

34. INTERSTITIAL WATER STUDIES, LEG 81¹

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ABSTRACT

Interstitial water studies on samples obtained during Leg 81 have revealed substantial changes with depth in dissolved calcium, magnesium, strontium, potassium, and lithium. Calcium and magnesium concentration changes result from alteration reactions, primarily in the basalts and also in the volcanic sediments overlying the basalts. Similarly, depletions in potassium are the result of reactions in volcanic sections of the drill holes. Lithium has its main source in the volcanic sediments. On the other hand, strontium-concentration maxima occur at the ooze-chalk boundary and are the result of carbonate recrystallization reactions. Distinct correlations between calcium gradients and extents of concentration maxima in strontium with sedimentation rates suggest (1) build up of calcium concentrations below diffusion communication depth and (2) increased rates of recrystallization of carbonate with rate of sedimentation. The latter process is probably related to the more "corrosive" character of the sediments as the result of organic carbon diagenesis.

INTRODUCTION

During Leg 81 of the Deep Sea Drilling Project (DSDP), four sites were drilled in the vicinity of Sites 403 and 404 on the margins of the Rockall Plateau (Fig. 1). Our previous work (Ellis et al., 1979) at Sites 403-406 of Leg 48 revealed large concentration gradients in calcium and magnesium, but unfortunately no deep penetrations to igneous basement rocks were accomplished. Similarly Manheim et al. (1972) established concentration gradients in calcium and magnesium at Site 116, whereas one data point level at Site 117 (~223 m sub-bottom) also revealed a large increase in calcium and a decrease in magnesium. Sites 552-555 of Leg 81 did reach volcanic basement rocks and thus represent a far more complete picture of the concentration gradients of interstitial water constituents.

In this chapter we present the data obtained both on *D. V. Glomar Challenger* and in our own laboratory on interstitial waters obtained during Leg 81. Studies of the oxygen isotope composition of the waters and the strontium isotope composition of dissolved strontium are presently underway, and these studies will in the future serve to constrain the mechanisms of the reactions postulated in this chapter as the cause of observed concentration changes.

METHODS AND RESULTS

Shipboard analyses comprised determination of pH, alkalinity, salinity, chloride, calcium, and magnesium. In our shore laboratory we determined values of strontium, lithium, potassium, sulfate, ammonia, and silica. Methods used have been described by Gieskes (1974), Gieskes and Lawrence (1976), and Gieskes et al. (1982).

All the data are tabulated in Table 1 and are graphically represented in Figures 2, 3, 4 and 5 (Sites 552, 553, 554, and 555).

DISCUSSION

Before presenting a general discussion of the data obtained in this study it appears appropriate to describe

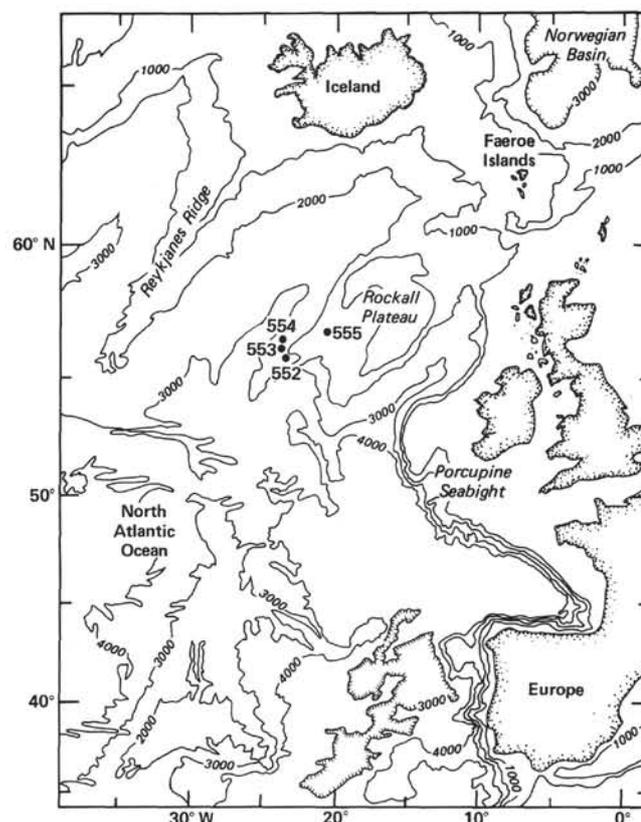


Figure 1. Map of Leg 81 sites.

the results of each individual site. Sedimentation rates over the last 50 m.y. are summarized in Figure 6.

Site 552 (Fig. 2)

The upper 173 m of the sediment column have been deposited at rates of ~20 m/m.y. These sediments consist primarily of foram-nannofossil oozes, which turn into chalks at ~142 m and deeper. Below 174.5 m depth volcanic contributions become increasingly important, with basalt occurring at 283 m.

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Table 1. Interstitial water chemistry, Leg 81.

