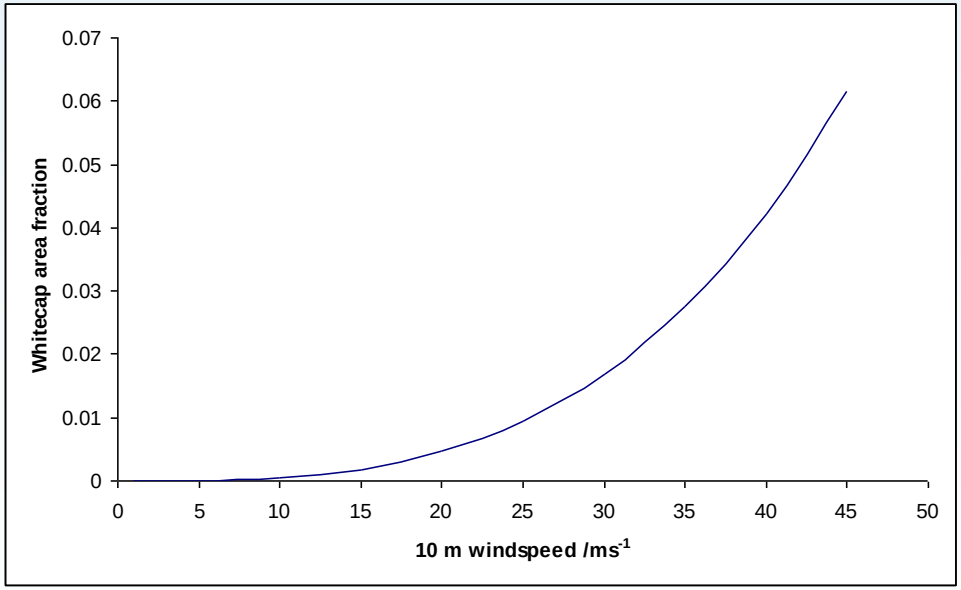
Average power needed:

Suppose the foam is a natural whitecap lasting 300s. Power needed to replenish 10^6 m^2 = 1 MW.

Suppose a modified foam lasts 1 month (2.6 Ms). Power needed to replenish 10^6 m^2 is **120 W**

Ocean whitecap area fraction depends on wind speed:

Area fraction= $3.16 \times 10^{-7}\ U^{3.2}$ (where U is the 10 m wind speed in m/s)



No.	Speed /ms^{-1}	Description
0	0	Calm
1	1-2	Light air
2	2-3	Light breeze
3	4-5	Gentle breeze
4	6-8	Moderate breeze
5	9-11	Fresh breeze
6	11-14	Strong breeze
7	14-17	Near gale
8	17-21	Gale
9	21-24	Severe gale
10	25-28	Storm

Beaufort wind force scale

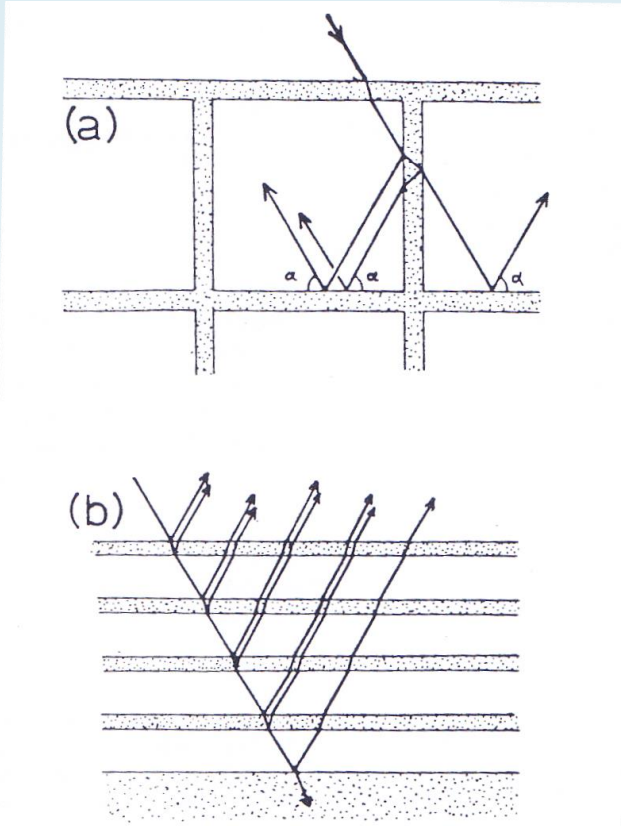


Fig. 1. a) A schematic representation of the bubble structure. The beam of light intersects the surface of the whitecap and each of the horizontal air-water interfaces at an angle α.

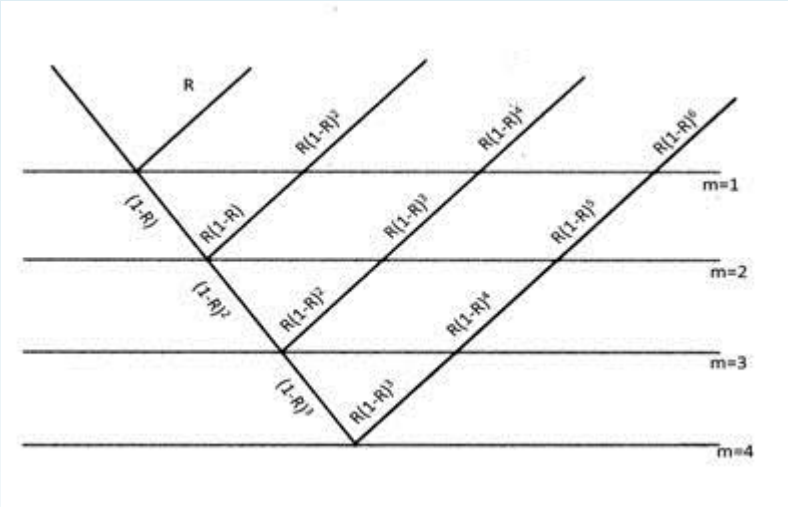
b) The modified structure neglecting the vertical walls. There are four layers of bubbles and hence nine interfaces from which reflectance is possible. The beam undergoes at most one reflection.

Stabeno and Monahan's model

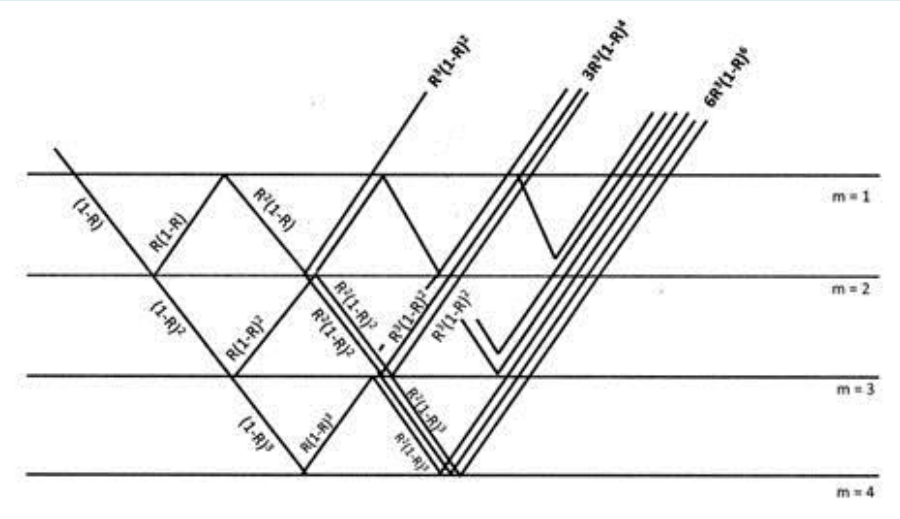
For an infinite number of layers this model gives a reflectance in the visible of 0.62 for water (n=1.33).

