17. INTERSTITIAL WATER STUDIES ON SMALL CORE SAMPLES, LEG 9[1]

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The chemistry of the pore fluids obtained on Leg 9 is remarkable primarily in its constancy. Excepting silicon and strontium, only at one site do the concentrations of the major and minor constituents deviate notably from sea water concentrations (see Tables 1 and 2). The trends, or lack of them, seen in these samples have been discussed previously and only references will be given here. The constancy of composition and similarity to sea water is particularly noteworthy, as the sediments at all of the 9 sites are thought to be intruded by the basal basalt. The pore fluid chemistry exhibits no evidence of intrusion except possibly at Site 84.

The chemical similarity of the interstitial waters and sea water that characterizes almost all of the samples from Sites 76 through 83 is typical of slowly deposited pelagic sediments. The average deposition rates for these sites does not exceed 3 cm/10^3 yr. The relationship between deposition rate and the concentrations of the major and minor ions of pore fluids has been discussed in some detail in the Leg 8 report (Manheim and Sayles, 1971). Large changes relative to sea water are seen only at Site 84 where the sediments are rapidly deposited and contain a high proportion of terrigenous and volcanic material. As noted in the reports of Legs 4 and 5 (Sayles *et al.*, 1970; Manheim *et al.*, 1970), such conditions characteristically produce large changes in the concentrations of the major and minor constituents.

The large (10-fold) increase in silicon is characteristic of virtually all pore fluids and reflects silicate solubility. The values in excess of 20 ppm silicon are characteristic of sediments containing biogenic amorphous silica. Samples containing 6 to 15 ppm silicon reflect the absence of amorphous silica and equilibration with crystalline silicates–usually clay or feldspar (Site 76). Shallow samples (less than 20 meters) commonly exhibit intermediate concentrations (15 to 20 ppm silicon) despite the presence of biogenic silica. This may reflect diffusional loss, but more probably, is due to sea water contamination of these very soft sediments. The moderate increases in strontium seen in the samples from Site 77 are thought to result from carbonate re-crystallization (see Manheim and Sayles, 1971).

All of the basal basalts encountered were interpreted in the Hole Summaries as being intruded into the sediments. The criteria upon which this interpretation is based are the presence of a "baked" contact, the presence of "hydrothermal" minerals (iron oxides, "hydrothermal" clay, rhodocrosite, dolomite, tridymite), brecciation of the overlying bed, or any combination of these. The contact effects are usually seen only in samples within 10 to 15 centimeters of the basalt; in all cases, up to 5 meters of sediment are missing near the contact and, consequently, the exact thickness of the alteration cannot be determined. In some instances no contact was recovered and the presence of tridymite is used as the sole criterion for suggesting an intrusive relationship.

The chemistry of the pore fluids provides no evidence of any alteration of chemical reaction attendant with intrusion. Diffusion has completely erased the changes in concentration that must have been produced by the large temperature increase adjacent to the contacts of the sediments with the basalts. This is not surprising as the interval of time available for re-adjustment is probably on the order of tens of millions of years. Previous data (Sayles and Manheim, 1971) has demonstrated the efficacy of diffusion in controlling concentration gradients in biogenic sediments.

Several studies have documented reaction between carbonates and adjacent basalts and between basalts and solutions of sea water composition. Murata and Erd (1964) and Thompson *et al.* (1968) have suggested that interaction between basalts and the overlying calcareous deposits commonly lead to lithification and re-crystallization of the sediments adjacent to the contacts. The lithified limestone reported in the Hole Summaries may be of this origin. Studies of submarine weathering of basalts reveal enrichment of some elements in the reaction products, notably boron (Thompson and Melson, 1970) and potassium (Hart, 1969).