Sample (interval in cm)	Sub-bottom depth (m)	pH	Alk meq (dm ⁻³)	S (g/kg)	Ca (mM)	Mg (mM)	Cl (g/kg)	Sr (μm)	Li (μm)	K (mM)	SO ₄ (mM)	NH ₄ (μm)	Si (μm)
Hole 552													
1-2, 144-150	3	7.41	2.82	36.8	11.1	52.7	19.51	115	31.3	10.6	26.8	0	354
3-3, 144-150	113	7.22	3.22	36.0	16.2	48.3	19.63	460	47.1	10.0	—	0	889
6-4, 114-120	141	7.21	3.11	36.0	17.7	46.6	19.61	460	52.3	9.9	24.9	0	788
9-4, 114-120	170	7.29	2.55	36.0	18.1	47.8	19.34	426	67.6	9.0	—	0	889
12-6, 144-150	203	7.44	1.87	36.0	19.5	47.2	19.51	382	67.1	9.0	25.3	0	743
16-1, 85-95	232	7.86	1.09	36.3	29.6	46.3	19.40	236	66.6	8.5	—	0	583
21-2, 135-150	282	7.17	0.64	36.6	33.0	44.3	19.73	194	71.4	7.1	24.4	0	346
Hole 552A													
6-3, 144-150	28	7.42	2.66	36.0	11.9	51.7	19.29	213	29.2	11.0	29.2	0	411
12-3, 144-150	59	7.27	3.15	36.3	13.3	50.7	19.44	345	31.4	10.3	27.4	0	585
18-3, 144-150	86	7.25	3.32	36.0	14.6	50.2	19.34	403	36.6	9.9	27.5	0	770
24-2, 144-150	112	7.29	3.34	36.0	15.7	48.4	19.54	429	47.2	9.8	27.5	0	744
30-2, 144-150	142	7.28	3.07	36.0	16.5	47.6	19.48	444	47.1	9.6	26.6	0	774
38-3, 144-150	183	7.24	2.90	36.0	17.9	46.8	19.62	443	62.6	9.6	26.3	0	876
Hole 553													
1-5, 144-150	8	7.39	2.98	35.8	11.1	53.3	19.43	120	31.3	11.6	26.3	0	412
Hole 553A													
4-4, 144-150	186	7.07	2.78	36.3	22.9	41.5	19.78	620	70.9	8.8	—	130.3	911
7-2, 140-150	211	7.09	2.59	36.3	24.2	41.1	19.73	564	72.8	7.8	23.7	124.8	962
11-2, 140-150	249	7.59	1.47	36.3	26.3	39.6	19.82	488	82.2	6.9	—	113.1	714
14-6, 140-150	284	7.85	0.69	35.2	30.4	36.7	19.65	402	76.5	6.68	25.7	127.5	147
18-1, 140-150	314	7.95	—	36.3	34.7	32.7	19.97	—	—	—	—	—	—
21-1, 140-150	343	7.87	—	35.8	37.2	31.6	19.68	—	—	—	—	—	—
24-1, 135-150	380	8.08	0.53	36.0	40.1	30.8	20.09	236	76.5	4.7	—	0	173
27-4, 140-150	404	7.92	0.66	36.6	44.7	31.6	20.28	236	76.4	4.3	24.8	0	152
37-5, 140-150	501	7.70	0.44	36.3	52.2	25.9	20.34	215	86.5	3.3	—	0	320
Hole 554													
1-4, 144-150	6	7.43	2.86	36.3	10.8	52.8	19.41	104	31.3	11.4	28.6	0	375
5-6, 144-150	47	7.37	3.16	36.0	11.8	52.3	19.61	156	31.4	11.0	27.5	0	559
7-4, 144-150	63	7.37	2.86	36.3	11.9	52.0	19.65	180	20.9	10.9	27.4	0	735
Hole 554A													
3-1, 144-150	97	7.38	2.65	37.1	11.9	51.8	19.53	179	26.0	10.7	27.4	0	556.4
6-2, 140-150	127	7.48	—	36.6	11.3	49.0	19.22	—	—	—	—	—	—
Hole 555													
2-3, 144-150	10	7.43	2.90	35.8	10.8	52.6	19.44	114	31.3	11.5	29.2	0	219
5-5, 144-150	42	7.33	3.02	36.0	11.2	53.5	19.64	156	31.4	10.7	—	0	637
8-5, 144-150	70	7.36	3.02	36.3	11.6	54.4	19.93	172	26.1	10.5	28.6	0	559
9-2, 144-150	94	7.37	2.78	37.1	11.5	52.9	19.51	208	20.8	10.6	—	0	573
11-2, 144-150	132	7.33	3.47	36.6	12.5	53.3	19.10	257	20.9	11.0	28.7	0	624
15-1, 144-150	169	7.31	3.68	36.0	12.7	51.5	19.64	305	26.3	9.7	—	0	762
19-2, 144-150	208	7.23	4.06	35.8	13.5	50.6	19.51	332	31.7	9.9	27.8	15.0	1018
22-1, 144-150	235	7.29	3.59	35.8	13.5	50.6	19.51	—	—	—	—	—	—
25-5, 141-149	270	7.25	3.91	37.1	14.7	52.6	20.45	321	36.9	8.2	—	0	579
31-1, 140-150	321	8.05	1.24	35.5	17.3	46.0	19.36	258	66.7	7.3	25.4	0	61
34-4, 140-150	354	7.48	1.25	35.5	18.7	46.0	19.53	251	97.5	7.0	—	87.4	20
37-2, 140-150	379	7.44	1.51	35.2	21.7	43.0	19.64	246	107.9	5.9	25.9	143.1	20
40-5, 140-150	412	7.28	0.73	35.2	24.5	39.6	19.34	250	112.5	5.7	—	128.0	61
43-3, 140-150	438	7.61	0.88	35.2	25.0	40.7	19.12	230	117.8	5.0	25.4	20.5	179
46-5, 140-150	469	7.47	1.41	36.3	26.1	41.7	19.48	210	107.9	5.0	—	0	195
48-4, 96-106	486	7.43	0.98	36.3	26.4	45.0	19.90	209	102.4	4.7	26.9	0	20
52-1, 140-150	520	7.39	1.19	36.6	26.0	46.1	19.93	184	97.5	4.8	—	0	20
55-1, 140-150	549	7.53	—	35.5	32.7	37.4	19.14	—	—	—	—	—	—
58-3, 140-150	580	7.41	—	35.5	41.3	29.8	19.56	—	—	—	—	—	—
61-3, 140-150	609	7.73	0.57	35.5	47.3	25.8	19.32	257	153.0	3.4	22.2	15.1	15
67-4, 140-150	666	7.29	—	36.3	62.7	20.6	19.59	—	—	—	—	—	—
88-4, 140-150	867	7.93	0.22	36.6	109.1	1.2	19.14	322	125.0	2.6	22.0	98.6	20
92-3, 0-10	902	8.08	—	38.5	128.3	0.2	20.00	—	—	—	—	—	—

Note: Dash equals no data.

