THE INORGANIC CONSTITUENTS OF ECHINODERMS.

By F. W. Clarke and W. C. Wheeler.

INTRODUCTION.

In a recent paper [1] on the composition of crinoid skeletons we showed that crinoids contain large quantities of magnesia, and that its proportion varies with the temperature of the water in which the creatures live. This result was so novel and surprising that it seemed desirable to examine other echinoderms and to ascertain whether they showed the same characteristics and regularity. A number of sea urchins and starfishes were therefore studied, their inorganic constituents being analyzed in the same manner as those of the crinoids. The specimens for analysis were carefully selected by Mr. Austin H. Clark, of the United States National Museum, to whom our thanks are due

SEA URCHINS.

The following sea urchins were chosen for analysis:

1. *Strongylocentrotus dröbachiensis* (O. F. Müller). Upernivik, Greenland, latitude 72° 48′ N.
2. *Strongylocentrotus fragilis* (Jackson). *Albatross* station 2946, off southern California. Latitude 33° 58′ 00″ N., longitude 119° 30′ 45″ W. Depth of water, 274.5 meters; bottom temperature, 13.6° C.
3. *Echinarachnius parma* (Lamarck). Coast of New England.
4. *Encope californica* (Verrill). Galapagos Islands, on or near the Equator.
5. *Lytechinus anamesus* (H. L. Clark). *Albatross* station 2938, off Wilmington, California. Latitude 33° 35′ 15″ N., longitude 118° 08′ 30″ W. Depth, 86 meters; bottom temperature 15° C.
6. *Loxechinus albus* (Molina). Port Otway, Patagonia. Latitude about 46°–47° S.
7. *Tetrapygus niger* (Molina). Coast of Peru.
8. *Tretocidaris affinis* (Philippi). *Albatross* stations 2316 and 2317, off Key West, Florida. Latitude 24° 25′ N., longitude 81° 47′ W. Depth, 85 meters; bottom temperature 24° C.
9. *Heterocentrotus mammillatus* (Linné). Low or Paumotu Archipelago, southern Pacific Ocean. Latitude between 14° and 24° S.

In the following analyses the loss on ignition covers carbon dioxide, water, and organic matter, the last item being often large. The deficiencies in summation are due to undetermined sea salts, adherent to or inclosed by the specimens. The CO_2 needed is calculated to satisfy the bases.

Analyses of sea urchins.

	1	2	3	4	5	6	7
SiO_2	0.12	0.26	0.14	3.86	8.52	0.05	0.31
R_2O_3	.34	.65	.27	5.03	3.01	.17	.30
MgO	2.58	2.68	2.97	4.75	3.04	3.07	2.82
CaO	47.34	41.08	49.17	43.42	37.92	45.87	48.86
P_2O_5	Trace.	.39	.05	Trace.	.19	Trace.	Trace.
Loss on ignition	48.53	52.21	45.74	43.01	45.38	49.47	44.98
	98.91	97.27	98.34	100.07	98.06	98.63	97.27
CO_2 needed	40.04	33.87	41.80	40.40	32.90	39.41	41.41

[1] U. S. Geol. Survey Prof. Paper 90–D (Prof. Paper 90, pp 33–37), 1914.

Rejecting the excess of volatile matter and recalculating to 100 per cent, we have the following composition of the inorganic constituents of the seven sea urchins of the preceding table:

Revised analyses of sea urchins.

	1	2	3	4	5	6	7
SiO_2	0.13	0.31	0.15	3.92	9.95	0.05	0.33
R_2O_3	.37	.80	.28	5.10	3.52	.19	.32
$MgCO_3$	5.99	7.05	6.61	12.26	7.45	7.27	6.31
$CaCO_3$	93.51	90.79	92.84	78.72	78.60	92.49	93.04
$Ca_3P_2O_8$	Trace.	1.05	.12	Trace.	.48	Trace.	Trace.
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Sea urchins Nos. 8 and 9, Tretocidaris and Heterocentrotus, must be considered separately from the others. No. 9, a giant form, was the subject of four analyses, the shell or test, the dental pyramid, the small white spines on the border of the peristome, and the large purplish-red spines. The large red spine analyzed was 15 centimeters long and weighed 13 grams.

Analyses of Heterocentrotus mammillatus.