P.J.Stabeno, E.C.Monahan, in Ocean Whitecaps, D.Reidel Publ. 1986, pp.261-266.

First reflection



Third reflection



$$^{1}R_{n} = R\sum_{n=1}^{n=N}(1-R)^{2(n-1)}$$

$$^{1}R_{n=\infty} = \frac{1}{2-R} \quad =0.53$$

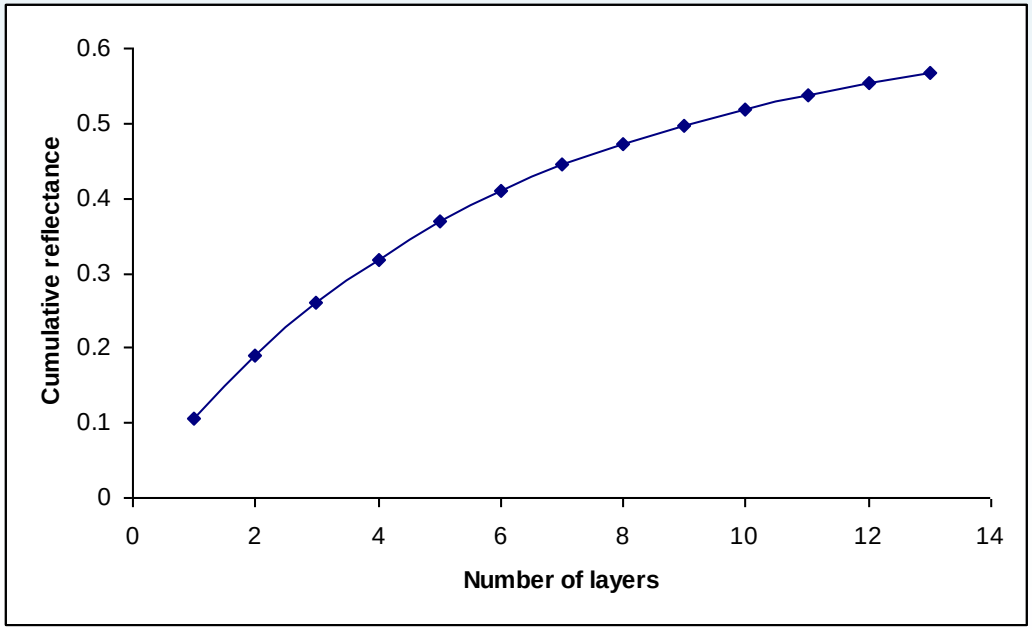
$$^{3}R_{n} = R^{3}\left[(1-R)^{2} + 3(1-R)^{4} + 6(1-R)^{6}\ldots\ldots\frac{n(n+1)}{2}(1-R)^{2n}\right]$$

$$^{3}R_{n=\infty} = \frac{(R-1)^{2}}{(2-R)^{3}} \quad =0.12$$

using n=1.535 which gives R=0.104 for each sheet of glass (reflection from both surfaces) but the reflectance for infinite number of sheets only varies from 0.62-0.65 for R=0.01 to 0.1.

M.A.Devetzoglou, J.R.G.Evans J.Marine Res. 72 (2014) 19-29

Construction of a mirror from a succession of glass plates (n=1.535).



n=	^1R	^3R	Total R	Expt.	Deviation %
1	0.1040	0.0009	0.105	0.105	0
2	0.0835	0.0022	0.191	0.188	-1.6
3	0.0670	0.0035	0.261	0.251	-3.8
4	0.0538	0.0047	0.319	0.298	-6.6
5	0.0432	0.0056	0.368	0.346	-6.0
6	0.0347	0.0063	0.409	0.377	-7.8
7	0.0278	0.0067	0.444	0.404	-9.0
8	0.0224	0.0070	0.473	0.435	-8.0
9	0.0179	0.0070	0.498	-	-
10	0.0144	0.0069	0.519	-	-
11	0.0116	0.0066	0.538	-	-
12	0.0093	0.0063	0.554	-	-
13	0.0075	0.0059	0.567	-	-

Increase in albedo

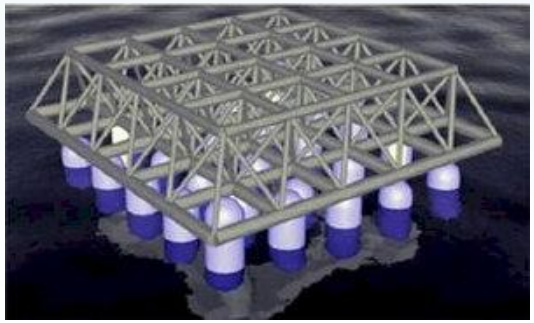
The Royal Society calls for an increase in surface albedo from 0.15 to 0.17. If it all comes from oceans alone, it's an increase of 0.028 (they cover 70% of the surface). If the foam has A=0.5 and ocean A=0.05 , this is obtained by foaming **6%** of ocean.

Ocean area

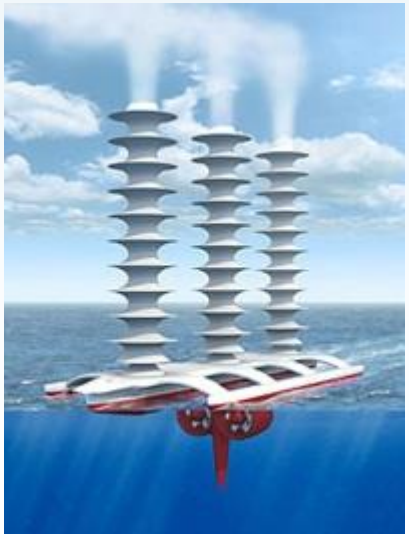
Ocean area is 3.6×10^{14} m^2. 6% of ocean is 2.2×10^{13} m^2. This needs 2.6 GW (≡ 1 power station) if foam residence time is 1 month.

Number of vessels

If two Flettner rotor vessels foam 5.2×10^9 m^2 each month, we need 4230 pairs of vessels. (As a comparison there are about 40,000 merchant ships worldwide).



