25. GEOCHEMISTRY OF ROSS SEA DIAMICTS

L. A. Frakes, Florida State University, Tallahassee, Florida[1]

INTRODUCTION

Cores of modern glacial-marine sediments from the Ross Sea, Amundsen Sea, and Bellingshausen Sea were analyzed for absolute abundance of 13 elements by Angino (1966). A primary result of the study was the determination that glacial-marine sediments are deficient with respect to crustal abundance in Fe, Al, Ni, Ti, and Cr, and contain excesses of Cu and V. In addition to these 80 samples, 9 of wider distribution around Antarctica were analyzed by Frakes and Crowell (in press), in which Fe was the only one of the elements listed by Angino that proved unaffected by provenance. However, though values are highly variable, a large majority of the total 89 samples display Mn concentrations in excess of crustal abundances. Sediments from Sites 270 through 273 inclusive were analyzed in an effort to determine whether their geochemistry more closely resembled that of these modern glacial-marine deposits, or rather that of tills (surplus of Fe, "normal" abundance of Mn; see Roaldset, 1972), and thus to give information on whether subaerial till deposition has taken place in the Ross Sea.

METHODS AND PROCEDURES

A total of 104 diamict samples from the four sites were analyzed for abundance of Fe, Mn, Ni, Cu, and V. The sediment was washed in distilled water, oven dried, disaggregated, and passed through a 100-mesh sieve. Only the fine fraction was sampled, in keeping with Angino's procedure. After standard digestion procedures in HF and aqua regia, the fluids were brought to known concentrations and analyzed on a Perkin-Elmer 303 Atomic Absorption Spectrophotometer and against standards at Florida State University. From replicate analyses, the standard error, including extraction, is calculated to be about ±10% for all elements.

Results of the determinations are given in Table 1, and Fe versus Mn are plotted in Figure 1. Stratigraphic variations in abundance and in the Fe/Mn ratio are shown in Figures 2 and 3. Mean values for Ross Sea diamicts and for other related sediments are given in Table 2.

ELEMENTAL ABUNDANCES

From Table 1 it is apparent that the abundance of Fe in these sediments is quite constant, being generally in the range of 2.0%-3.5%, but with one extremely high value of 7.99% (Sample 271-2-1, 104-106 cm) and only six inordinately low values ranging down to 0.79%. Mn is more variable, ranging from 70 to 1368 ppm. Ni presents relatively low values between 12 and 50 ppm, as does Cu (6-105 ppm) and V (7-112 ppm). Compared with crustal abundances estimated by Taylor (1964), glacial sediments from the Ross Sea sites are seen to be markedly deficient in Fe, Mn, Ni, and V. Values for Cu are mostly below the approximate crustal concentration but diamicts from the lower part of Site 270 display excesses of Cu.

Modern glacial-marine sediments analyzed by Angino (1966) and Frakes and Crowell (in press) contain Fe in amounts between about 2.2% and 5.5% (mean, 3.8%); there is thus a definite and pronounced deficiency of Fe in the Ross Sea diamicts (mean value, 2.85%). Compared with modern glacial-marine sediments, diamicts from Sites 270-273 are even more pronouncedly deficient in Mn. Values range from about 400 to 4400 ppm in the former and from 70 to 1368 ppm in the latter. Ni is apparently about equally abundant in the two sediment types. Cu and V are markedly deficient in the Ross Sea diamicts in this comparison. These differences may reflect diagenetic changes the sediments undergo during burial.

In contrast, continental tills apparently are enriched in Fe and Mn, although available analyses are few (22) and from a single region in Norway (Roaldset, 1972). These tills contain substantially more Fe and Mn than most Cenozoic diamicts from the Ross Sea.

STRATIGRAPHIC VARIATION

Elemental abundances are shown by stratigraphic position in Figures 2 and 3. For the eastern Ross Sea, Sites 270-272 penetrated much of the dipping sequence seen on the seismic profiles, but there are probably unsampled gaps between the sites and there may be overlap in the youngest sediments at each site. Site 273 is diagrammed separately. The Fe/Mn ratio is also plotted stratigraphically.

