

33. INTERSTITIAL WATER STUDIES ON SMALL CORE SAMPLES, LEG 19¹

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The sediments cored on Leg 19 consist primarily of diatomaceous oozes with variable proportions of volcanic material and terrigenous clays and silts. With a few exceptions, deposition rates are high at these sites, usually exceeding $5\text{cm}/10^3\text{y}$. The interstitial solutions sampled exhibit compositional changes which previously have been found to characterize rapidly deposited terrigenous sediments. Some of the largest changes in Na^+ , K^+ , Mg^{2+} , Cl^- , and HCO_3^- yet found in DSDP samples occur in the pore waters studied from this leg (see Table 1).

Depletion of interstitial SO_4^{2-} is extensive at many of the Leg 19 sites (185, 186, 189, and 191), and alkalinities of more than ten times that of ocean water are associated with these SO_4^{2-} depletions. Although some of the Ca^{2+} loss observed at the latter sites may be an artifact caused by post-sampling precipitation of CaCO_3 (Gieskes, in press), real depletion of Ca^{2+} in the pore solutions is inferred to occur. In accord with earlier observations, alkalinities often decrease towards the bottom of the holes. This is most markedly demonstrated at Sites 185, 186, and 189 where alkalinities in the deepest samples are as much as 15 meq/kg lower than in the uppermost ones. Ca^{2+} , which has been depleted in the higher portions of the sedimentary section, begins to increase at depths of 100 to 200 meters as the alkalinity falls. Eventually, Ca^{2+} becomes enriched relative to ocean water at Sites 185, 186, 189, and 192. Large depletions of Mg^{2+} occur at all of the Leg 19 sites. The Mg^{2+} concentrations observed at Sites 184, 185, and 186 are the lowest yet found in DSDP samples ($<0.2\text{ gm/kg}$).

The concentrations of both Na^+ and Cl^- are significantly lower than those of mean ocean water in the deeper samples from Sites 184, 185, 186, and 189. At Site 186, the chlorinity at 108 meters is almost 20% less than that of mean ocean water. Similar decreases of Na^+ and Cl^- have been observed in samples from Legs 11 and 15.

The observed decrease in Cl^- (and Na^+) concentrations must be due to dilution because Cl^- cannot be taken up appreciably by the solid phases of the sediment. The source of the fresh solutions is uncertain. All of the sites exhibiting such Cl^- decreases are characterized by clay-rich sediments and rapid sedimentation. Artesian flow such as found 120 km off the coast of Florida (Manheim, 1967) seems unlikely but is a possibility. The sites at which low Cl^- values occur are adjacent to the Aleutian Island chain and may be underlain by older sedimentary basement. Artesian flow could occur in the basement rock and cannot be ruled out without more extensive structural information. Chemical reactions (e.g., oxidation of organic matter) can

produce H_2O in sediments, but the quantities produced in normal marine sediments are trivial compared to the amounts required. The fresh water could be supplied by the clays themselves, being released from the interlayers during burial and compaction. However, the complete removal of interlayer water from montmorillonite requires temperatures approaching 100°C (Grim, 1968). Such temperatures cannot be found at the depths where Cl^- depletion is found, especially at Site 186. The source of the considerable quantities of fresh water required thus represents an unsolved and intriguing question.

The Na/Cl ratio also deviates from the value characteristic of ocean water (0.556). The ratio for most of the samples (except at Sites 183, 188, and 191) is significantly higher than that of ocean water, falling in the range 0.560 to 0.575. In contrast, pelagic sediments are characterized by ratios which scatter about the ocean water value, seldom deviating by more than ± 0.007 . The observed departures from the ocean water value are close to our detection limit, but are significant. The estimated accuracy in the determination of Na/Cl is ± 0.007 ; a Copenhagen seawater standard treated exactly as the samples yielded a Na/Cl ratio of 0.552.

