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Observations on the metabolism of the corallines.

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The results of this investigation suggest a clearer view of the problem of lime deposits and the conditions of organic deposition. The coralline studies are widely distributed and convenient for experiment because of their activity. Although no direct record of their internal changes can be suitably followed, we can determine the changes in the external milieu—changes which will complement those occurring within the organism. In the external milieu, sea water, the carbonic acid-carbonate system, especially with Ca and Mg, is of particular biological significance.

No observations have yet been so distributed as to give complete or even consistent ideas on the whole process of carbonate deposition. Deposition may occur (1) by the accumulation of carbonates incorporated inside of organisms, or (2) by precipitation from the surrounding water by the photosynthetic removal of CO_2. Removal of single ions from sea water is impossible, and deposits within the tissues appear principally as $CaCO_3$. Diffusion of lime into the alga would be facilitated (1) by its precipitation within the organism and (2) by the use of carbonic acid in photosynthesis. Each process would reduce the concentration of these ions within the plant. Diffusion must essentially be, at some point, a factor limiting this process of metabolism.

Titration of sea water to an end point of pH 4.0 with methyl orange gives the excess base, or concentration of weak acid anions, called X-base.

The average (normality) of the sea water was $(25.68 \pm .92) \times 10^{-4}$ N. That of carbonate + bicarbonate, which constitute about half of the X-base, was .0013 N.

Calcium in this sea water was 0.0114 M. If the X-base change of corallines results in an equivalent calcium removal, the amount would be 0.00065 M. As a smaller quantity of magnesium is also removed and its concentration is 0.0507 M, the percent change would be very small. The X-base changes may be very easily followed; while such calcium and magnesium changes approach the limits of accurate determination.

Corallines were selected as material partly because of their geologic interest. Count Solms[1] finds that the alga must have the power to decompose lime at the growing points. Berthold[2] claims to have observed that there is little lime deposited in shaded habitats. Both observations seem to indicate that the lime deposition is dependent on external as well as on internal factors.

The large surface of *Corallina,* as compared with the other corallines, and its hardiness made us use this form for the experiments. As already shown by Meigen, *Corallina* contains calcite and magnesite. Oltmans[3] cited an analysis of Högbom, who found in a *Lithothamnion* from the Bermudas 82.4 percent calcite and 12.4 percent magnesite. About 11 percent $MgCO_3$ was found in a sample of the *Corallina* used in our experiments. Clarke's data[4] give several other similar analyses. Only 37.8 percent of the organism is water.

Filtered water showed a reduction in the X-base, but the difference was so small that unfiltered sea water was used. The corallines themselves, with their large surface, carry an amount of Epizoa which may interfere with the accuracy of the experiment. Especially the calcareous tubes of a worm, *Serpula,* may cover a large portion of the algal surface, but the material selected was almost free from contamination.

Weighed amounts of the alga were placed in Pyrex flasks. A battery of six flasks was used, through which was bubbled a continuous stream of clean outside air. The air was previously led through sea water to prevent evaporation in the flasks. By this procedure the pH remained constant throughout the experiment for 50 hours or more. Series in which the flasks lost weight were discarded. The upper series of three flasks was illuminated by a 75-watt Mazda lamp, 50 centimeters distant. The lower series was kept in darkness.

Total excess base was determined by titration with .01N HCl against methyl orange. The end point selected was pH 4.0, by

[1] Solms-Laubach, *Monogr. Zool. Station Naples,* 1881, iv, Leipsic.

[2] Berthold, *Jahrb. f. Wiss. Bot.,* 1882, iii, 569.

[3] Oltmanns, *Morph. u. Biol. der Algen,* 1923, iii, 7.

[4] Clarke, *U. S. Geol. Survey Bull.,* 1920, 695.

comparison with 0.05M KH phthalate. The reduction of X-base and the pH is recorded in the accompanying table.

If the total available excess base for coralline metabolism be assumed to be .0013N (total carbonate), we may duplicate the smoothed tabulated curve by mathematical expressions, "av. b." is base available for coralline use, judging from the amount ordinarily used under such conditions.

Series	Date	Water in gm.	Alga in gm.	Time in hours	X-base light	X-base dark	X-base control	pH
I	16	200	24.5	50	14.90		25.55	8.55
					15.80			
II	18	200	25	20	14.95	17.86	25.65	8.55
					15.10	17.88		
V	26	200	5	42.50	13.85	17.45	26.58	8.55
				66.50	13.70	16.48		
				95.59	15.98	19.34		
VII	5	200	5	1.15	24.74		25.20	8.50
				2.10	22.51			
				3.05	21.80			
				5.45	19.95			
				7.30	19.70			
X	20	250	5	8	19	22.30	25.70	8.55
				22.25	13.50	18.90		
				23	14.75	19.65		
XII	25	200	5	45	15.10		25.64	8.50
				48	14.63		18.52	

t (h)	av. b. light	av. b. if $\log. \frac{13}{13-x} = 2.9 \times 10^{-5}t$	av. b. dark	av. b if $x = 1.5\,t$
2.5	4.2	3.80	2.	2.37
5.0	6.3	5.50	3.2	3.36
10.	8.6	8.40	4.7	4.75
15.	10.3	10.30	6.0	5.82
20.	11.3	11.32	6.9	6.72
25.	12.0	12.00	7.6	7.50
35.	12.6	12.66	8.7	8.86