The anomalously high abundances of Fe and Mn in sediment from the upper part of the sequence (Sample 271-2-1, 104-106 cm) may be a relict of strongly oxidizing conditions during deposition and in such case, these sediments could actually represent subaerially deposited till (see Table 2). Alternatively, the high concentrations may reflect postdepositional mobility of Fe and Mn, from a lower, reducing zone, and precipitation in an oxidizing zone near the surface as seen elsewhere (Mothersill and Shegelski, 1973). However, the sediments analyzed are not surface sediments. They occur at a hole depth of about 41 meters, and further, the sample from Core 1, 9.5 meters higher, shows "normal" concentrations of Fe and Mn, suggesting that any oxidizing

[1]Present address: Monash University, Clayton, Victoria, Australia.

TABLE 1
Concentration of Elements Calculated from Sample Weight

Sample (Interval in cm)	Fe (%)	Mn (ppm)	Ni (ppm)	Cu (ppm)	V (ppm)	Fe/Mn
270-1-1, 128-130	3.3160	632	39	31	62	52.5
270-3-1, 133-135	3.3081	551	50	25	76	60.0
270-5-2, 39-42	2.4782	296	41	28	79	83.7
270-7-1, 126-128	2.2960	272	32	15	71	84.4
270-7-3, 107-109	2.3860	298	30	21	67	80.1
270-8-1, 86-89	2.5591	310	25	19	75	82.6
270-9-3, 6-9	2.7115	334	26	18	91	81.2
270-10-1, 78-82	2.6143	318	26	22	94	82.2
270-11-1, 110-112	2.7928	325	34	29	88	85.9
270-11-2, 0-6	3.9344	382	49	35	88	103.0
270-11-2, 29-33	3.0996	370	39	37	88	83.8
270-12-4, 65-70	2.8504	318	31	21	106	89.6
270-12-1, 8-11	2.7364	304	30	78	81	90.0
270-13-3, 35-40	2.6986	312	23	20	79	86.5
270-14-3, 140-150	2.8886	322	31	16	110	89.7
270-15-3, 20-24	3.2654	424	29	17	51	77.0
270-16-4, 79-82	3.0904	327	30	19	80	94.5
270-17-4, 63-65	3.1205	329	26	17	71	94.8
270-18-2, 044-46	3.0200	346	35	21	81	87.3
270-18-5, 126-130	2.8550	286	29	105	72	99.8
270-19-3, 31-34	3.0726	344	30	33	74	89.3
270-20-1, 72-76	3.0800	335	35	18	73	91.9
270-20-4, 81-83	3.3955	351	33	16	89	96.7
270-21-2, 43-45	2.8429	329	32	16	48	86.4
270-21-5, 136-167	3.1197	335	33	17	48	93.1
270-22-5, 0-3	2.9259	292	31	19	46	100.2
270-23-3, 85-87	2.4635	249	29	16	50	98.9
270-25-1, 70-74	3.1502	339	34	21	48	92.9
270-26-6, 0-3	1.8389	188	16	14	41	97.8
270-28-5, 18-20	2.8795	321	38	23	46	89.7
270-29-4, 150-153	2.9873	323	35	55	90	92.5
270-31-2, 117-120	2.9727	332	26	27	84	89.5
270-32-2, 15-16	2.7826	314	31	98	67	88.6
270-33-6, 45-47	3.0800	322	29	51	67	95.7
270-36-4, 66-74	2.6251	254	38	95	64	103.4
270-39-3, 104-105	2.5264	281	34	49	52	89.9
270-40-4, 118-120	2.5491	276	41	48	38	92.4
270-43-2, 66-68	3.2444	484	43	14	37	67.0
271-1-1, 120-122	2.8995	468	35	22	35	62.0
271-2-1, 104-106	7.9884	1368	21	12	7	58.4
271-3-1, 130-132	2.9580	490	35	21	47	60.4
271-3-2, 20-22	2.9807	472	28	21	37	63.1
271-4-1, 110-112	2.7747	459	30	21	35	60.5
271-5-2, 128-130	2.7176	503	27	20	33	54.0
271-5-3, 100-101	2.7109	477	31	21	31	56.8
271-5-4, 138-140	3.6498	660	31	20	36	55.3
271-12-1, 128-130	2.8381	500	31	23	43	56.8
272-1-1, 113-115	2.6299	320	33	56	71	82.2
272-1-3, 74-76	2.7637	431	26	25	40	64.1
272-2-1, 107-109	2.6844	461	40	25	33	58.2
272-2-4, 68-70	2.6844	457	39	37	29	58.7
272-3-2, 76-78	2.4200	393	40	22	76	61.6
272-4-2, 27-29	2.4272	432	33	18	60	56.2
272-4-5, 96-98	2.5466	418	28	22	61	60.9
272-5-2, 83-85	2.5189	413	43	40	74	61.0
272-6-2, 31-33	2.3291	366	36	22	68	63.6
272-7-2, 60-62	2.3523	370	27	19	68	63.6
272-8-3, 29-31	3.0226	524	33	20	76	57.7
272-9-2, 103-105	2.9668	472	35	22	74	62.9
272-10-2, 142-144	2.8617	542	35	21	70	52.8
272-10-5, 111-113	2.9024	565	33	22	76	51.4
272-11-4, 21-23	2.8468	437	33	21	76	65.1
272-13-2, 72-74	2.8702	579	37	20	70	49.6
272-14-3, 34-36	2.8528	619	44	22	80	46.1
272-15-2, 54-56	2.9580	785	35	21	70	37.7
272-16-2, 103-105	2.9170	357	50	22	104	81.7