Sedimentation rates of ~20 m/m.y. usually are associated with only minor decreases in dissolved sulfate as a result of sulfate reduction processes (cf., Table 1).

Concentration gradients in dissolved calcium and magnesium are linear in the upper 200 m, below which a relatively rapid increase in dissolved calcium occurs. Apparently the main sink for magnesium occurs in the underlying basalts, whereas dissolved calcium is also produced in the lower ~100 m of volcanic sediments.

Dissolved strontium shows a clear maximum at ~150 m, i.e., close to the boundary of the ooze-to-chalk transition zone. Clearly this strontium is released by calcium carbonate shells during the carbonate recrystallization

process (Baker et al., 1982). In the lower-lying volcanic sediments strontium concentrations are much lower, presumably as a result of uptake in the alteration products of volcanic matter.

Potassium has its principal sink in the underlying sediments and/or basalt.

Lithium concentrations increase rapidly below ~150 m, i.e., in the siliceous-volcanic zone. We believe that the source of this lithium is the alteration of volcanic matter or of biogenic silica (see also Gieskes, 1981).

Dissolved silica concentrations reflect the presence of biogenic silica in the upper 200 m, the lower sediment column shows lower concentrations, mostly as a result

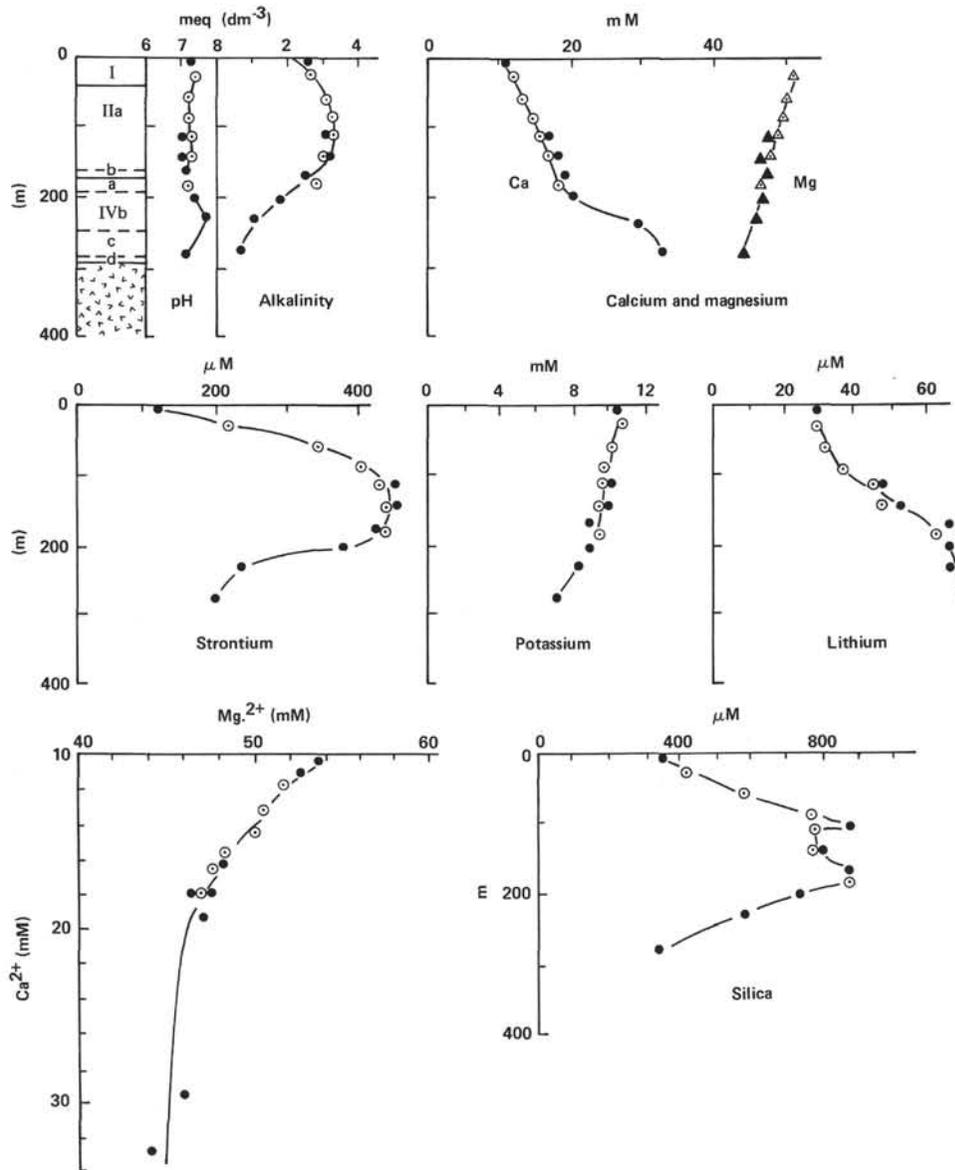


Figure 2. Interstitial water chemistry, Site 552. Lithologic Unit I. Foram-nanno ooze. Subunit IIa. Foram-nanno ooze, biogenic silica; chalk increases below 142 m. Subunit IIb. Nanno-foram chalk. Unit III. Foram-nanno chalk with Mn-nodules at base. Subunit IVa. Nannochalk-tuffs-chert at base. Subunit IVb. Calcareous-biosiliceous volcanic ash; tuffs. Subunit IVc. Nannochalk, marlstones, chert. Subunit IVd. Ferruginous diatom claystone. (Open symbols = Hole 552A; closed symbols = Hole 552).

of the transformation of biogenic silica to siliceous mudstones and cherts.

Site 553 (Fig. 3)

Interstitial water data obtained at this site show strong similarities to those obtained at Site 552. Concentration gradients are more pronounced for all components, especially dissolved calcium, magnesium, strontium, and potassium. The most logical explanation for this phenomenon is that Pleistocene-Pliocene sedimentation rates at Site 553 have been higher at this site than at Site 552. Estimated accumulation rates in the upper 217 m are 25–26 m/m.y., compared to ~20 m/m.y. at Site 252.