On account of our ignorance of the processes involved we can only suggest this empirical analysis. The light reaction is closely expressed by this mono-molecular reaction equation; one substance is acted upon, and the velocity of the reaction is proportional to the amount of that substance present. The dark reaction curve can be duplicated by E. Schütz's law[5], the intrinsic meaning of which is the following[6]:

[5] Schütz, *Ztschr. Physiol. Chem.*, 1885, ix, 577.
[6] Euler, *Chemie der Enzyme*, 1920, Vol. I, 124, 2d ed.

If $x = t$ or $x^2 = a^2t$, differentiation will give

$$\frac{dx}{dt} = \frac{a^2}{2x}$$

In this case the velocity of the reaction will be inversely proportional to the amount of decomposed substance.

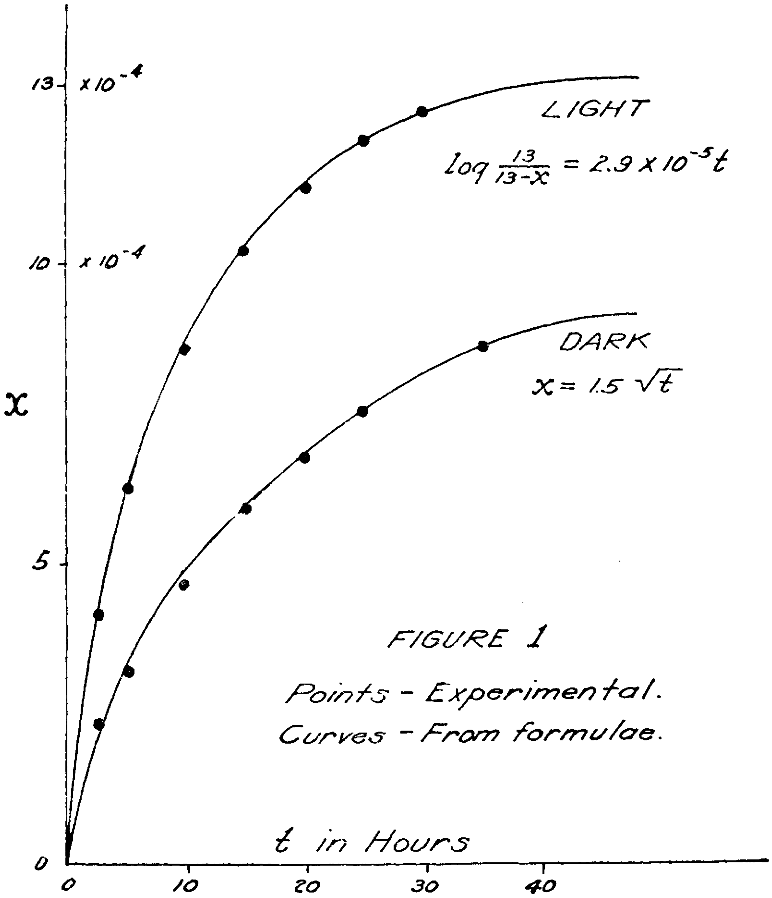
	X-base used	2 Ca^{++}	2 Ca^{++} + X-base used
Sea water	0.0000	0.0228	0.0228
8h light	0.00067		
23h light	0.00109	0.0216	0.0227
8h dark	0.00034	0.0227	0.0230
23h dark	0.00061	0.0224	0.0230

The reduction in carbonate is approximately equivalent to the Ca^{++} removal.

In contrasting the effect of other algæ on X-base each form seems to have its own particular metabolic behavior, which is apparent in this change. Several grams of the coralline *Lithophyllum* were without effect on the X-base. *Ulva* increases the X-base, while the red alga *Gigartina* seems to cause a slight decrease. The effect is enhanced in the light. The brown alga, *Leathesia,* proved to be without effect on the X-base, but changed the pH. A great many metabolic peculiarities of various algæ seem to find their expression in the total excess base. The characterization of the various forms will be found in the table.

Plant 10 gm.	X-base after 24 hours.		pH.	
	Light.	Dark.	Light.	Dark.
Corallina	13.58	18.03	8.55	8.55
Ulva	34.40	30.85	8.65	8.35
Gigartina	24.14	25.20	8.40	8.25
Leathesia	25.25	25.40	8.80	8.60

All plants were collected at the same ecological stratum (Fucus zone).



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A method for recording continuous blood pressure.

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With the usual apparatus used in clinical study, such as the blood pressure manometer or the Erlanger capsule recording on a smoked drum, the pressure changes in the cardio-vascular system