TABLE 1 – *Continued*

Sample (Interval in cm)	Fe (%)	Mn (ppm)	Ni (ppm)	Cu (ppm)	V (ppm)	Fe/Mn
272-17-3, 21-23	2.6684	424	38	19	62	62.9
272-19-2, 70-72	0.7890	70	12	6	9	112.7
272-21-5, 42-44	2.0005	200	22	15	84	100.0
272-22-6, 94-96	1.5337	163	29	16	55	94.1
272-24-2, 51-53	1.6082	186	17	21	60	86.5
272-27-1, 68-70	1.6006	174	22	41	49	92.0
272-29-2, 99-101	2.1263	220	24	49	56	96.7
272-30-2, 20-22	3.0539	242	39	40	56	126.2
272-33-2, 103-105	2.3509	282	25	45	65	83.4
272-37-3, 92-94	2.2259	310	35	30	60	71.8
273-1-1, 130-132	2.9551	307	30	21	62	96.3
273-1-1, 70-72	2.3186	184	28	37	68	126.0
273-1-2, 70-72	2.8935	405	31	25	71	71.5
273-1-3, 70-72	5.4330	780	28	23	70	69.7
273-2-1, 130-132	3.1814	452	30	25	82	70.4
273-2-2, 70-72	2.8204	384	32	26	76	73.5
273-2-3, 70-72	2.9498	431	39	33	85	69.5
273-2-4, 70-72	3.5322	474	40	30	84	74.5
273-4-1, 120-122	2.8356	389	40	23	84	72.9
273-4-2, 70-72	2.9252	397	29	25	83	73.7
273-7-2, 83-87	2.6816	388	33	26	89	69.1
273-7-3, 70-72	2.8582	388	42	26	112	73.7
273-8-3, 115-120	2.7056	396	32	27	96	68.3
273-9-1, 100-104	2.6473	372	32	38	106	71.2
273A-6-2, 70-72	1.9821	192	33	31	45	103.2
273A-7-1, 105-107	3.0087	320	33	58	68	94.0
273A-8-2, 70-72	2.7747	403	43	37	54	68.9
273A-8-4, 85-87	2.4417	217	33	20	37	112.5
273A-9-2, 62-63	2.9229	372	34	30	60	78.6
273A-11-3, 82-84	5.5477	713	29	21	59	77.8
273A-11-4, 108-110	2.9492	382	39	32	58	77.2
273A-13-3, 125-127	2.8995	357	35	32	52	81.2
273A-14-1, 130-133	2.9521	376	36	32	50	78.5
273A-16-2, 112-116	2.5387	290	47	24	47	87.5
273-17-1, 136-139	2.5547	291	39	22	52	87.8
273A-22-2, 63-65	3.1636	478	44	27	38	66.2
273-23-2, 55-60	2.7565	401	35	22	39	68.7
273A-25-2, 72-75	2.7886	405	34	22	53	68.9