The increases in Na/Cl found at most of the sites on this leg are the best documented evidence to date of the reaction of Na^+ in the pore fluids. As Cl^- does not react appreciably with the solid phases of the sediment, the increase in the Na/Cl ratio must then be indicative of the release of Na^+ into solution by the enclosing solids. A similar increase in Na/Cl was also found at several of the Leg 11 sites (102, 104, and 106). Such an increase in Na^+ relative to Cl^- might be anticipated; the sediments at sites exhibiting this effect contain appreciable amounts of unweathered terrigenous detritus such as feldspars. Weathering of both plagioclase and alkali feldspar will release Na^+ to solution. We should note, however, that exceptions to this increase in Na^+ do exist. Significant depletion of Na^+ relative to Cl^- is indicated by a decrease in Na/Cl below the ocean water value at Sites 105 (Leg 11) and 148 (Leg 15). No precise knowledge of the reactions involved are available.

REFERENCES

- Gieskes, J. M., in press. Interstitial water studies, Leg 15. *In* Edgar, N. T., Saunders, J. B. et al. Initial Reports of the Deep Sea Drilling Project, Volume XV.
- Grim, R. E., 1968. *Clay Mineralogy*. New York (McGraw-Hill) [2nd Ed.]. Ch. 8.
- Manheim, F. T., 1967. Evidence for submarine discharge of water on the Atlantic continental slope of the southern United States, and suggestions for further search. *Trans. New York Acad. Sciences, Ser. II*, 29, 839.

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TABLE 1
Major Constituents and Si Content of Pore Fluids

Sample	Depth (m)	Age	Description	Na ^a (g/kg)	Na ^b (g/kg)	K (g/kg)	Ca (g/kg)	Mg (g/kg)	Total Cations (meq/kg)	Cl (g/kg)	SO ₄ (g/kg)	Alk. (meq/kg)	HCO ₃ ^c (g/kg)	Total Anions (meq/kg)	Sum ^d (g/kg)	Salinity ^e	H ₂ O (‰) ^f	pH ^f	Si (ppm)
Site 183 (52°34.3'N, 161°12.3'W, water depth 4,708 m, Aleutian Abyssal Plain)																			
183-11-5	106	Pliocene	Olive gray silty and silt-rich clays; large proportions of diatoms.	10.9	10.9	0.34	0.57	1.11	601	19.4	2.23	8.9	0.54	602	35.1	34.7	37	8.1	16.8
	28-3	Oligocene (?)	Olive gray silt.	10.9	10.9	0.18	0.60	1.20	607	19.4	2.53	5.7	0.34	607	35.2	35.2	—	7.9	3.3
Site 184 (53°42.6'N, 170°55.4'W, water depth 1,910 m, Umnak Plateau)																			
184-2-6	136	Pliocene	Olive gray diatom ooze.	11.2	11.0	0.34	0.53	0.87	586	19.4	1.87	8.0	0.49	593	34.7	33.8	—	7.6	25
	4-4	Pliocene	Grayish olive diatom ooze; bedding moderately deformed.	11.2	11.0	0.33	0.59	0.85	589	19.4	1.91	7.2	0.44	594	34.7	33.8	55	7.6	26
	7-6	Pliocene	Dark olive gray diatom ooze; bedding moderately deformed.	11.1	11.0	0.33	0.68	0.85	591	19.4	1.95	3.6	0.22	592	34.5	34.1	—	7.7	26
	10-4	Pliocene	Dark olive gray clay-rich diatom ooze; bedding moderately deformed.		11.0	0.33	0.75	0.81	590	19.4	1.99	—	—	—	—	33.8	—	7.7	29
	14-3	Upper Miocene	Dark olive gray clay-rich diatom ooze; bedding moderately deformed.	11.0	10.9	0.33	0.89	0.70	586	19.2	1.92	6.9	0.42	589	34.5	33.6	—	8.0	25
	20-5	Upper Miocene	Dark olive gray clay-rich diatom ooze; bedding moderately deformed.	10.6	10.7	0.24	1.51	0.31	573	19.0	1.34	6.2	0.38	569	33.4	33.0	—	7.6	31
	22-6	Upper Miocene	Dark olive gray clayey diatom ooze.	—	10.6	0.20	(1.7) ^g	0.19	—	18.9	1.16	3.4	0.21	562	—	32.2	—	—	24
Site 185 (54°25.7'N, 169°14.6'W, water depth 2,110 m, Umnak Plateau)																			
185-4-6	42	Pleistocene	Dark grayish olive to grayish olive diatom silty clay.	11.0	10.8	0.41	0.09	1.01	569	19.5	0.29	22.2	1.35	577	33.6	33.0	46	7.8	24
	6-6	Pleistocene	Various shades of olive gray silty clay-rich diatom ooze.	11.2	10.9	0.38	0.06	0.81	552	19.3	<0.01	20.1	1.23	564	33.0	32.5	46	8.0	22
	7-5	Pliocene	Dark olive gray to grayish olive silt and clay-rich diatom ooze.		10.8	0.34	0.09	0.80	550	19.2	<0.01	—	—	—	—	32.2	—	7.8	22