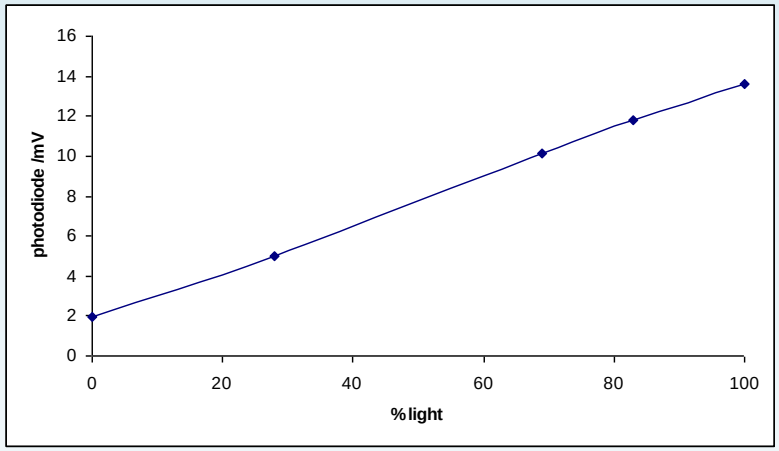
The 'Manchester bobber' : wave energy to compressed air



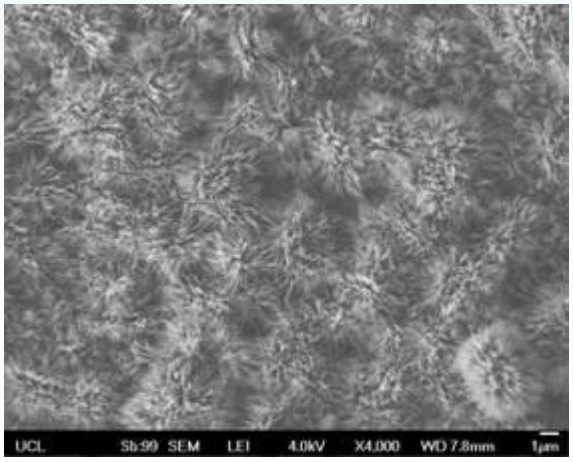
Flettner rotor ship: wind to compressed air

The Mitsubishi Air Lubrication System (MALS) pumps air bubbles onto the bottom of a ship's hull to reduce friction.

0°/45 ° diffuse reflectance measurement uses a slide projector, mirror, BPX 65 photodiode and 10 kΩ resistor shunt.



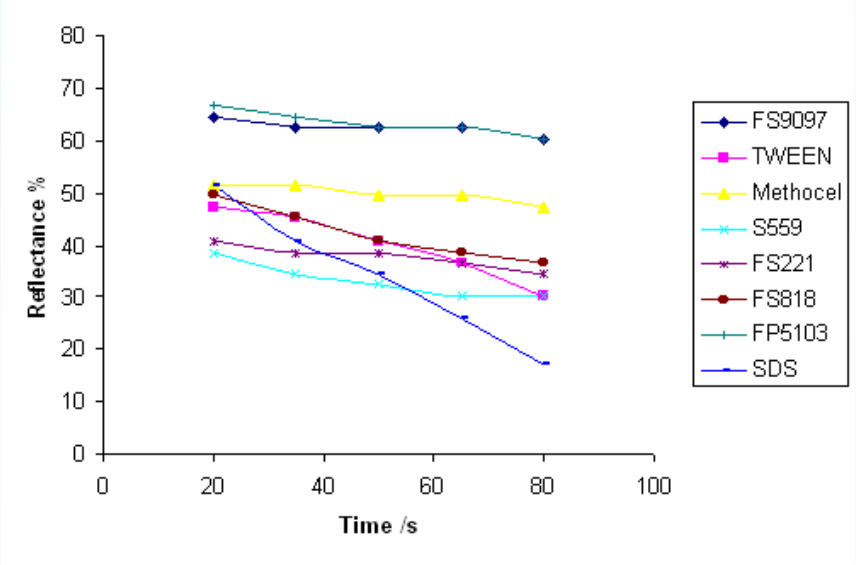
Photodiode-shunt linearity check



Ebonol C™ treated copper (black reference)

Foam type	Reflectance %	
	0 s	20 s
SDS	59*	51.6
TWEEN 20	50	47.3
Methocel	53	51.6
S-559-100	43	38.7
FS 221	43	40.9
FS 818-6	55	49.5
FP 5103	68	66.7
FS 9097	66	64.5

(* neglecting the upturn of the curve at 20 s)



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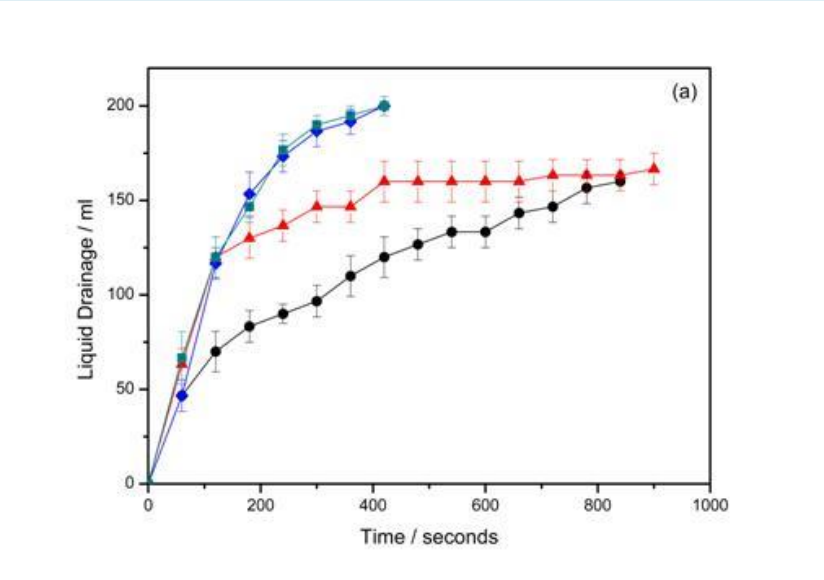
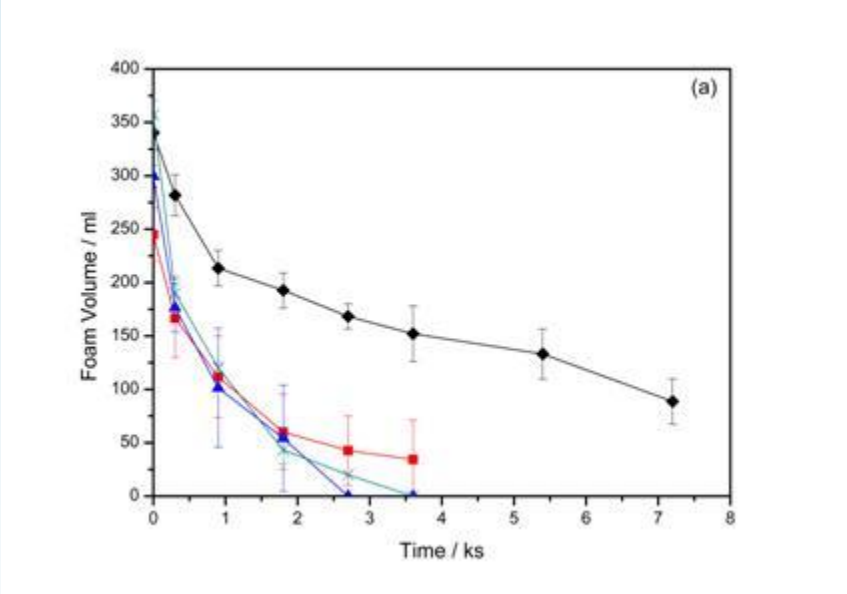
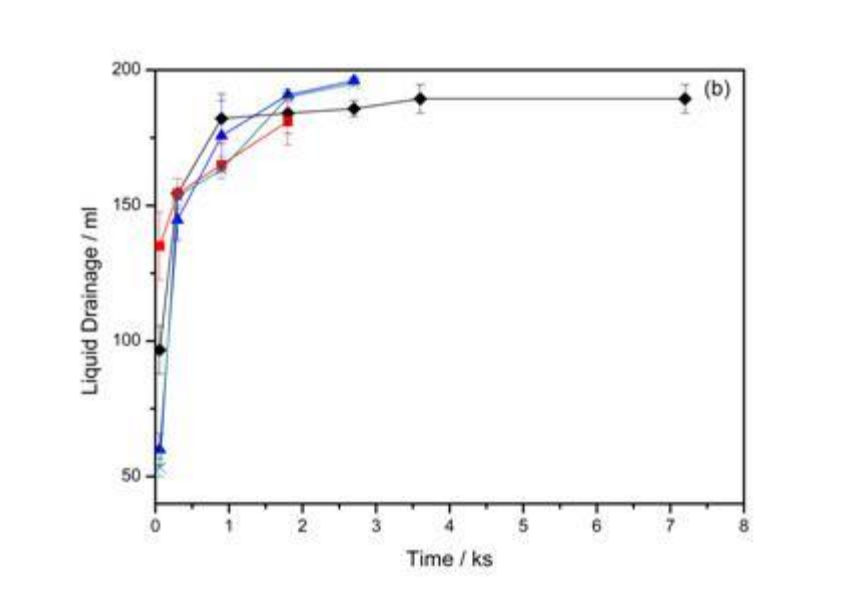