process which was in operation must have been intermittent and ceased sometime after deposition of Core 2 materials ("Pliocene" or later). Both possibilities are strengthened by the likelihood that coarse debris is concentrated in the upper part of the sequence at Site 271, judging by numerous drilled fragments of clasts and by poor core recovery. It is not possible to determine whether these sediment characteristics result from extensive reworking (and attendant oxidation) of glacial-marine detritus, or from subaerial deposition as till, but there is no doubt that a major change took place in the depositional regime at about the time Core-2 materials were laid down.

High concentrations of Fe and Mn also occur at two levels at Site 273—in Cores 1 and 11A. Core 1 (age uncertain) contains evidence of bottom disturbance in the form of reworked diatom assemblages, but Core 11A (middle Miocene) lacks obvious traces of disconformity or reworking. It is likely that Fe and Mn concentrations here were brought about by extensive oxidation accompanied by reworking of bottom sediments, at least in the case of Core-1 materials.

Beyond these anomalously high concentrations in young cores, Fe and Mn do not display striking changes down the sequence. Fe is slightly more abundant and Mn somewhat less concentrated in the older part of the sequence, at Site 270, and these trends are enhanced in the Fe/Mn curve. The suggestion is that the older sediments have been progressively subjected to more extensive oxidation than younger ones, during either deposition or diagenesis or both. A change in provenance also could bring about the observed variations.

Fe and Mn abundances show their greatest variation in the lower part of Site 272 (below Core 14) and between Cores 8 and 8A at Site 273, and this is again reflected in the Fe/Mn ratios. Absolute abundances are relatively low for these easily oxidized elements here, as they are also for Ni, suggesting that a reducing environment prevailed during diagenesis and possibly during sedimentation as well. Effectiveness of reducing conditions in preventing precipitation or adsorption of these elements onto clay particles was highly variable, however, judging by fluctuations in the Fe/Mn ratio. If a feature of primary sedimentation, reducing conditions