Dissolved calcium has its principal source in the underlying basalts. Dissolved magnesium does show concentration depth variations that suggest uptake in the volcanic sediments as well as in the underlying basalts.

Dissolved lithium has its principal source in the volcanic section, whereas dissolved potassium shows a large concentration decrease and seems to have a sink both in the volcanic sediments and in the underlying basalts.

Site 554 (Fig. 4)

This site has been characterized by very slow sedimentation rates since the Pleistocene (during which rates were 20–30 m/m.y.). The chalk transition is at 95 m and

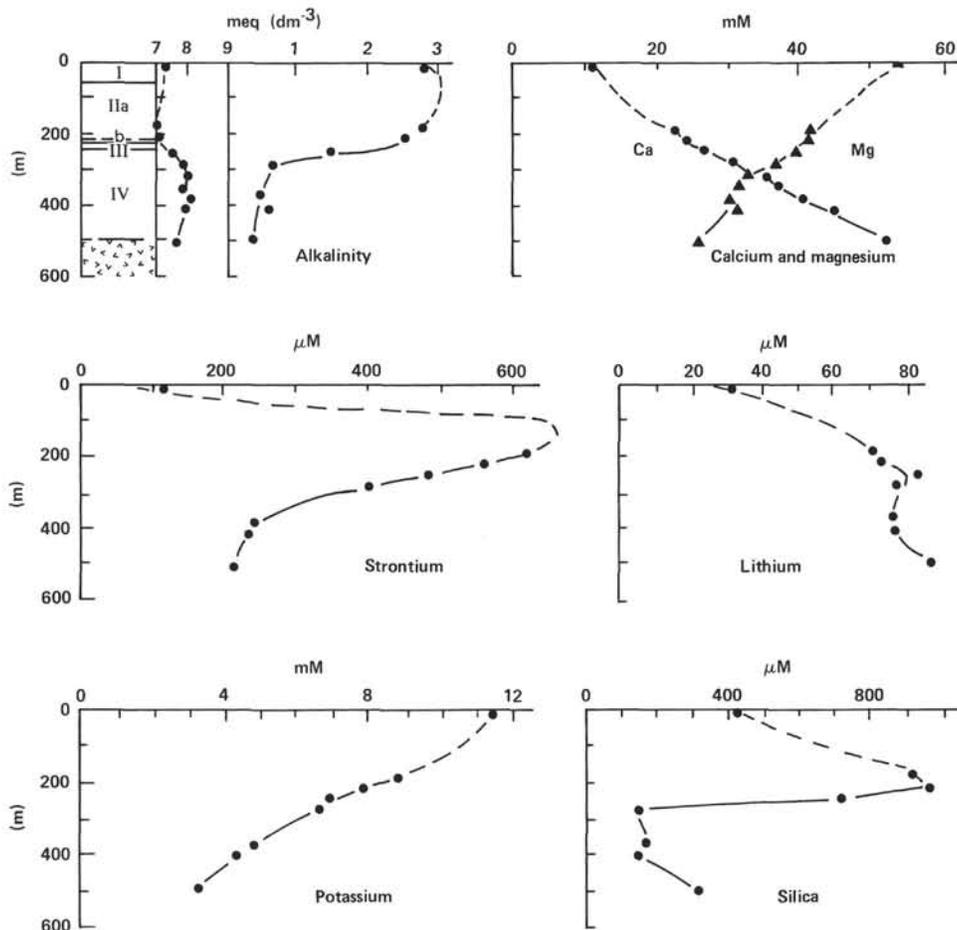


Figure 3. Interstitial water chemistry, Site 553. Lithologic Unit I. Unknown. Subunit IIa. Nanno ooze and foram-nanno ooze. Subunit IIb. Foram chalk. III. Nanno-foram chalk with Mn-nodules at base. Unit IV. Volcanic sediments and tuffs.

tuffaceous marlstones occur below a depth of 119 m and grade into basalt flows at 127 m.

The general characteristic of this site is the virtual absence of significant concentration gradients. The decrease in magnesium at the base of the sediment column may well be in error. The maximum in strontium is much less pronounced than at Sites 552 and 553, but still indicates that active recrystallization occurs at the ooze-chalk boundary (~95 m). We will later consider the problem of the near absence of concentration gradients at this site in greater detail.

Site 555 (Fig. 5)

Site 555 has been characterized by relatively slow sedimentation rates during the last ~15 m.y. (about 16–18 m/m.y., cf. Fig. 6).

Changes in calcium and magnesium in the upper 300 m are very small—that is, in Units I and II, which consist mostly of calcareous oozes and chalks. The ooze/chalk transition occurs at ~250 m, at which depth once again a maximum in dissolved strontium is observed.

Below 300 m concentration gradients increase, roughly at the level where the first distinct decreases in porosity are observed. Especially between 350 and 420 m very low porosities characterize the sediments. At reduced porosities, changes in gradients are typically expected

(McDuff, 1978). A sink for magnesium must be located at ~400 m, probably associated with the silicification processes occurring in these layers. Below 520 m, concentration changes with depth become large and appear to continue through the section characterized by volcanoclastic sediments and lava flows between 670 and 820 m. We believe that to a large extent changes in dissolved calcium and magnesium result from exchange with underlying basalts, much in the manner proposed by McDuff (1981) and Lawrence and Gieskes (1981). Changes within the sediment column are due to less important reactions involving alteration of volcanic matter in the sediment column (Gieskes and Lawrence, 1981).

Changes in dissolved potassium indicate sinks in the volcanic sediments as well as in the underlying basalts.

Lithium concentrations support production of lithium in the volcanic sediments as at Sites 552 and 553.