Liquid drainage of foamed protein surfactants in sea water (200 ml volume) (● albumin; ♦ gelatine type B; ▲ gelatin type A; ■ whey protein isolate)

Product	**Supplier**
Whey Protein Isolate (WPI) (90%) 18,400 $gmol^{-1}$	Buy Wholefoods Online, Kent, UK
Type A gelatin from porcine skin (G1890) 50,000 – 100,000 $gmol^{-1}$	Sigma-Aldrich Ltd.Dorset, UK
Type B gelatin from bovine skin (G9391) 50,000 – 100,000 $gmol^{-1}$	Sigma-Aldrich Ltd. Dorset, UK
Albumin (Ovalbumin) from chicken egg white (A5253) 44,300 $gmol^{-1}$	Sigma-Aldrich Ltd. Dorset, UK

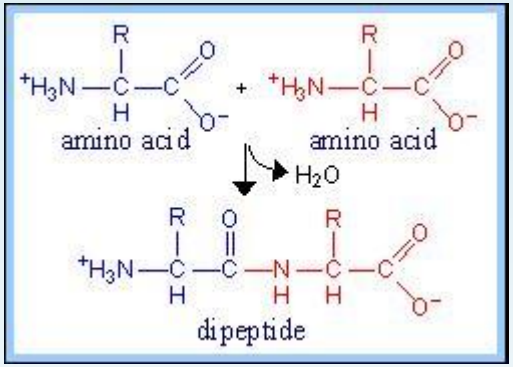


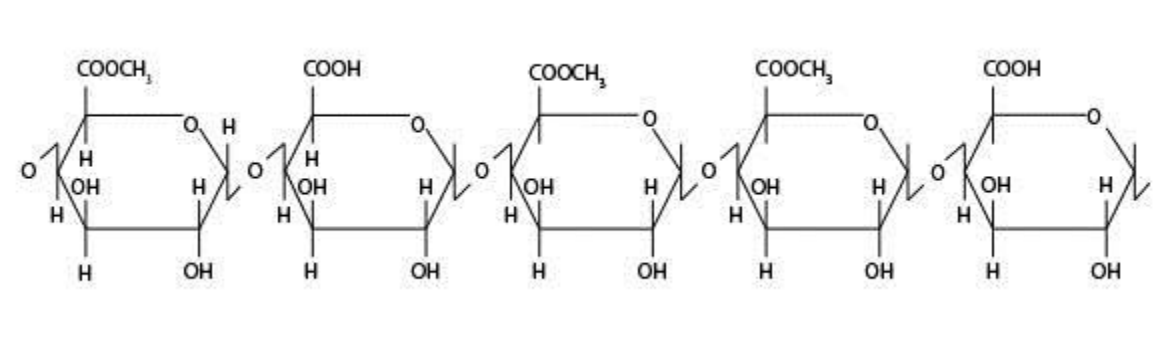
Mean foam volume



Volume drained

1% WPI in seawater and in distilled water at room temperature and after heating to 60 °C. Error bars reflect measurement error of ± 5 ml. (♦ heated in seasalt solution at 60 °C for 4 hours; ■ in distilled water at 20 °C; ▲ in seasalt solution at 20 °C; X heated in distilled water at 60 °C for 4 hours)



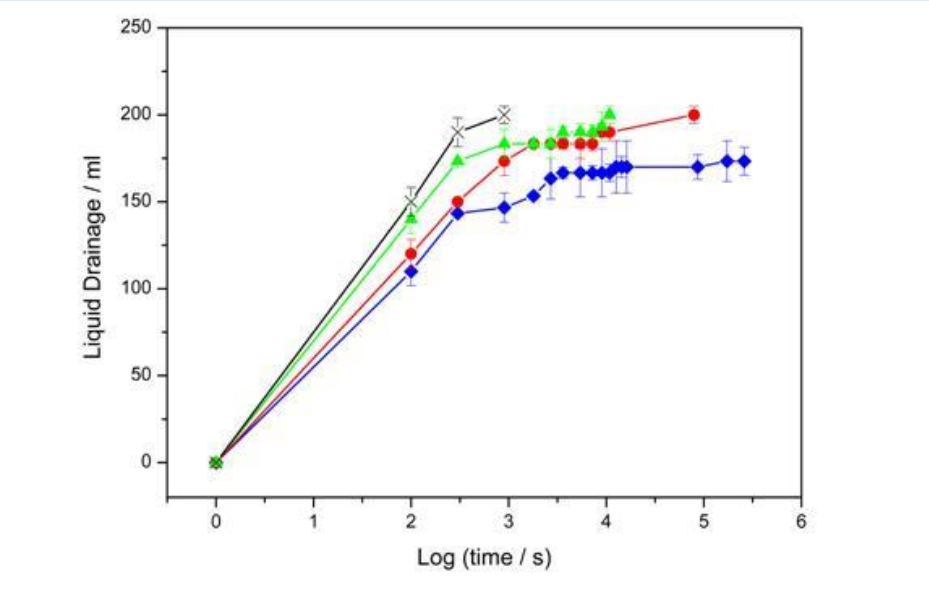


Protein: a polypeptide made by linking many amino acids (just two are linked here)

Pectin: galacturonic acid which is partly esterified: note that some of the acid groups (COOH) have methyl groups (CH_3)attached.