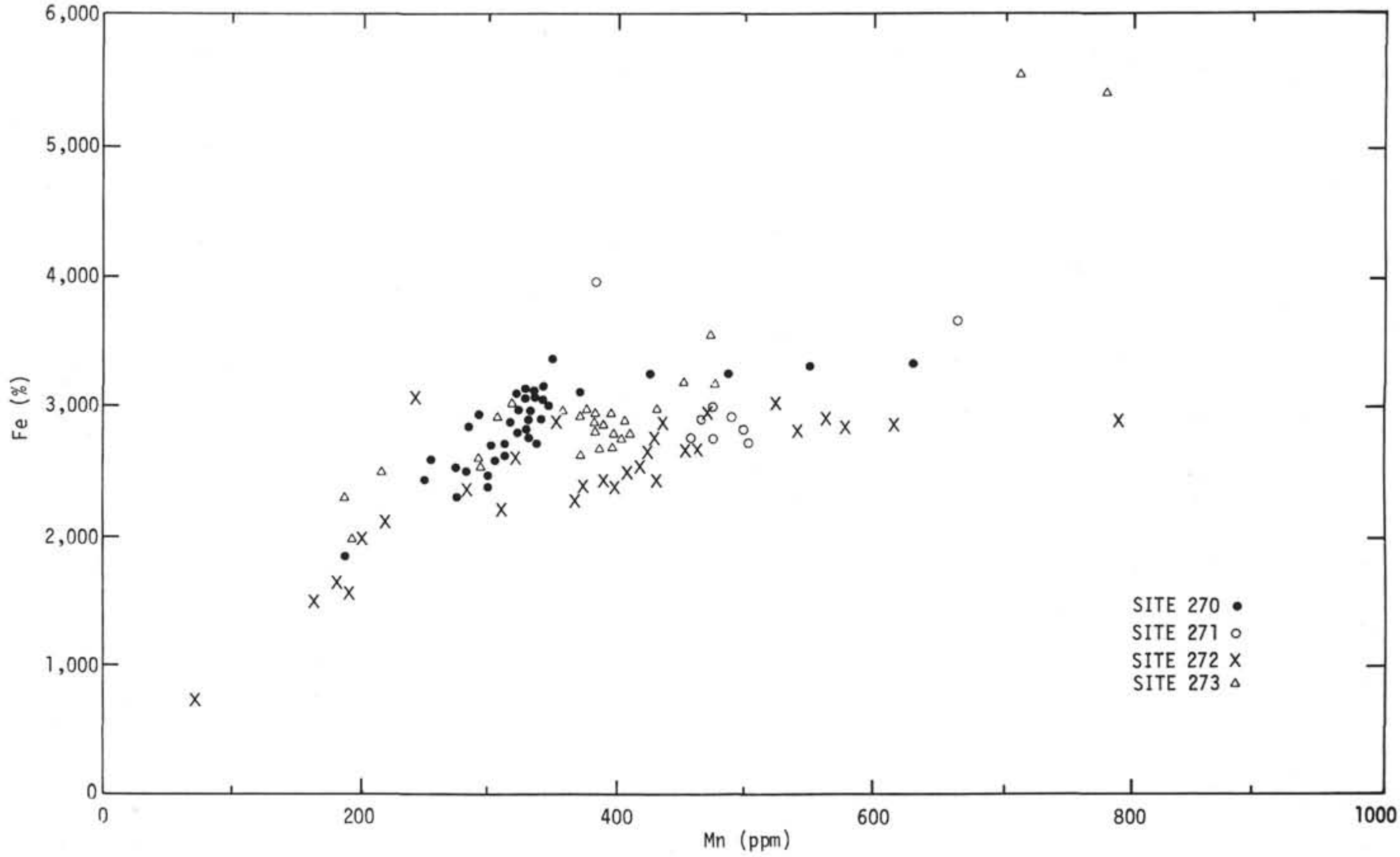

Figure 1. *Fe vs Mn for Ross Sea Sites.*

were in force during the middle Miocene at both Sites 272 and 273.

In terms of concentration of at least Fe and Mn, diamicts from the Ross Sea drill sites occupy positions at the lower end of a spectrum; higher concentrations occur in the immediately overlying modern sediments of the Ross Sea, and yet higher ones are known from continental tills. Also, they are very similar in these abundances to Paleozoic tillites, some of which contain marine invertebrate faunas (Frakes and Crowell, in press). However, three samples (from Cores 271-2, 273-1, and 273A-11) contain more than 5% Fe and thus resemble tills. In the present interpretation, deficiencies in Fe and Mn are explained in terms of removal during diagenesis under reducing conditions, while surpluses are considered to reflect oxidizing conditions during deposition of the near-surface sediments at Sites 271 and 273. At Site 273 association with reworked microfloras indicates that the lower part of Core 1 lies within a zone of slow accumulation, or that it contains a disconformity. At Site 271, reworking probably characterizes a thick zone that includes Core 2. Both zones are overlain by less enriched sediments and are taken to represent an as yet undated time of bottom exposure to oxidizing processes. The precise nature of this event is not known but the chemistry of the sediments is in keeping with deposition of continental till.