At three sites on Leg 9 (77, 79, 81) interstitial water samples were collected within two or three meters of the basalt sediment contact. Any interaction currently occurring between the basalt and the sediments should produce chemical changes that are discernible in these pore fluids. The boron data presented in Table 2 show no significant deviation from sea water concentrations

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TABLE 1
Major Constituents of Pore Fluids from Leg 9.
Values in g/kg (°/oo) Except as Noted

Sample Designation	Depth (m)	Age	Description	Na[a]	Na[b]	K	Ca
Hole 76 (14° 05.9'S, 145° 39.6'W, water depth 4598 m, N. of Tuamotu Ridge)							
1-6	8	Pleistocene (?)	Dusky brown phillipsite clay mud	10.8	10.7	0.47	0.42
Hole 76A (14° 05.9'S, 145° 39.6'W, water depth 4598 m, N. of Tuamotu Ridge)							
1-4	6	Lower Pliocene-Pleistocene	Yellow brown foraminiferal-nannofossil ooze	10.8	10.8	0.44	0.44
2-2	22	Lower Pliocene-Pleistocene	Dusky brown nannofossil-phillipsite clay mud	11.0	10.9	0.48	0.45
Hole 77B (00° 28.9'N, 133° 13.7'W, water depth 4291 m)							
1-5	14	Pleistocene	Varicolored interlaminated beds of foraminiferal-radiolarian-nannofossil ooze	10.7	10.6	0.43	0.42
8-4	78	Pliocene	Varicolored interlaminated beds of foraminiferal-radiolarian-nannofossil ooze	10.8	10.9	0.42	0.43
18-6	167	Upper Miocene	Varicolored interlaminated beds of foraminiferal-radiolarian-nannofossil ooze	10.6	10.6	0.47	0.45
28-4	255	Lower Miocene	Varicolored interbedded foraminiferal-radiolarian-nannofossil chalk	10.9	10.4	0.42	0.46
38-6	346	Upper Oligocene	White foraminiferal-nannofossil chalk	10.9	10.7	0.41	0.45
42-5	381	Upper Oligocene	White foraminiferal-radiolarian-nannofossil chalk	10.7	10.5	0.41	0.41
51-6	464	Lower Oligocene	White foraminiferal-radiolarian-nannofossil ooze chalk	10.8	10.8	0.40	0.42
52-CC	467	Lower Oligocene	Dusky brown nannofossil-clay mudstone	10.5	10.5	0.33	0.44
Hole 78 (07° 57.0'N, 127° 21.4'W, water depth 4378 m, N. of Clipperton Fracture Zone							
1-5	8	Middle Miocene	Pale orange clay-nannofossil chalk ooze	10.7	10.8	0.42	0.41
10-0	81	Lower Miocene	Very pale orange foraminiferal-radiolarian-nannofossil-chalk ooze	10.6	10.9	0.42	0.42
15-4	131	Lower Miocene	Bluish-white foraminiferal-radiolarian-nannofossil chalk	10.8	10.6	0.43	0.44
25-5	224	Upper Oligocene	Light greenish gray foraminiferal-radiolarian-nannofossil chalk	10.6	10.7	0.44	0.42
33-4	294	Upper Oligocene	Very pale yellow-orange foraminiferal-nannofossil chalk	10.9	10.7	0.41	0.39