Degree of esterification = number of esterifed groups/ total number of acid groups

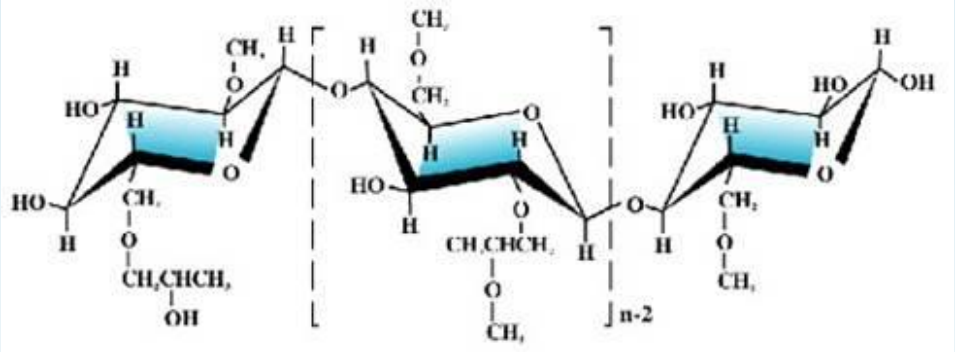
Product	Supplier
Low methyl ester Pectin Sample B-3886	CP Kelco, Lille Skensved, Denmark
High Methyl ester Pectin Sample B-3887	CP Kelco, Lille Skensved, Denmark
Type A gelatin from porcine skin (G1890) 50,000 – 100,000 $gmol^{-1}$	Sigma-Aldrich Ltd. Dorset, England
Type B gelatin from bovine skin (G9391) 50,000 – 100,000 $gmol^{-1}$	Sigma-Aldrich Ltd. Dorset, England



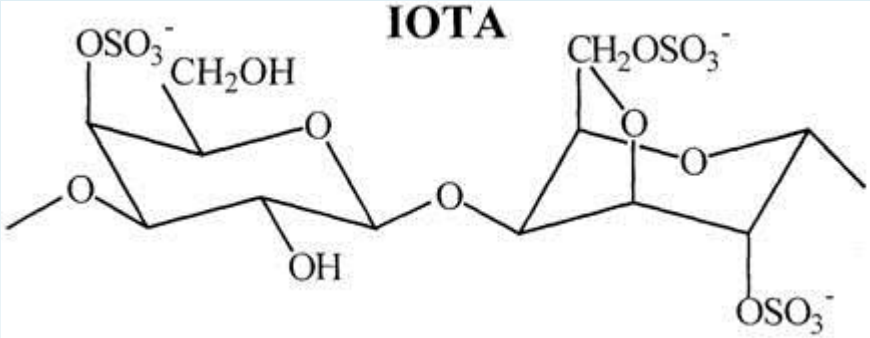
Mean liquid drainage against time of gelatin type A, gelatin type B, HM Pectin foamed with gelatin type A and HM Pectin foamed with gelatin type B in sea water. Error bars indicate standard error plus error in measuring liquid drainage (±5 ml).(◆ 0.5 wt.% HM pectin – 0.5 wt.% type A gelatin; ● 0.5 wt.% HM pectin – 0.5 wt.% type B gelatin; ▲ 0.5 wt.% gelatin type A; **x** 0.5 wt.% gelatin type B).

	Drainage / ml	Reflectance
0.05 wt.% LM pectin - 0.5 wt.% type A gelatin	130±25	0.77±0.04
0.20 wt.% LM pectin - 0.5 wt.% type A gelatin	77±14	0.76±0.04
0.35 wt.% LM pectin - 0.5 wt.% type A gelatin	50±25	0.69±0.06
0.50 wt.% LM pectin - 0.5 wt.% type A gelatin	23±14	0.66±0.06

Liquid drainage after 4 hours from gelled LM pectin - gelatin type A foams in seawater. Reflectance was calculated against a barium sulfate standard Experiments were repeated 3 times and a 95% interval was calculated from a t-distribution.