GENERAL DISCUSSION

At all four sites of Leg 81, concentration gradients in dissolved calcium, magnesium, strontium, and potassium have been observed. Concentration gradients of calcium and magnesium appear to be determined mainly by exchange between the volcanic sediments and basaltic basement and the overlying sediments. The concentration depth profile of strontium on the other hand is

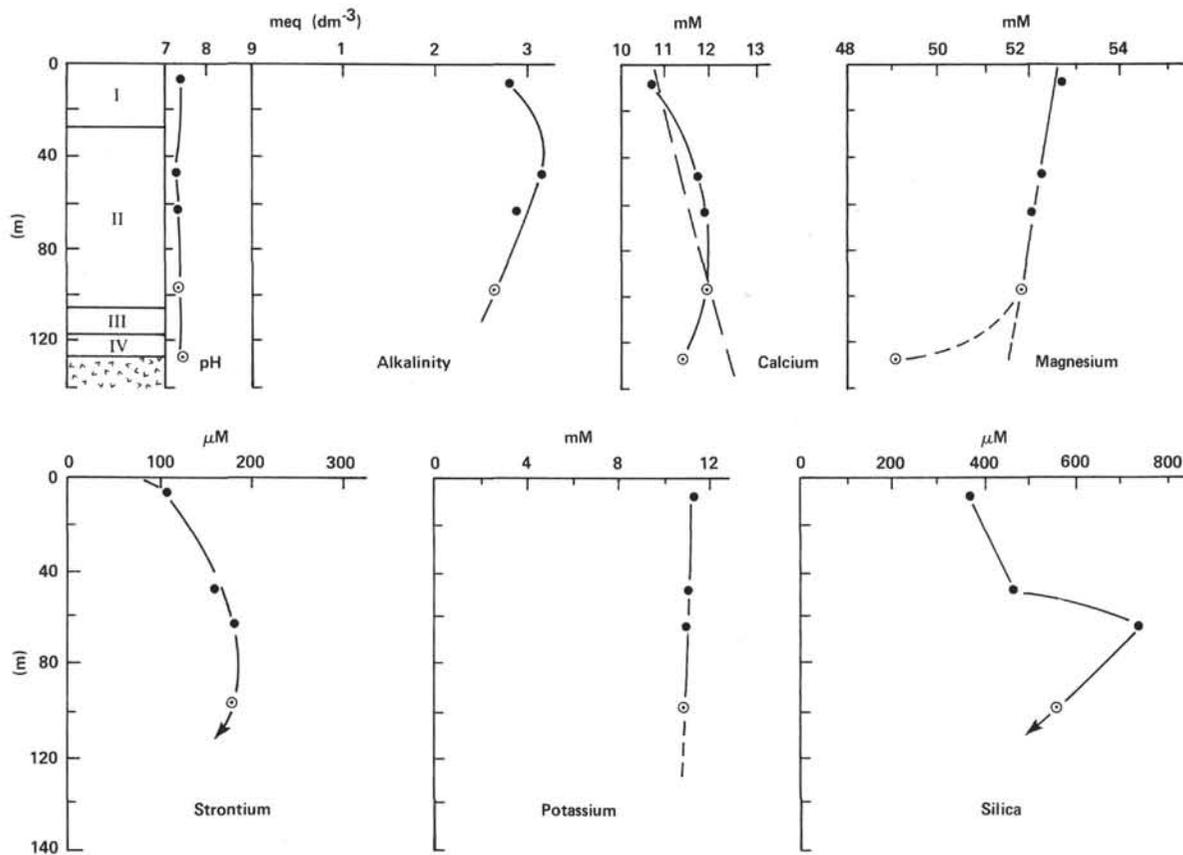


Figure 4. Interstitial water chemistry, Site 554. Lithologic Unit I. Foram oozes and marls. Unit II. Foram-nanno oozes; chalk at base. Unit III. Chalks—Mn nodules at base. Unit IV. Tuffaceous marlstones and tuffs. (Open symbols = Hole 554A; closed symbols = Hole 554).

largely a function of carbonate recrystallization processes, the maximum usually occurring at the depth of the ooze-chalk transition. These observations are in general agreement with previous interpretations of such concentration changes. McDuff (1981) and Gieskes and Lawrence (1981) have shown that alteration reactions in basalts of Layer II and of volcanic matter dispersed in Layer I are the principal causes of the observed increases in dissolved calcium and decreases in magnesium. Mass balance calculations based on the oxygen isotope distribution in the interstitial waters have shown that the main cause of $\delta^{18}\text{O}$ depletions (and calcium release) is alteration of basalts in Layer II, with a relatively minor contribution by volcanic matter dispersed in the sediments (Lawrence and Gieskes, 1981; Gieskes and Lawrence, 1981). The contributions by volcanic matter in the sediments have been shown to be related to rapid changes in the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of dissolved strontium (Hawkesworth and Elderfield, 1978; Elderfield and Gieskes, 1982; Gieskes et al., in press). Concentration changes in calcium and magnesium usually appear unrelated to those in dissolved strontium (Gieskes, 1983), mostly because dissolved strontium increases are principally the result of carbonate recrystallization reactions (Baker et al., 1982; Elderfield et al., 1982). Any small changes in magnesium associated with this latter process are expected to be minor (Matter et al., 1975), at best on the order of

the strontium concentration changes, and hence would hardly be detectable on top of the much larger changes in dissolved magnesium as a result of reactions involving volcanic matter alteration.