TABLE 1 – Continued

Sample	Depth (m)	Age	Description	Na ^a (g/kg)	Na ^b (g/kg)	K (g/kg)	Ca (g/kg)	Mg (g/kg)	Total Cations (meq/kg)	Cl (g/kg)	SO ₄ (g/kg)	Alk. (meq/kg)	HCO ₃ ^c (g/kg)	Total Anions (meq/kg)	Sum ^d (g/kg)	Salinity ^e	H ₂ O (‰) ^f	pH ^f	Si (ppm)
185-8-4	172	Pliocene-Upper Miocene	Dark olive gray to grayish olive clayey to silty diatom ooze.	11.1	10.9	0.33	0.08	0.77	549	19.3	<0.01	16.2	0.99	560	32.6	31.9	–	7.8	27
20-5	668	Upper Miocene	Olive gray diatom-rich silty clay.	10.2	10.4	0.14	1.40	0.15	539	18.7	<0.01	3.5	0.22	533	30.8	30.6	–	8.0	17.0
Site 186 (51°07.8'N, 174°00.3'W, water depth 4,522 m, north wall of Aleutian Trench)																			
186-3-6	18	Upper Pleistocene	Dark greenish gray diatom ooze; gassy; disturbed.	–	10.1	0.38	0.07	0.84	521	17.8	–	34.7	2.12	–	–	30.8	–	8.1	22
6-3	108	Middle Pleistocene	Olive gray diatom silty clay; gassy; disturbed.	9.4	9.1	0.33	0.10	0.72	470	15.7	<0.01	39.4	2.40	482	26.7	27.5	–	8.2	22
9-6	168	Middle Pleistocene	Very dark gray diatom silty clay; gassy; disturbed.	9.2	9.3	0.31	0.09	0.73	476	16.0	<0.01	22.3	1.36	473	27.7	27.8	–	8.0	22
20-4	462	Upper Miocene	Olive gray, spicule bearing diatom silty clay.	10.2	9.9	0.28	0.19	0.68	504	17.3	0.36	21.5	1.31	516	30.3	29.4	–	8.0	20
Site 188 (53°45.2'N, 178°39.6'E, water depth 2,649 m, inner flank of Bowers Ridge)																			
188-3-5	33	Middle Pleistocene	Light olive gray clayey silt rich diatom ooze.	11.0	10.9	0.42	0.40	1.24	605	19.5	2.43	10.7	0.65	612	35.6	35.2	48	7.9	20
6-1	125	Lower Pleistocene	Grayish olive clay-rich diatom silt.	11.0	10.8	0.42	0.29	1.20	594	19.5	2.00	10.9	0.66	604	35.1	35.2	50	8.0	26
9-3	230	Pliocene	Olive gray diatom ooze.	11.1	10.8	0.36	0.20	1.13	583	19.5	1.81	5.5	0.34	594	34.4	34.1	–	7.5	38
Site 189 (54°02.1'N, 170°13.4'E, water depth 3,437 m, northern flank of Aleutian-Komandorsky Ridge)																			
189-4-3	86	Lower Pleistocene	Dark greenish gray diatom bearing silty clay.	10.8	10.8	0.39	0.20	0.90	565	19.2	<0.01	20.7	1.26	563	32.8	33.0	–	8.2	19.8
7-2	298	Pliocene	Olive gray silt-rich diatom-carbonate-pyrite bearing clay.	10.9	10.8	0.26	0.48	0.44	537	18.9	0.24	5.4	0.33	543	31.6	31.1	–	8.2	15.0
Site 190 (55°33.6'N, 171°38.4'E, water depth 3,875 m, Aleutian Basin)																			
190-10-3	153	Lower Pleistocene	Olive gray diatom silty clay to clay-rich silty diatom ooze.	11.1	11.0	0.32	0.40	0.46	544	19.2	<0.01	5.5	0.34	548	31.8	30.8	44	8.2	21
14-6	428	Upper Miocene	Olive gray diatom silty clay.	11.3	10.8	0.28	0.70	0.38	542	18.8	(1.41) ^h	3.8	0.23	563	33.1	30.8	–	8.0	30