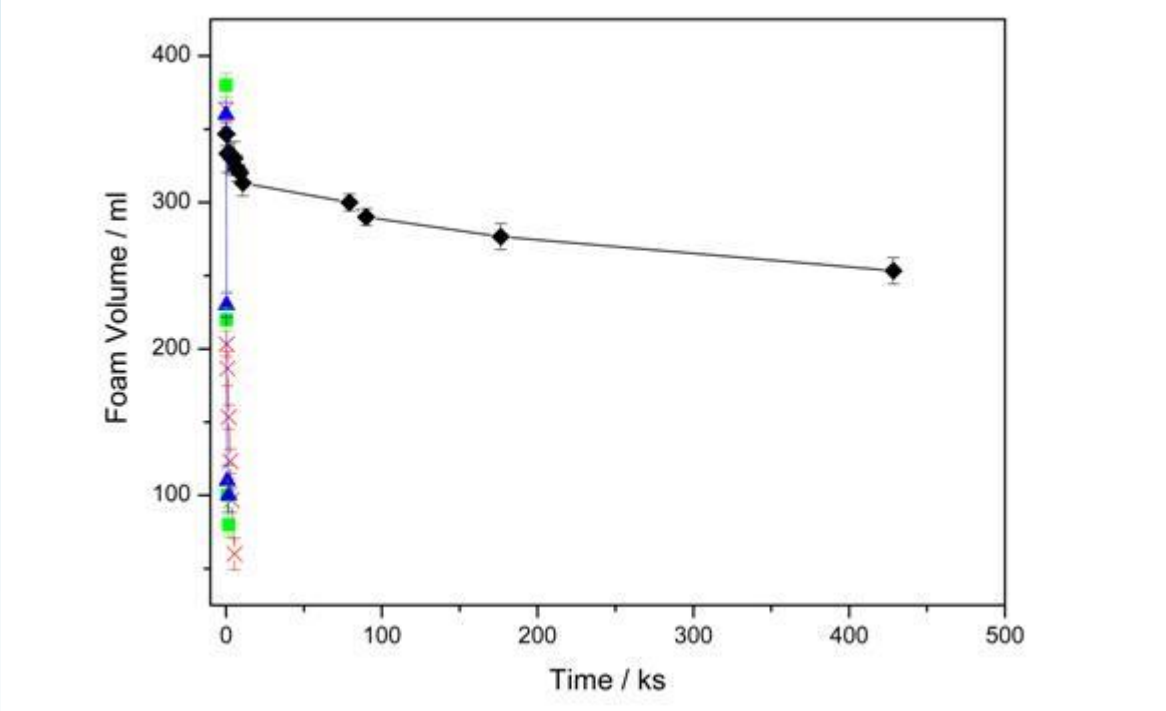


Hydroxypropyl methyl cellulose

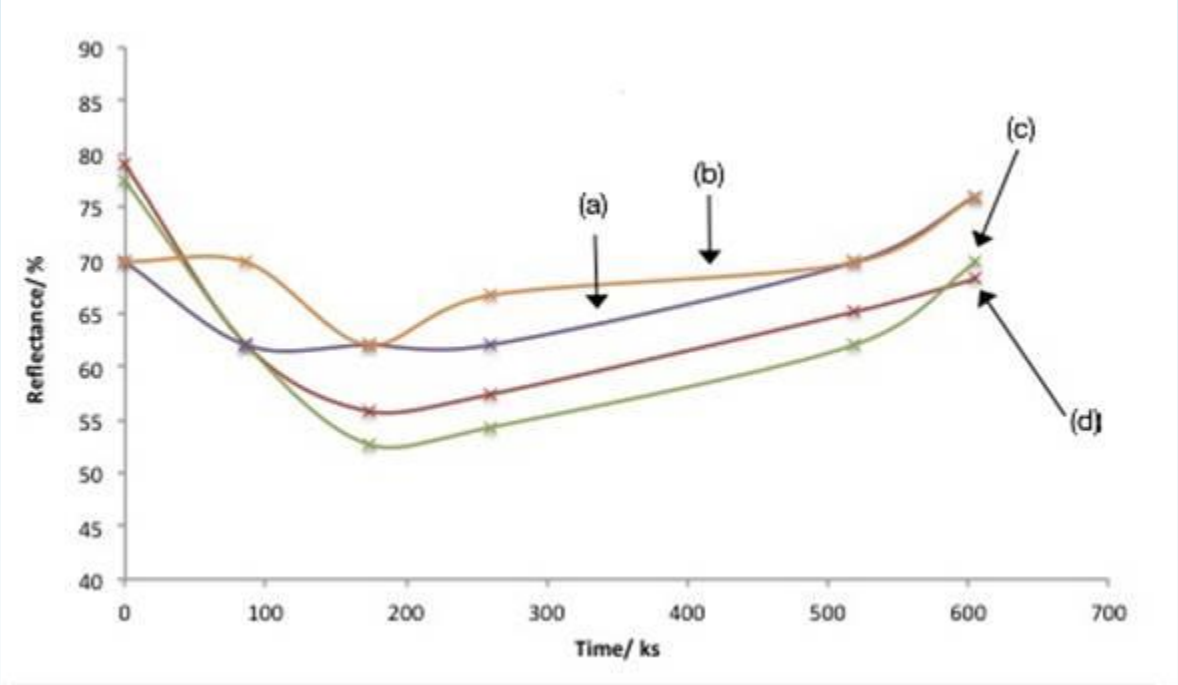


Iota carrageenan

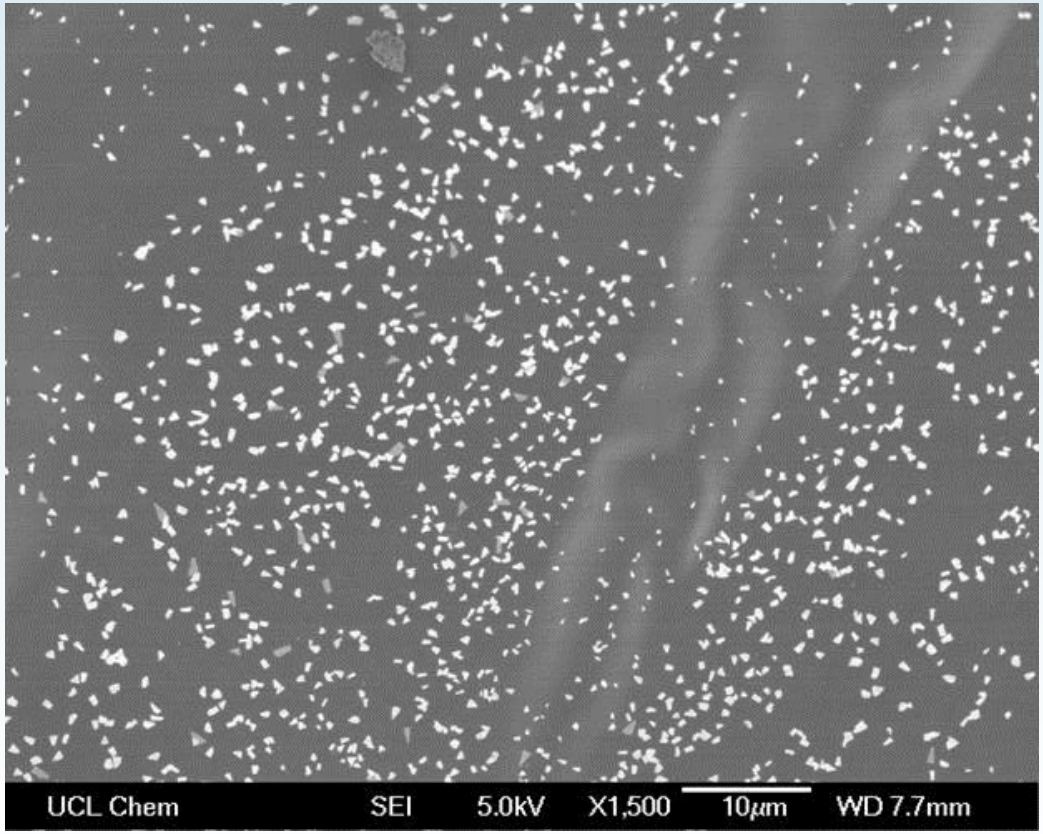
Product	Supplier
Hydroypropyl methylcellulose E50 FG Iota carrageenan (GP379)	Dow Chemical Company Ltd, Middlesex, UK Gelcarin FMC Biopolymers, Bournal, Beligum



Foam volume of methylcellulose - iota carrageenan solutions in distilled water against time (♦ 0.5 wt.% iota carrageenan gum – 0.5 wt.% methyl cellulose; ■ 0.1 wt.% iota carrageenan gum – 0.5 wt.% methyl cellulose; ▲ 0.5 wt.% methyl cellulose in seawater; **x** 0.5 wt.% methyl cellulose in distilled water).