	Actual analyses.			
	Test.	Dental pyramid.	White spines.	Red spines.
SiO_2	0.02	0.02	0.05	0.05
R_2O_3	.13	.08	.13	.26
MgO	5.21	5.50	3.74	4.47
CaO	43.60	46.02	48.26	47.72
P_2O_5	Trace.	Trace.	Trace.	Trace.
Loss on ignition	49.62	47.00	46.46	45.99
	98.58	98.62	98.64	98.49
CO_2 needed	39.99	42.21	42.03	42.41
	Revised analyses.			
	Shell.	Dental pyramid.	White spines.	Red spines.
SiO_2	0.02	0.02	0.05	0.05
R_2O_3	.15	.09	.14	.28
$MgCO_3$	12.30	12.31	8.33	9.89
$CaCO_3$	87.53	87.58	91.48	89.78
$Ca_3P_2O_8$	Trace.	Trace.	Trace.	Trace.
	100.00	100.00	100.00	100.00

From these analyses we see that the inorganic constituents of Heterocentrotus are not uniformly distributed. The shell and teeth are alike and rich in magnesium carbonate; the coarser spines are much less magnesian. The composition of the entire skeleton, if it can be called so, would probably be somewhere near that of the red spines alone, only a little higher in magnesia.

A similar example is offered by No. 8, Tretocidaris. In the specimen analyzed the shell and spines were taken separately, but the spines were dead when the urchin was collected. The analyses are as follows:

Analyses of Tretocidaris affinis.

Actual analyses.			Revised analyses.		
	Shell.	Spines.		Shell.	Spines.
SiO_2	0.11	0.53	SiO_2	0.12	0.56
R_2O_3	.15	.14	R_2O_3	.17	.15
MgO	4.02	2.07	$MgCO_3$	9.33	4.63
CaO	45.80	49.79	$CaCO_3$	90.38	94.66
P_2O_5	Trace.	Trace.	$Ca_3P_2O_8$	Trace.	Trace.
Loss on ignition	48.32	46.28			
				100.00	100.00
	98.40	98.81			
CO_2 needed	44.40	41.41			

Here again the spines are lower in their content of magnesia than the shell.

In two of the analyses, Nos. 4 and 5, large percentages of silica and sesquioxides appear. These are due to inclosed or adherent sand and mud, which were visible in the specimens but not readily removable. On rejecting these impurities and recalculating to 100 per cent, the percentages of magnesium carbonate become 8.49 and 13.47, respectively. With these corrections, and assuming the percentages found for the shells rather than the spines in Nos. 8 and 9, the following table has been constructed:

Percentage of magnesium carbonate in sea urchins.

	Locality.	Latitude.	Depth.	Temperature.	$MgCO_3$.
			Meters.	°*C.*	*Per cent.*
Strongylocentrotus dröbachiensis	Greenland	72° 48′ N.	(?)	(?)	5. 99
Tetrapygus niger	Peru	(?)	(?)	(?)	6. 31
Echinarachnius parma	New England	42°–45° N.	(?)	(?)	6. 61
Strongylocentrotus fragilis	California	33° 58′ N.	274. 5	13. 6	7. 05
Loxechinus albus	Patagonia	46°–47° S.	(?)	(?)	7. 27
Lytechinus anamesus	California	33° 35′ N.	85	15	8. 49
Tretocidaris affinis	Key West	24° 25′ N.	85	24	9. 33
Heterocentrotus mammillatus	Paumotu	14°–24° S.	(?)	(?)	12. 30
Encope californica	Galapagos	Equator	(?)	(?)	13. 47

A comparison of these figures with those found for the crinoids shows the same regular variation with temperature. The sea urchins from cold regions are relatively low in magnesia; those from the Tropics are high. There is, however, one apparent exception—the urchin from Peru. This abnormality may be due to growth in very deep water, which is almost always cold, or to the Humboldt current, which flows northward from the Antarctic Ocean. It is unfortunate that actual temperature observations are so few in this series of analyses. They resemble those of the crinoids very closely, except that the latter seem to average somewhat higher in magnesium carbonate. More analyses are needed to determine the fact.

STARFISHES AND OPHIURANS.

Eleven starfishes, including brittle stars, were analyzed, as follows:

1. *Asterias vulgaris* (Packard). Eastport, Maine. Latitude 44° 55′ N., longitude 67° 00′ W.
2. *Asterias tanneri* (Verrill). *Albatross* station 2309. Latitude 35° 43′ 30″ N., longitude 74° 52′ W. Depth, 102 meters; bottom temperature not given.
3. *Asterina miniata* (Brandt). Pacific Grove, California. Latitude 36° 36′ N., longitude 121° 55′ W.
4. *Leptasterias compta* (Stimpson). *Albatross* station 2250. Latitude 40° 17′ 15″ N., longitude 69° 51′ 45″ W. Depth, 86 meters; bottom temperature, 10.8° C.
5. *Benthopecten spinosus* (Verrill). *Albatross* station 2568. Latitude 39° 15′ 00″ N., longitude 68° 08′ 00″ W. Depth, 3,249 meters; bottom temperature, 2.7° C.
6. *Luidia clathrata* (Say). Near Charleston, South Carolina. Latitude 32° 47′ N., longitude 79° 57′ W. Depth, between 2 and 22 meters.
7. *Acanthaster planci* (Linné). Palmyra Island, in the Pacific Ocean, west of south from Hawaii. Latitude 5° 49′ N.
8. *Gorgonocephalus arcticus* (Gray). Off Cape Cod, Massachusetts. About latitude 42° N.
9. *Gorgonocephalus caryi* (Lyman). Alaska.
10. *Ophioglypha sarsii* (Lütken). *Albatross* station 2176. Latitude 39° 32′ 30″ N., longitude 72° 21′ 30″ W. Depth, 553 meters; bottom temperature, 5° C.
11. *Ophioderma cinereum* (Müller and Troschel). Ensenada Honda, Culebra Island, east of Porto Rico. Latitude 18° 20′ N., approximately.