Mg	Total Cations (meq/kg)	Cl	SO_4	Alk. (meq/kg)	HCO_3	Total Anions (meq/kg)	Sum[d]	Refractometer	H_2O (°/oo)	*p*H
1.16	594	19.29	2.59 (2.48)	4.4 (3.5)*	0.27 (0.22)	600	34.9	35.3	60	7.8
1.23	604	19.39	2.50 (2.70)	3.4 (3.6)	0.21 (0.22)	604	35.0	35.2	56	7.7
1.16	604	19.47	2.65 (2.64)	4.9 (4.6)	0.30 (0.28)	608	35.4	35.3	–	7.6
1.25	596	19.41	2.60 (2.60)	3.5	0.21	604	34.9	35.3	47	7.6
1.18	603	19.36	2.50	4.8 (4.0)	0.29 (0.25)	601	35.1	35.0	69	7.5
1.14	589	19.38	2.35 (2.38)	5.3 (4.5)	0.33 (0.28)	590	34.7	35.0	55	7.6
1.12	578	19.26	2.96 (2.43)	5.3 (4.1)	0.32 (0.25)	603	34.9	35.0	59	7.7
1.12	591	19.33	2.37 (2.45)	5.7 (5.3)	0.35 (0.33)	600	34.7	35.0	–	7.6
1.20	587	19.48	2.02 (2.41)	3.5 (4.0)	0.22 (0.24)	599	34.2	35.2	29	7.7
1.23	602	19.36	2.50 (2.70)	4.2 (4.2)	0.26 (0.25)	604	35.0	35.5	29	7.8
1.18	584	18.84	2.52	2.7	0.17	586	34.0	34.2	–	7.7
1.25	604	19.26	2.60	3.7	0.22	601	35.0	35.2	69	7.7
1.15	600	18.84	2.59	4.8	0.29	590	34.6	34.6	61	7.9
1.16	589	19.39	2.46	4.7	0.29	602	34.8	35.0	34	7.7
1.15	592	19.42	2.46	4.4	0.27	602	34.9	35.0	59	7.7
1.22	600	19.41	2.58	4.9	0.30	606	35.0	35.2	–	7.8

TABLE 1 – *Continued*

Sample Designation	Depth (m)	Age	Description	Na[a]	Na[b]	K	Ca
Hole 79 (02° 33.0′N, 121° 34.0′W, water depth 4574 m)							
1-4	5	Pleistocene	Varicolored interbedded foraminiferal-nannofossil-radiolarian ooze & chalk ooze, some clay	10.8	10.8	0.43	0.39
4-5	201	Middle Miocene	Bluish white & bluish gray nannofossil-radiolarian chalk ooze and chalk	10.5	10.9	0.43	0.43
8-CC	352	Lower Miocene	Grayish-pink orange & very pale orange nannofossil-radiolarian oozes	10.5	10.9	0.45	0.46
16-3	408	Lower Miocene	Very pale orange foraminiferal-nannofossil-radiolarian chalk with about 1% clay	11.0	10.9	0.41	0.42
Hole 80 (00° 57.7′S, 121° 33.2′W, water depth 4411 m)							
1-6	8	Pleistocene	Varicolored interbedded foraminiferal-nannofossil-radiolarian oozes	10.6	10.6	0.42	0.42
2-4	67	Upper Miocene	Varicolored; interbedded, 5-75 cm beds; foraminiferal-nannofossil-radiolarian oozes	10.9	10.8	0.42	0.43
5-6	194	Lower Miocene	Varicolored; interbedded, 5-25 cm beds; clay-nannofossil-chalk mudstones	–	10.6	0.38	(0.43)
Hole 80A (00° 57.7′S, 121° 33.2′W, water depth 4411 m)							
4-6	117	Lower Miocene	Very pale orange foraminiferal-nannofossil chalks	10.8	10.8	0.44	0.44
Hole 81 (01° 26.5′N, 113° 48.5′W, water depth 3865 m, W. side of the E. Pacific Rise)							
1-6	8	Pliocene	Varicolored; interbedded, 2-25 cm sharp contacts; foraminiferal-nannofossil-radiolarian oozes	10.5	10.6	0.41	0.41
2-3	323	Middle Miocene	Varicolored; interbedded, mottling throughout; nannofossil-radiolarian oozes	10.9	10.8	0.44	0.41
6-CC	409	Lower Miocene	Yellow brown foraminiferal-nannofossil chalk with iron oxide, clay and pyrite	10.6	10.8	0.33	0.40
Hole 82 (02° 35.5′N, 106° 56.5′W, water depth 3707 m, W. side of Ridge Crest)							
1-1	Surface of Sediment	Pleistocene	Dark yellow brown foraminiferal-nannofossil-radiolarian ooze with about 15% clay	10.8	10.7	0.40	0.39