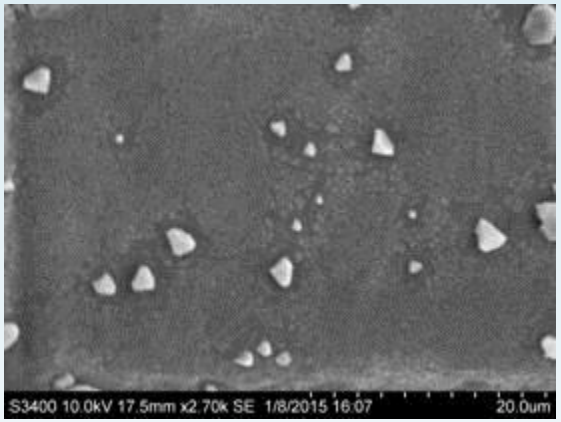
Change in reflectance of foams with time. Initial decay in reflectance was caused by foam coarsening. Subsequent increase was caused by seasalt precipitation as fine near-monodisperse crystals (a) 0.5 wt.% GelcarinTM 812 – 0.5 wt.% MethocelTM MX0209, (b) 0.5 wt.% GelcarinTM 812 – 0.5 wt.% MethocelTM A4M, (c) 0.5 wt.% GelcarinTM 379 – 0.5 wt.% MethocelTM E50, (d) 0.5 wt.% GelcarinTM 379 – 0.5 wt.% MethocelTM MX0209.



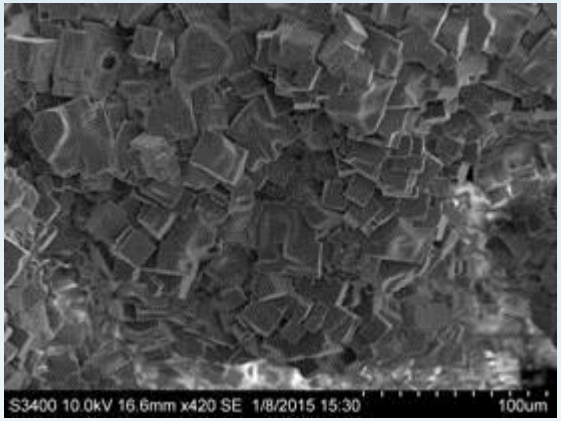
Scanning electron micrographs of (A) the dried upper surface of foam prepared from 0.5 wt.% GelcarinTM 379 – 0.5 wt.% MethocelTM E50

Salt water evaporated from matt back Petri dishes (A) no additives (B) with 0.5 wt.% hydroxypropyl methyl cellulose

(47 Zg salt in oceans)

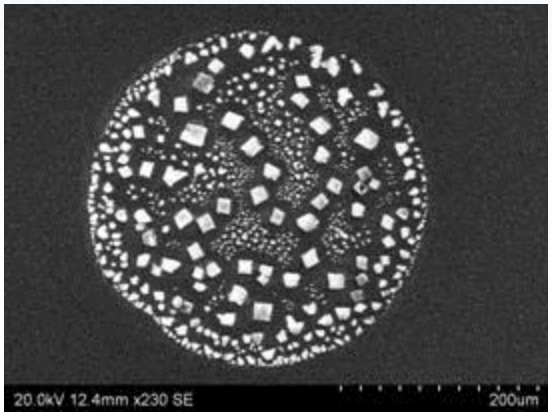


(A) The surface of a dried unfoamed solution of MethocelTM E50 HPMC in SeamixTM as shown macroscopically in This fine microstructure produced high reflectance of 77%.



(B) The much coarser seasalt deposit from an unfoamed solution of 0.5 wt.% carrageenan (Gelcarin 379) in SeamixTM: the coarse microstructure produced lower reflectance of 36%

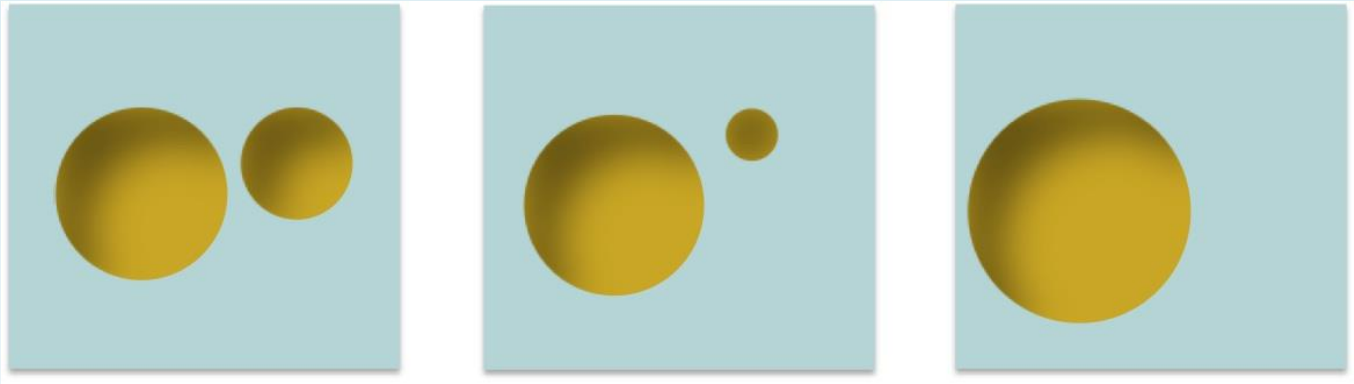
The residue from drying artificial seasalt on a sputter-coated gold surface: Ostwald ripening causes a depletion region around each large crystal.



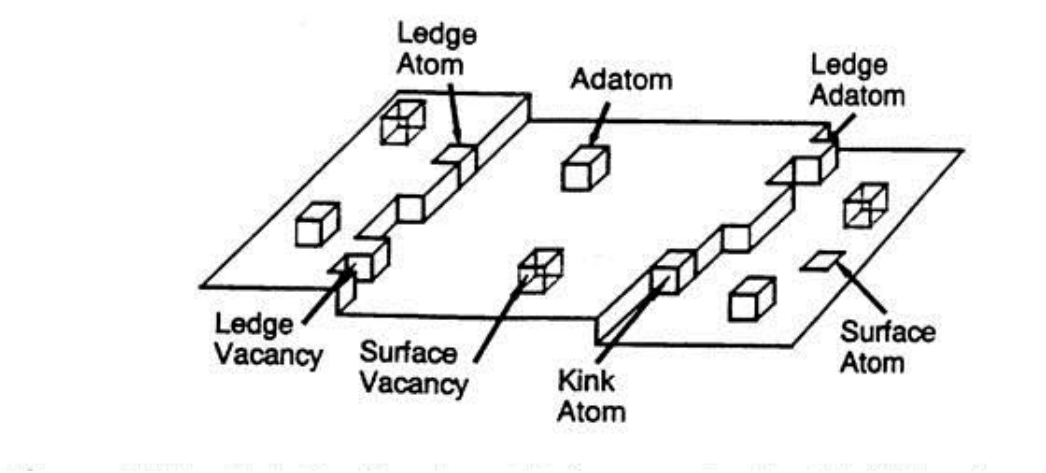
Surface	Reflectance %	95% C.L.*%	n
Reference surfaces			
Barium sulfate (from Ref. 19)	97	0.11	14
Polytetrafluroethylene (PTFE)	93	0.24	14
Matt black Petri dish (1)	2.9	0.21	6
Matt black Petri dish (2)	4.0	0.02	6
Ebonol C™ treated copper (1)	1.9	0.05	6
Ebonol C™ treated copper (2)	1.5	0.12	6
Experimental surfaces			
Seamix™ as –received (10 mm depth)	79	0.99	6
Seamix™ solution evaporated (no additive)	18	1.32	6
Seamix™ solution evaporated (0.5 % Methocel™ E50)	77	0.42	6
Seamix™ solution evaporated (0.5 % Gelcarin 379)	36	0.61	6

Reflectance of the reference surfaces and seasalt with different microstructures.