TABLE 1 - Continued

Sample	Depth (m)	Age	Description	Na ^a (g/kg)	Na ^b (g/kg)	K (g/kg)	Ca (g/kg)	Mg (g/kg)	Total Cations (meq/kg)	Cl (g/kg)	SO ₄ (g/kg)	Alk. (meq/kg)	HCO ₃ ^c (g/kg)	Total Anions (meq/kg)	Sum ^d (g/kg)	Salinity ^e	H ₂ O (%) ^f	pH ^f	Si (ppm)
Site-191 (56°56.7'N, 168°10.7'E, water depth 3,854 m, Kamchatka Basin)																			
191-4-6	86	Middle Pleistocene	Olive gray silt-rich clayey diatom ooze.	10.7	10.8	0.36	0.18	1.11	580	19.5	<0.01	26.7	1.63	576	33.5	34.4	47	8.0	19.5
5-6	142	Middle Pleistocene	Very dark gray diatom- rich silty clay.	11.2	10.9	0.33	0.10	0.96	567	19.5	<0.01	30.2	1.84	580	33.9	33.8	36	8.3	15.0
Site 192 (53°00.6'N, 164°42.8'E, water depth 3,014 m, Emperor Seamount Chain)																			
192-4-6	26	Pleistocene	Olive gray diatoma- ceous silty clay.	10.5	10.9	0.45	0.35	1.11	592	19.5	0.87	10.0	0.61	578	33.4	34.4	45	8.5	17.0
7-4	78	Pliocene	Dark greenish gray diatomaceous silty clay.	10.8	10.9	0.40	0.27	0.95	575	19.5	0.70	7.7	0.47	572	33.1	33.3	43	8.2	18.5
9-6	128	Pliocene	Dark greenish gray diatomaceous silty clay.	10.9	11.0	0.41	0.25	0.83	570	19.6	0.30	9.2	0.56	567	32.8	33.0	42	8.4	17.5
15-4	274	Upper Miocene	Olive gray clay-rich diatom ooze.	11.2	11.1	0.38	0.28	0.69	563	19.6	0.30	6.2	0.38	567	32.8	32.8	50	8.1	26
17-3	328	Upper Miocene	Dark gray clay-rich diatom ooze.	11.2	11.2	0.38	0.33	0.65	569	19.6	0.37	5.3	0.32	567	32.8	32.5	-	8.2	25

^aSodium determined by difference between anions and cations excluding Na.

^bSodium determined by atomic absorption analysis.

^cHCO₃ is calculated from total alkalinity, assuming this is entirely due to bicarbonate ion.

^dThe sum incorporates the sodium values determined by difference.

^eSalinity of pore fluids taken from heat-sealed sections of plastic pipe prior to subdivision of samples for analysis. Salinity values determined with Goldberg temperature-compensated refractometer.

^fWater content and pH are taken from shipboard summaries.

^gCalcium determined by difference for Sample 184-22-6.

^hThe SO₄ of this sample appears to be in error, as it is considerably higher than would be expected. Such an error would account for the poor agreement between the Na by difference and analysis, and also between the sum and the salinity.