Mg	Total Cations (meq/kg)	Cl	SO_4	Alk. (meq/kg)	HCO_3	Total Anions (meq/kg)	Sum[d]	Refractometer	H_2O (°/oo)	pH
1.22	601	19.27	2.71	3.4	0.21	602	35.0	35.0	50	7.7
1.21	606	19.22	2.14	3.9	0.24	590	34.6	35.0	49	7.7
1.17	605	19.43	1.77	4.0	0.24	588	34.4	35.0	–	7.6
1.22	606	19.60	2.83	3.4	0.21	614	35.6	35.5	27	7.6
1.28	598	19.24	2.66	3.0	0.18	600	34.8	35.0	49	7.5
1.23	603	19.52	2.66	4.5	0.27	609	35.3	35.3	52	7.7
1.17	588	19.25	2.51	3.3	0.20	599	34.5	35.2	–	7.7
1.20	602	19.44	2.53	3.4	0.21	603	35.1	35.3	41	7.6
1.22	592	19.30	2.07	2.9	0.18	590	34.2	35.0	50	7.6
1.13	595	19.39	2.52	3.8	0.23	603	34.9	35.0	42	7.6
1.23	600	19.03	2.57	2.6	0.16	593	34.5	35.0	–	7.7
1.22	595	19.20	2.82	3.1	0.19	602	34.9	35.0	58	7.6

TABLE 1 – *Continued*

Sample Designation	Depth (m)	Age	Description	Na[a]	Na[b]	K	Ca
Hole 82 – *Continued*							
3-4	142	Upper Miocene	Varicolored; thinly interbedded; foraminiferal-nannofossil-radiolarian chalk oozes w/glc.	10.7	10.6	0.40	0.40
5-6	200 ?	Upper Miocene	Dark colored foraminiferal-nannofossil-radiolarian chalk	10.7	10.6	0.39	0.41
Hole 83 (04° 02.8'N, 95° 44.2'W, water depth 3646 m, E. side of Ridge Crest)							
1-2	2	Pleistocene	Foraminiferal-nannofossil-radiolarian ooze with 30-40% clay	10.7	10.9	0.42	0.39
7-4	228	Middle Miocene	Varicolored; thin mottled beds; nannofossil-radiolarian chalk oozes.	10.6	10.8	0.42	0.42

*( ) indicates replicate samples carried through the entire analytical procedure.

[a] Sodium determined by differences between anions and cations excluding Na.

[b] Sodium determined directly. Values in parenthesis refer to separate samples carried through the entire sampling and analytical processes. The total cation values shown are determined using these values and means of duplicate determinations, where available.

[c] HCO_3 is calculated from total alkalinity, assuming this is entirely due to bicarbonate ion.

[d] The sum incorporates the calculated Na values and means of replicate value where available. Minor constituents are not included but, with the exception of strontium in some samples, contribute less than 0.1 ‰ to the sum.

[e] *p*H and water content are taken from shipboard summaries.

Mg	Total Cations (meq/kg)	Cl	SO_4	Alk. (meq/kg)	HCO_3	Total Anions (meq/kg)	Sum[d]	Refractometer	H_2O ($^{\circ}/_{\circ\circ}$)	*p*H
1.24	593	19.46	2.30	3.8	0.24	600	34.6	35.0	53	7.5
1.19	589	19.10	2.57	4.2	0.26	596	34.5	34.9	–	7.7
1.22	605	19.20	2.67	3.4	0.27	599	35.1	35.0	61	7.6
1.25	605	19.44	2.20	2.9	0.18	596	34.7	35.5	60	7.7

TABLE 2
Minor Constituents, Leg 9[a]. Concentrations in mg/kg (ppm)