The last locality is in or on the edge of the equatorial current. The *Albatross* stations were all fixed on cruises between Cape Hatteras and Nantucket. The analyses are as follows:

Analyses of starfishes.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	0.45	0.79	0.03	1.21	2.06	0.27	0.19	1.77	1.08	0.98	0.21
R_2O_3	.21	.55	.20	.48	.79	.36	.14	.62	.72	.53	.09
MgO	2.59	3.83	3.98	3.05	3.93	4.89	4.36	3.36	2.82	3.99	5.80
CaO	35.71	38.51	36.85	30.35	40.54	41.30	33.18	36.13	29.80	42.14	41.32
P_2O_5	.07	.24	.14	.13	.11	.14	.07	.22	.32	.29	.07
Loss on ignition	60.18	54.89	57.64	63.91	51.66	52.03	62.07	55.72	63.37	50.95	51.58
	99.21	98.81	98.84	99.13	99.09	98.99	100.01	97.82	98.11	98.88	99.07
CO_2 needed	30.84	34.30	33.05	27.08	35.94	37.70	30.81	31.65	25.80	37.29	38.79

Revised analyses of starfishes.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	0.64	1.01	0.03	1.94	2.47	0.32	0.27	2.39	1.77	1.15	0.24
R_2O_3	.30	.70	.27	.77	.94	.42	.20	.84	1.18	.62	.12
$MgCO_3$	7.79	10.28	11.24	10.27	9.88	12.13	13.33	9.53	9.71	9.84	14.11
$CaCO_3$	91.06	87.44	88.06	86.57	86.42	86.77	85.99	86.60	86.18	87.65	85.34
$Ca_3P_2O_8$	.21	.57	.40	.45	.29	.36	.21	.64	1.16	.74	.19
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

In the following table the analyses are arranged in the order of ascending magnesium carbonate, like those of the sea urchins:

Percentage of magnesium carbonate in starfishes.

	Locality.	Latitude.	Depth.	Temperature.	$MgCO_3$
			Meters.	° *C.*	*Per cent.*
Asterias vulgaris	Eastport	44° 55′ N.	(?)	(?)	7.79
Gorgonocephalus arcticus	Cape Cod	42° ± N.	(?)	(?)	9.53
Gorgonocephalus caryi	Alaska	(?)	(?)	(?)	9.71
Ophioglypha sarsii	Station 2176	39° 32′ N.	553	5	9.84
Benthopecten spinosus	Station 2568	39° 15′ N.	3,249	2.7	9.88
Leptasterias compta	Station 2250	40° 17′ N.	86	10.8	10.27
Asterias tanneri	Station 2309	35° 43′ N.	102	(?)	10.88
Asterina miniata	California	36° 36′ N.	(?)	(?)	11.24
Luidia clathrata	Charleston	32° 47′ N.	(?)	(?)	12.13
Acanthaster planci	Palmyra Island	5° 49′ N.	(?)	(?)	13.33
Ophioderma cinereum	Culebra	18° 20′ N.	(?)	(?)	14.11

CRINOIDS.

In order to make the comparison between the three groups of echinoderms more complete, two additional crinoid skeletons were analyzed, as follows:

1. *Zygometra microdiscus* (Bell). Aru Islands, near the western tip of New Guinea. Latitude 5°–6° S.
2. *Chlorometra rugosa* (A. H. Clark). Near Rotti, Lesser Sunda Islands. Latitude 10° 39′ S., longitude 123° 40′ E. Depth, 520 meters.

Analyses of crinoids.

Actual analyses.			Revised analyses.		
	1	2		1	2
SiO_2	0.04	0.05	SiO_2	0.05	0.06
R_2O_3	.48	.23	R_2O_3	.62	.27
MgO	4.92	3.99	$MgCO_3$	13.37	9.87
CaO	37.19	42.72	$CaCO_3$	85.48	89.80
P_2O_5	.17	Trace.	$Ca_3P_2O_8$	.48	Trace.
Loss on ignition	55.05	51.69		100.00	100.00
	97.85	98.68			
CO_2 needed	34.47	37.95			

Combining these data with those given in our paper upon the crinoids, we have the following table:

Percentage of magnesium carbonate in crinoids.