The importance of the sites drilled during Leg 81 is in their closely spaced distribution and in the fact that they are characterized by similar sedimentation patterns but by dissimilar accumulation rates. Figure 6 shows a general diagram of sedimentation rates at Sites 552 to 555. Dissimilarities are especially noticeable during the last ~ 10 –12 million years (Quaternary–middle Miocene). Average rates are as follows for this period: Site 552: ~ 20 m/m.y., Site 553: ~ 25 m/m.y., Site 554: ~ 10 m/m.y., and Site 555: ~ 16 –17 m/m.y. For these reasons it appears appropriate to investigate the role of increased sedimentation rates on the nature of the concentration gradients. In the following discussion we assume an average diffusion coefficient for Ca^{2+} , Mg^{2+} , and Sr^{2+} of $\sim 2 \times 10^{-6}$ cm^2/s (McDuff, 1981), and we will consider the "diffusion path length" ($\sqrt{2Dt}$) over the last 10 million years, as well as the so called communication length ($z = D/u$, where u = sedimentation rate: Gieskes, 1975). In Table 2 data are presented on the sedimentation rates, the diffusion path length, communication length, and the depth of basaltic basement. Inspection of this table indicates that the diffusion path length is smaller than the depth of basement at Sites 553 and 555, and larger

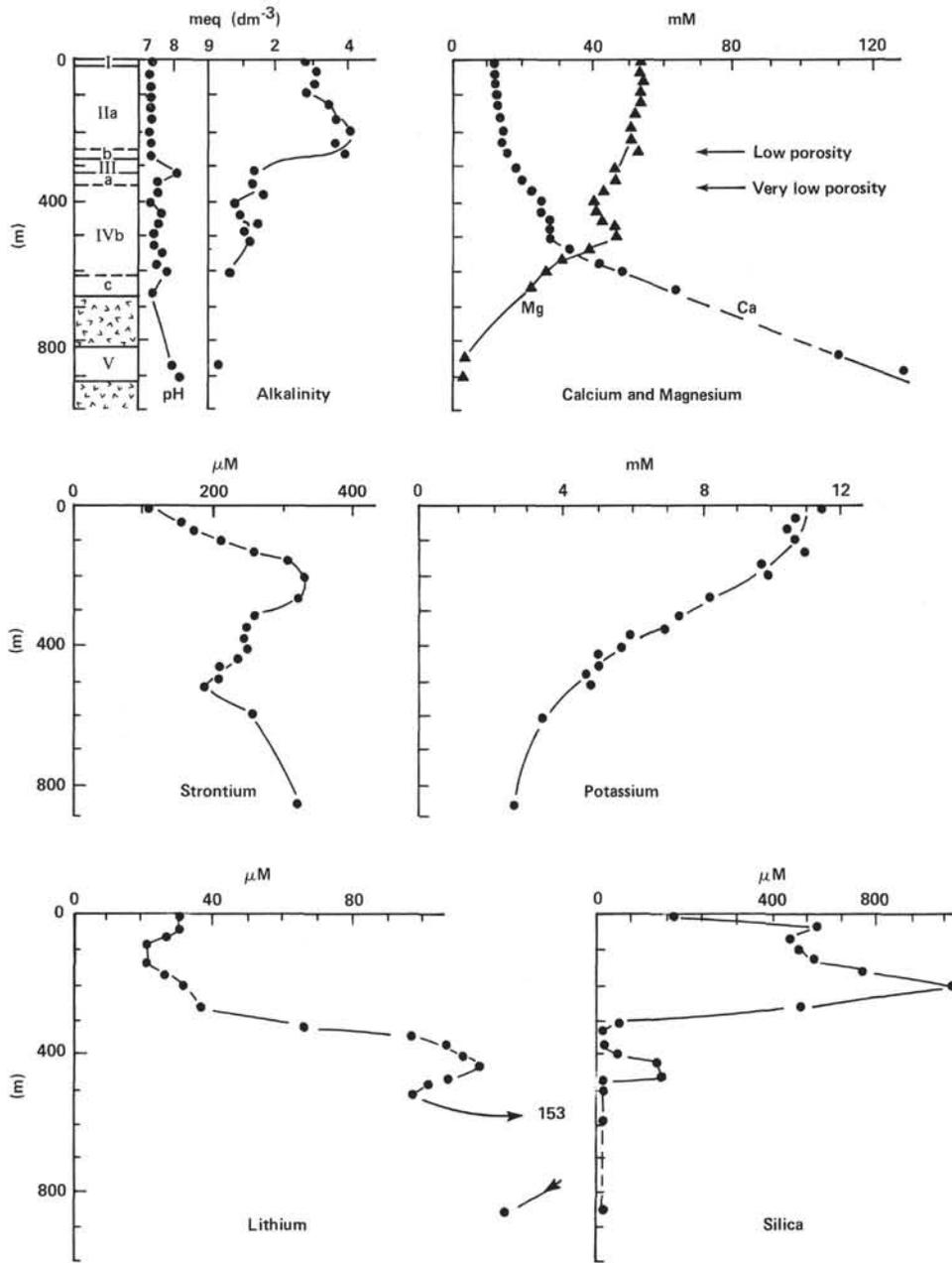


Figure 5. Interstitial water chemistry, Site 555. Lithologic Unit I. Cyclic calcareous muds and ooze. Subunit IIa. Foram-nanno ooze. Subunit IIb. Foram chalk and ooze. Unit III. Vitric tuff, chalk, and limestone. Subunit IVa. Zeolitic tuff and lapilli tuff. Subunit IVb. Carbonaceous mudstones, tuffs. Subunit IVc. Volcanic tuff, sandstones, and mudstones. Unit V. Volcanic tuffs, sandstones, and mudstones.

at Sites 552 and 554. Similarly the communication length at Site 552 is about equal to basement depth, smaller at Sites 553 and 555, and only much larger at Site 554.

Strontium concentration maxima correlate very well with sedimentation rates as can be seen from Figure 7. Typically, the ooze-chalk boundary at each site occurs at about the same age, i.e., ~10 million years. Calcium gradients are linear to depths well below these strontium maxima, and the slopes of the gradients correlate well with sedimentation rates (Figs. 7, 8).