Sample Designation	Depth (m)	Age	Description	B	Sr	Si (col)
Holes 76 and 76A						
76-1-6	8	Pleistocene (?)	Dusky brown phillipsite clay mud	–	–	8 (8)
76A-1-4	6	Lower Pliocene-Pleistocene	Yellow brown foraminiferal-nannofossil ooze	4.5	8.0	8 (8)
2-2	22	Lower Pliocene-Pleistocene	Dusky brown nannofossil-phillipsite clay mud	5.0 (6.1)*	8.8 (9.6)	11 (11)
Hole 77B						
1-5	14	Pleistocene	Varicolored interlaminated beds of foraminiferal-radiolarian-nannofossil ooze	4.5 (4.5)	12.4 (12.6)	17 (19)
8-4	78	Pliocene	Varicolored interlaminated beds of foraminiferal-radiolarian-nannofossil ooze	5.6 (5.6)	31 (29)	27 (26)
18-6	167	Upper Miocene	Varicolored interlaminated beds of foraminiferal-radiolarian-nannofossil chalk ooze	4.5	36	35 (34)
28-4	255	Lower Miocene	Varicolored interbedded foraminiferal-radiolarian-nannofossil chalk	4.0 (4.0)	37 (34)	26 (26)
38-6	346	Upper Oligocene	White foraminiferal-nannofossil chalk	4.3 (5.0)	24 (27)	26 (27)
42-5	381	Upper Oligocene	White foraminiferal-radiolarian-nannofossil chalk	4.5 (4.0)	18.8 (18.0)	27 (26)
51-6	464	Lower Oligocene	White foraminiferal-radiolarian-nannofossil ooze chalk	4.5 (5.6)	12.0 (11.6)	25 (24)
52-CC	467	Lower Oligocene	Dusky brown nannofossil-clay mudstone	4.5	9.6	26
Hole 78						
1-5	8	Middle Miocene	Pale orange clay-nannofossil chalk ooze	4.0	7.9	16
10-0	81	Lower Miocene	Very pale orange foraminiferal-radiolarian-nannofossil chalk ooze	4.0	8.5	15
15-4	131	Lower Miocene	Bluish-white foraminiferal-radiolarian-nannofossil chalk	4.0	11.0	26
25-5	224	Upper Oligocene	Light greenish gray foraminiferal-radiolarian-nannofossil chalk	4.5	11.4	30
33-4	294	Upper Oligocene	Very pale yellow-orange foraminiferal-nannofossil chalk	3.5	10.3	26
Hole 79						
79-1-4	5	Pleistocene	Varicolored interbedded foraminiferal-nannofossil-radiolarian ooze & chalk ooze, some clay	4.0	7.5	21

TABLE 2 – *Continued*

Sample Designation	Depth (m)	Age	Description	B	Sr	Si (col)
Hole 79 – *Continued*						
4-5	201	Middle Miocene	Bluish white & bluish gray nannofossil-radiolarian chalk ooze and chalk	4.3	15.8	23
8-CC	352	Lower Miocene	Grayish-pink orange & very pale orange nannofossil-radiolarian chalk oozes	4.8	17.9	32
16-3	408	Lower Miocene	Very pale orange foraminiferal-nannofossil-radiolarian chalk with about 1% clay	4.6	10.0	29
Holes 80 and 80A						
80-1-6	8	Pleistocene	Varicolored interbedded foraminiferal-nannofossil-radiolarian oozes	4.4	9.8	23
2-4	67	Upper Miocene	Varicolored; interbedded, 5-75 cm beds; foraminiferal-nannofossil-radiolarian oozes	4.7	11.9	27
5-6	194	Lower Miocene	Varicolored; interbedded, 5-25 cm beds; clay-nannofossil-chalk mudstones	4.8	10.2	21
80A-4-6	117	Lower Miocene	Very pale orange foraminiferal-nannofossil chalks	3.9	11.9	28
Hole 81						
81-1-6	8	Pliocene	Varicolored; interbedded, 2-25 cm sharp contacts; foraminiferal-nannofossil-radiolarian oozes	4.6	12.6	22
2-3	323	Middle Miocene	Varicolored; interbedded; mottling throughout; nannofossil-radiolarian oozes	4.2	22	40
6-CC	409	Lower Miocene	Yellow brown foraminiferal-nannofossil chalk with iron oxide, clay and pyrite	4.6	8.0	31
Hole 82						
82-1-1	Surface of Sediment	Pleistocene	Dark yellow brown foraminiferal-nannofossil-radiolarian ooze with about 15% clay	4.7	7.6	18
3-4	142	Upper Miocene	Varicolored; thinly interbedded; foraminiferal-nannofossil-radiolarian chalk oozes w/glc.	3.8	9.9	30
5-6	200 ?	Upper Miocene	Dark colored foraminiferal-nannofossil-radiolarian chalk	3.7	7.5	26
Holes 83 and 83A						
83-1-2	2	Pleistocene	Foraminiferal-nannofossil-radiolarian ooze with 30-40% clay	4.5	8.1	14