* 95 % confidence interval from a ‘t’ distribution deduced where appropriate from the sample and standard using the error propagation rule; n is the number of readings.



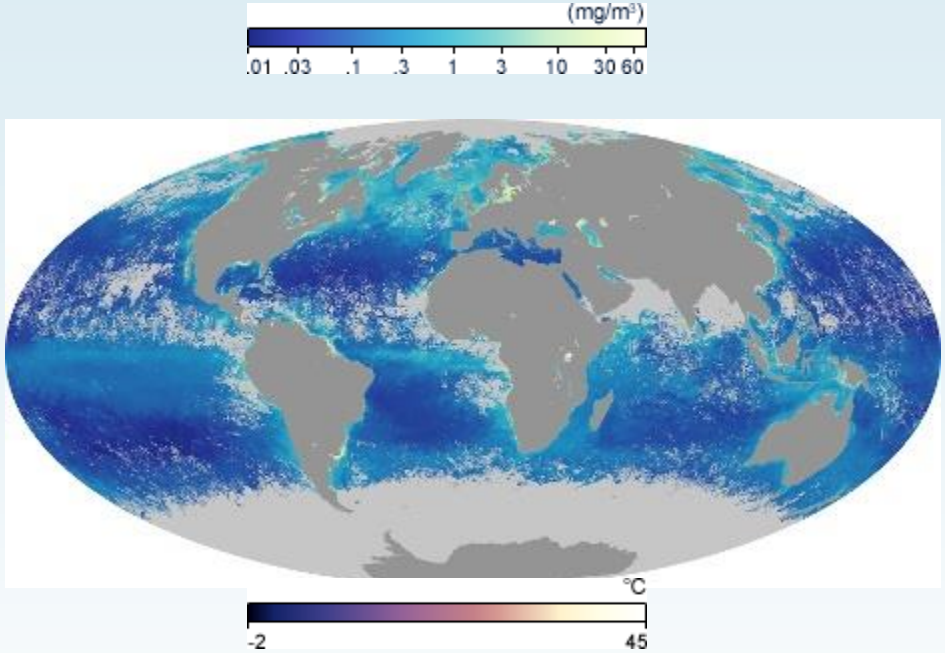
Ostwald ripening: atoms on the surface with high curvature have fewer nearest neighbours and therefore increased solubility. They reprecipitate on the surface with lower curvature. The lowest free energy state is a single sphere.



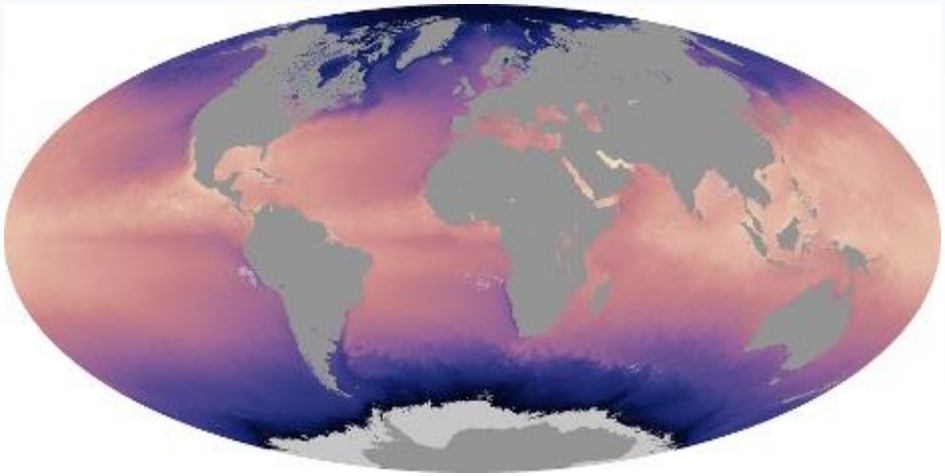
The same process occurs on faceted crystal surfaces because there is a higher proportion of nearest neighbour sites eg ledge vacancies.

Thank you for your attention

Chlorophyll



Temperature



http://earthobservatory.nasa.gov/GlobalMaps/

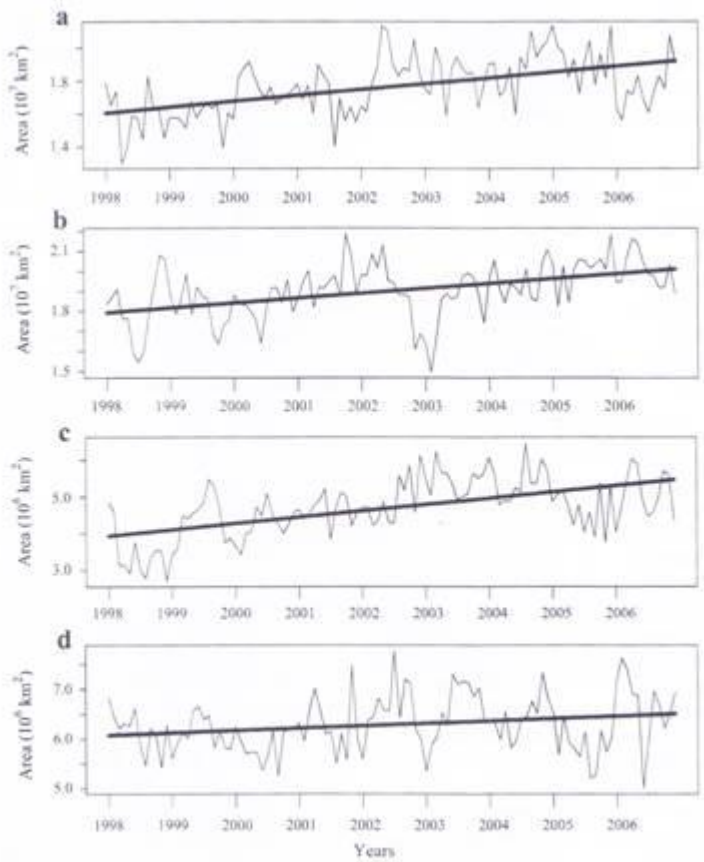


Figure 1. Time series of the monthly mean area (km^2) with surface chlorophyll less than or equal to 0.07mg chl/m^3 between 5°–45° N/S latitude with the seasonal cycle modeled removed in (a) the North Pacific, (b) the South Pacific, (c) the North Atlantic, and (d) the South Atlantic. Straight lines are the linear terms from the GAMs.

J.J.Polovina, E.A.howell, M.Abecassis, Geophys. Res. Lett. 35 L03618 2008.