Let us now consider the steady state diffusion equation (McDuff, 1978; Gieskes, 1983):

$$0 = \frac{\delta}{\delta z} \left(p D_b \frac{\delta c}{\delta z} \right) - p u \frac{\delta c}{\delta z} + R$$

where p = porosity; D_b = bulk diffusion coefficient; u = pore water advective velocity relative to sediment-sea interface; R = production of dissolved strontium (magnesium or calcium). If $u < 25$ m/m.y. and D_b is constant at $\sim 2 \times 10^{-6}$ cm²/s, then the diffusive term is the dominant transport term, and if $R = 0$, linear concentration gradients should result. The production of strontium occurs well within the communication length, and thus any differences in the concentration depth profiles

Table 2. Diffusion calculations, Sites 552, 553, 554, and 555, Leg 81.

Site	(m/m.y.)	Path length for diffusion, $\sqrt{2Dt}^a$ (m)	Communication depth, D/u (m)	Depth of basement (m)
552	20	340	300	290
553	25	340	240	500
554	10	340	554	128
555	17	340	353	670

$t = 10$ m.y. ago.

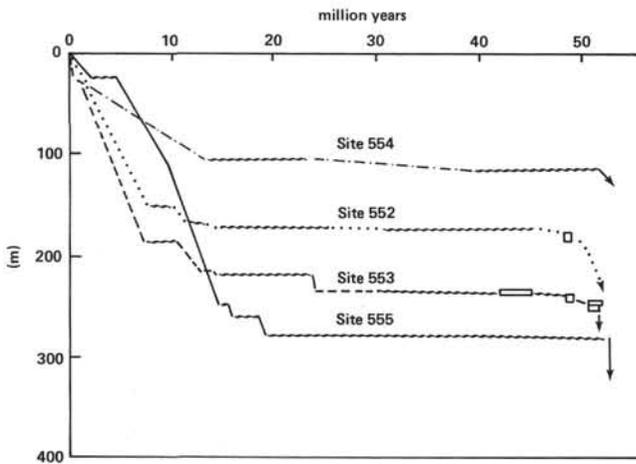


Figure 6. Sedimentation rate diagram for Sites 552-555.

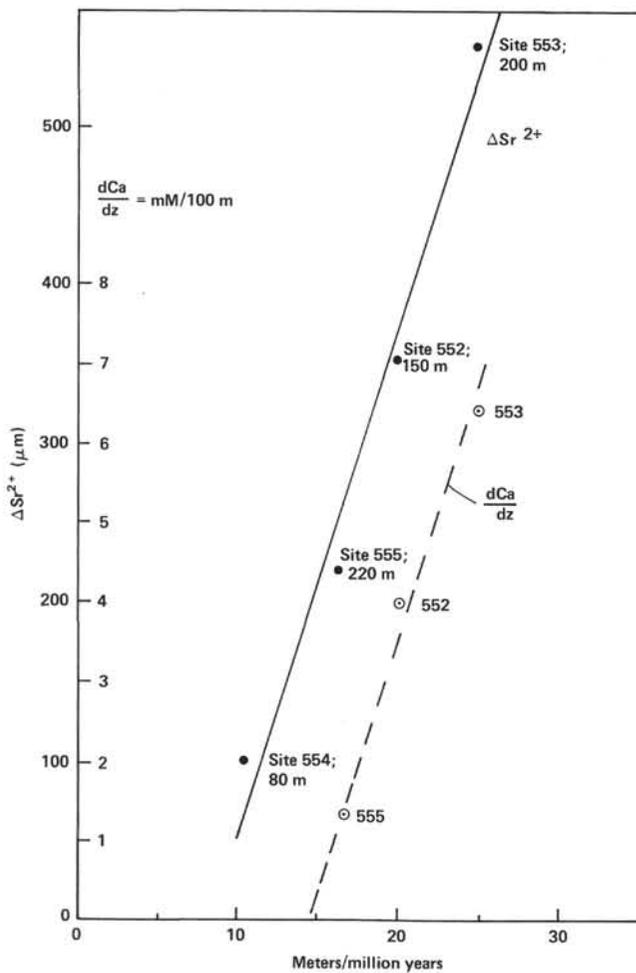


Figure 7. Concentration changes in Sr and gradients in Ca vs. recent sedimentation rates.

must be caused by the production term. Therefore, recrystallization rates are a function of sedimentation rate and are probably related to a more "corrosive" nature of the sediment, resulting for instance from increased

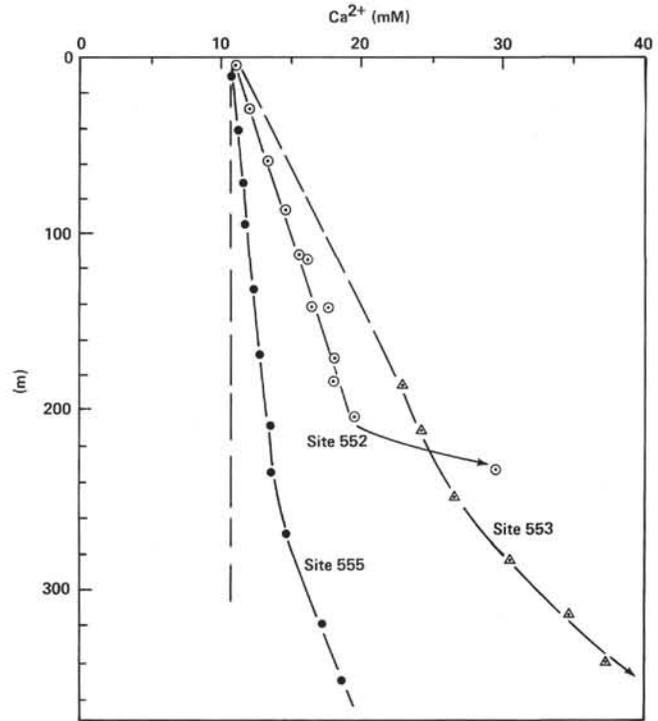


Figure 8. Concentration-depth gradients of calcium, Sites 552, 553, 555.

production of CO_2 or HCO_3^- as a result of sulfate reduction. This was suggested previously by Sayles and Manheim (1975).