TABLE 2 – *Continued*

Sample Designation	Depth (m)	Age	Description	B	Sr	Si (col)
Holes 83 and 83A – *Continued*						
83-7-4	228	Middle Miocene	Varicolored; thin mottled beds; nannofossil-radiolarian chalk oozes	3.9	8.0	35
83A-10-6	103	Pliocene	Light bluish-green and gray green, foraminiferal-nannofossil-radiolarian oozes	4.2	8.5	32
83A-14-6	166	Upper Miocene	Light gray-green foraminiferal-nannofossil-radiolarian ooze	4.5	8.0	33
Hole 84						
84-1-4	6	Pleistocene	Varicolored; interbedded, 1-75 cm; foraminiferal-nannofossil-radiolarian oozes w/glc.	5.2	12.4	19
9-5	80	Pleistocene	Olive gray foraminiferal-nannofossil-radiolarian chalk ooze with g/c. and volc.	4.7	19.2	36
17-1	145	Pliocene	Light greenish-gray foraminiferal-nannofossil-radiolarian chalk with volc.	4.5	27	42
27-5	242	Upper Miocene	Light greenish-gray-bluish white foraminiferal-nannofossil-radiolarian chalk	4.9	18.9	45

[a]Analysis for Ba was carried out but standard results were erratic below 0.3 ppm. No sample concentrations exceeded this value.

Note: *(Duplicate values in parentheses)

(4.6 ppm) for the samples adjacent to basalts (77B-52-CC, 79-16-3, 81-6-CC). It appears that reactions leading to the enrichment of boron in the weathering products are not currently taking place.

The case for potassium is not so clear as regards reaction of the basalts with the interstitial solutions. At two sites (77 and 81) noticeable depletions of potassium are recorded in the pore water samples adjacent to the basalt-sediment contact. At the third site (79) a slight enrichment (0.02 g/kg) is seen. Frequently we have found that potassium is depleted in clayey sediments. Preliminary lithologic descriptions in the Hole Summaries note that clay is a significant component of the 77B-52-CC and 81-6-CC sediments, the two samples with low potassium concentrations. The absence of potassium depletion in Sample 79-16-3 and the lack of alteration of the boron contents lead us to conclude that no appreciable reaction is presently occurring between the basalts and the overlying sediments. The depletion of potassium observed in the samples from Sites 77 and 81 is attributable to reaction in the clayey sediments overlying the basalts.

On the basis of the data presented here, it is apparent that reaction between the basalt, the overlying sediments, and the interstitial solutions is very limited at normal *in situ* temperatures. Either these reactions are not occurring presently or they proceed at a rate that is slow relative to diffusion. The zone of sediment affected, at least in the examples examined here, is normally only a few centimeters thick, at most a few tens of centimeters.

The apparent lack of continuing reaction, noted above, implies that where lithification occurs, it happens relatively early in the history of the basalt-sediment assemblage. The lithification may be the result of heating of the sediment through intrusion or reaction at normal *in situ* temperatures. These reactions appear to be self-limiting, probably as a result of control by very slow diffusion through the reaction products (lithified carbonate sediment and weathered basalt). Whatever the control, the reactions are very limited in extent even though the time scale is possibly tens of millions of years; they are of little consequence in the diagenesis of the overlying sediments.

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