Genus.	Locality.	Latitude.	Depth.	Temperature.	$MgCO_3$.
			Meters.	° *C.*	*Per cent.*
Heliometra	Northern Japan	43° N	315	1.5	7.28
Promachocrinus	Antarctic	67° S.	375	−1.8	7.86
Ptilocrinus	British Columbia	52° 39′ N	2,858	1.8	7.91
Anthometra	Antarctic	67° S.	375	−1.8	8.23
Psathyrometra	Northern Japan	44° N	(?)	1.6	9.25
Hathrometra	Massachusetts	39° 56′ N	329	7.8	9.36
Florometra	Washington	47° 29′ N	1,145	3.3	9.44
Chlorometra	Rotti	10° 39′ S.	520	(?)	9.87
Bythocrinus	Gulf of Mexico	28° 38′ N	255	(?)	10.09
Pentametrocrinus	Southern Japan	34° N	1,123	3.4	10.15
Hypalocrinus	Philippine Islands	9° 37′ N	612	10.2	10.16
Metacrinus	Southern Japan	30° 58′ N	278	13.3	10.34
Parametra	Philippine Islands	9° 15′ N	502	12	11.08
Ptilometra	Australia	33° 15′ S.	(?)	(?)	11.13
Isocrinus	Cuba	24° N	(?)	(?)	11.56
Catoptometra	Philippine Islands	8° N	104	(?)	11.68
Crinometra	Cuba	23° 10′ N	59	26.2	11.69
Tropiometra	Brazil	25° 54′ S.	(?)	(?)	11.77
Endoxocrinus	Cuba	24° N	(?)	(?)	11.79
Pachylometra	Philippine Islands	8° N	1,044	(?)	12.20
Craspedometra	Philippine Islands	5° 12′ N	32	(?)	12.34
Capillaster	Philippine Islands	6° N	36	(?)	12.69
Zygometra	Aru Islands	5°–6° S.	(?)	(?)	13.37

The percentage of magnesium carbonate in Chlorometra is low for the latitude of the locality; but that is doubtless due to the depth of the water (520 meters) in which the crinoid lived. The probable temperature at that depth was between 7° and 10° C.

GENERAL CONSIDERATIONS.

From the evidence now available, it seems almost certain that the inorganic constituents of any echinoderm will have the composition of a moderately magnesian limestone. There may be exceptions, but none has yet been found. The three tables, for crinoids, sea urchins, and starfishes, all tell the same story, and with remarkable unanimity. Furthermore, the proportion of magnesium carbonate appears to be a function of temperature, the organisms from warm regions being richer in it than the cold-water forms. The exceptions to this rule are apparent rather than real; for cold or warm currents and varying depths of water account for all seeming irregularities. The sea urchins seem to be a little poorer in magnesia than either of the other groups, but the analyses are fewer and therefore less conclusive. Silica and sesquioxides are probably altogether extraneous, although it is possible that small quantities of them may really belong to the organisms. In phosphate of lime the starfishes are richest, and all the specimens analyzed contain it in small amounts. Whether it is an essential constituent or not is uncertain. As shown by Meigen's reaction, all the echinoderms studied are calcitic, and no evidence of aragonite in them was found.

The temperature regularity shown by the analyses offers an interesting biological problem with which we can not undertake to cope. It is not due to differences of composition in the solid matter of sea water, for that is practically uniform all the world over. In all the great oceans, and even in minor bodies of water like the Mediterranean, the Baltic, and the Black Sea, the proportion of magnesia to lime is very nearly if not actually constant. In gaseous contents and especially in carbon dioxide the waters vary; the gases being more soluble in cold than in warm water. Whether this fact has any relation to the phenomenon under discussion we can not attempt to say. We can only report the facts and leave their biological discussion to others.

On the geological bearing of the evidence now before us it is easy to speculate; but here great caution is needed. It would be unwise to assume that magnesian sediments are more abundantly deposited in warm than in cold climates, and so to develop a system of what might be called paleoclimatology. Against such an attempt there are two obvious reasons. First, the sediments are only in small part derived from echinoderm remains. Other agencies are more important in the formation of marine limestones. Secondly, a dense population, so to speak, of cold-water organisms may deposit much more magnesia than a sparse population of warm-water forms. The data now in hand, with all their suggestiveness, are too few to warrant any far-reaching generalizations. It is our intention to carry the investigation still further, studying other marine invertebrates by the same methods as those which we have followed here. If other analysts choose to enter this field of research, their results will be welcomed by us.