In the case of the calcium (and magnesium) gradient (Figs. 7 and 8) the main source (sink for magnesium) is located in the underlying basalts, i.e., at depths greater than the communication length. We argue that in this case the increased slope of the calcium gradient, which would imply an increased flux of dissolved calcium, is mainly the result of a buildup of calcium concentration at depths greater than the communication length. If diffusion from underlying basalts is sufficiently slow, then gradients will be small at low sedimentation rates, cf. Site 554.

CONCLUSIONS

Concentration gradients in dissolved strontium at Sites 552-555 of Leg 81 have been shown to be related to the process of carbonate recrystallization. Rates of these re-

crystallization processes increase with sedimentation rates, primarily as a result of increased "corrosiveness" of the sedimentary environment, presumably the result of increased amounts of reactive organic carbon.

Concentration changes in dissolved calcium (increases) and magnesium (decreases) are related to reactions taking place in underlying volcanic sediments and basalts. Increases in concentration gradients with sedimentation rate result primarily from the buildup of calcium (or removal of magnesium) below the so-called diffusive communication depth. Basement serves as the primary source of dissolved calcium and also as an important sink for magnesium and potassium.

Dissolved lithium is produced in the volcanic sediments overlying basement basalts.

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REFERENCES

- Baker, P. A., Gieskes, J. M., and Elderfield, H. E., 1982. Diagenesis of carbonates in deep sea sediments—evidence from Sr/Cr ratios and interstitial dissolved Sr^{2+} data. *J. Sediment. Petrol.*, 52: 71–82.
- Elderfield, H., and Gieskes, J. M., 1982. Sr-isotopes in interstitial waters of marine sediments from Deep Sea Drilling Project cores. *Nature*, 300:493–497.
- Elderfield, H., Gieskes, J. M., Baker, P. A., Oldfield, R. K., Hawkesworth, C. J., and Miller, R., 1982. $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{18}\text{O}/^{16}\text{O}$ ratios, interstitial water chemistry and diagenesis in deep-sea carbonate sediment of the Ontong-Java Plateau. *Geochim. Cosmochim. Acta*, 46:2259–2268.
- Ellis, R., Pine, J., and Gieskes, J. M., 1979. Interstitial water studies, Leg 48. In Montadert, L., Roberts, D. G., et al., *Init. Repts. DSDP*, 48: Washington (U.S. Govt. Printing Office), 297–303.
- Gieskes, J. M., 1974. Interstitial water studies, Leg 25. In Simpson, E., Schlich, R., et al., *Init. Repts. DSDP*, 25: Washington (U.S. Govt. Printing Office), 361–394.
- _____, 1975. Chemistry of interstitial waters of marine sediments. *Ann. Rev. Earth Planet. Sci.*, 3:433–453.
- _____, 1981. Deep sea drilling interstitial water studies: Implications for chemical alteration of the oceanic crust, Layers I and II. *SEPM Spec. Publ.* 32:149–167.
- _____, 1983. The chemistry of interstitial waters of deep sea sediments: Interpretation of Deep Sea Drilling data. In Riley, J. P., and Chester, R. (Eds.), *Chemical Oceanography* (Vol. 7): New York (Academic Press), 221–269.
- Gieskes, J. M., Elderfield, H., Lawrence, J. R., Johnson, J., Meyers, B., and Campbell, A., 1982. Geochemistry of interstitial waters and sediments, Leg 64, Gulf of California. In Curran, J. R., Moore, D. G., et al., *Init. Repts. DSDP*, 64: Washington (U.S. Govt. Printing Office), 675–694.
- Gieskes, J. M., Elderfield, H., Lawrence, J. R., and LaKind, J., in press. Interstitial water studies, Leg 78A. In Biju-Duval, B., Moore, J. C., et al., *Init. Repts. DSDP*, 78A: Washington (U.S. Govt. Printing Office).
- Gieskes, J. M., and Lawrence, J. R. 1976. Interstitial water studies, Leg 35. In Hollister, C. D., Craddock, C., et al., *Init. Repts. DSDP*, 35: Washington (U.S. Govt. Printing Office), 407–424.
- _____, 1981. Alteration of volcanic matter in deep sea sediments: Evidence from the chemical composition of interstitial waters from deep sea drilling cores. *Geochim. Cosmochim. Acta*, 45:1687–1703.
- Hawkesworth, C. H., and Elderfield, H., 1978. The strontium isotope composition of interstitial waters from Sites 245 and 336, DSDP. *Earth Planet. Sci. Lett.*, 40:423–432.
- Lawrence, J. R., and Gieskes, J. M., 1981. Constraints on water transport and alteration in the oceanic crust from the isotopic composition of pore water. *J. Geophys. Res.*, 86:7924–7934.
- McDuff, R. E., 1978. Conservative behavior of calcium and magnesium in interstitial waters of marine sediments: Identification and interpretation. [Ph.D. dissert.]. University of California, San Diego.
- _____, 1981. Major cation gradients in DSDP interstitial waters: The role of diffusive exchange between seawater and upper oceanic crust. *Geochim. Cosmochim. Acta*, 45:1705–1713.
- Manheim, F. T., Sayles, F. L., and Waterman, L. S., 1972. Appendix I. Interstitial water studies on small core samples, DSDP, Leg 12. In Laughton, A. S., Berggren, W. A., et al., *Init. Repts. DSDP*, 12: Washington (U.S. Govt. Printing Office), 1193–1200.
- Matter, A., Douglas, R. G., and Perch-Nielsen, K. 1975. Fossil preservation, geochemistry and diagenesis of pelagic carbonates from Shatsky Rise, Northwest Pacific. In Larson, R. L., Moberly, R., et al., *Init. Repts. DSDP*, 32: Washington (U.S. Govt. Printing Office), 891–921.
- Sayles, F. L., and Manheim, F. T., 1975. Interstitial solutions and diagenesis in deeply buried marine sediments: Results of the Deep Sea Drilling Project. *Geochim. Cosmochim. Acta*, 39:103–127.

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