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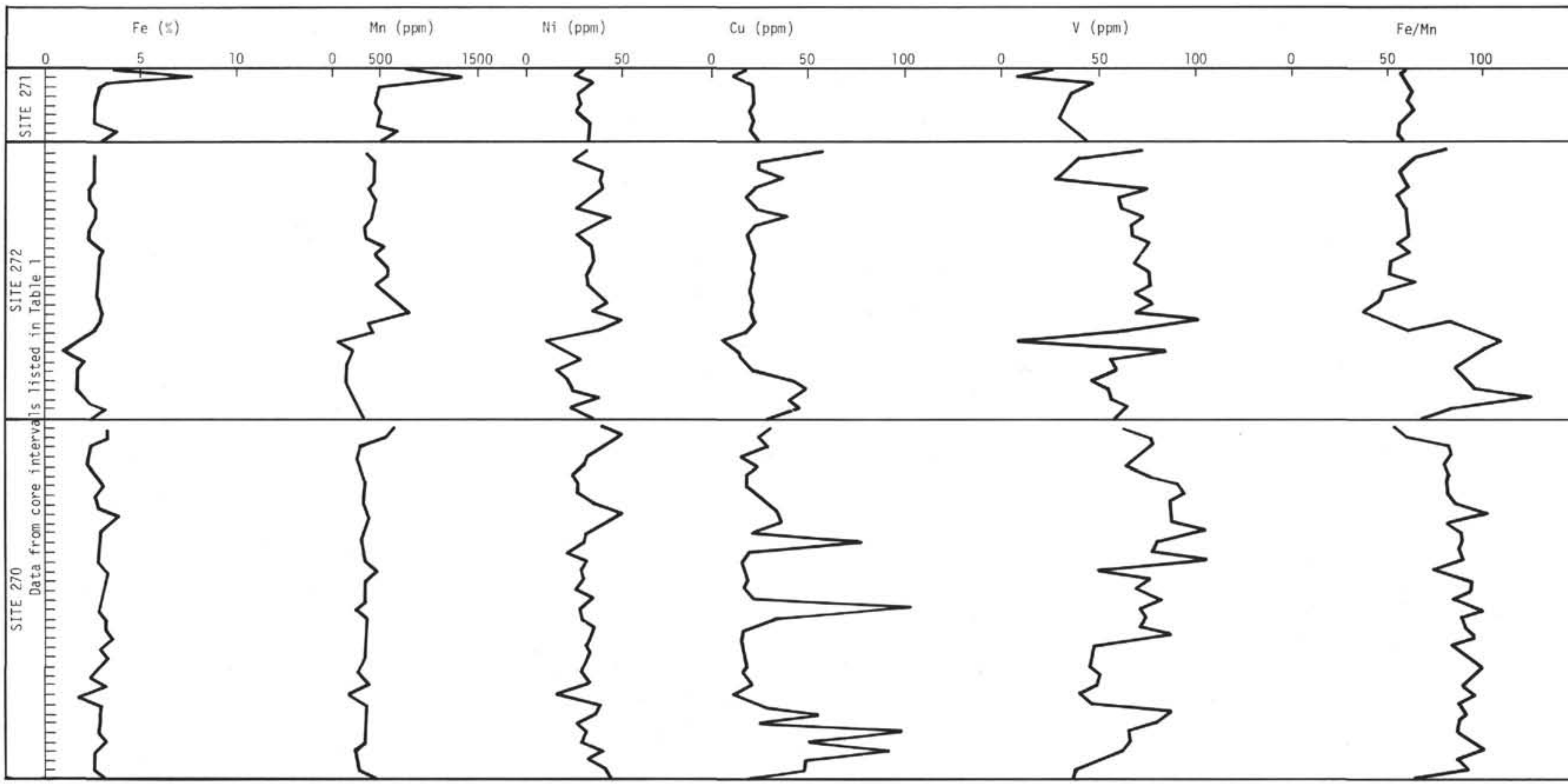

Figure 2. *Some elemental abundances and Fe/Mn for Sites 270, 271, and 272, plotted stratigraphically.*

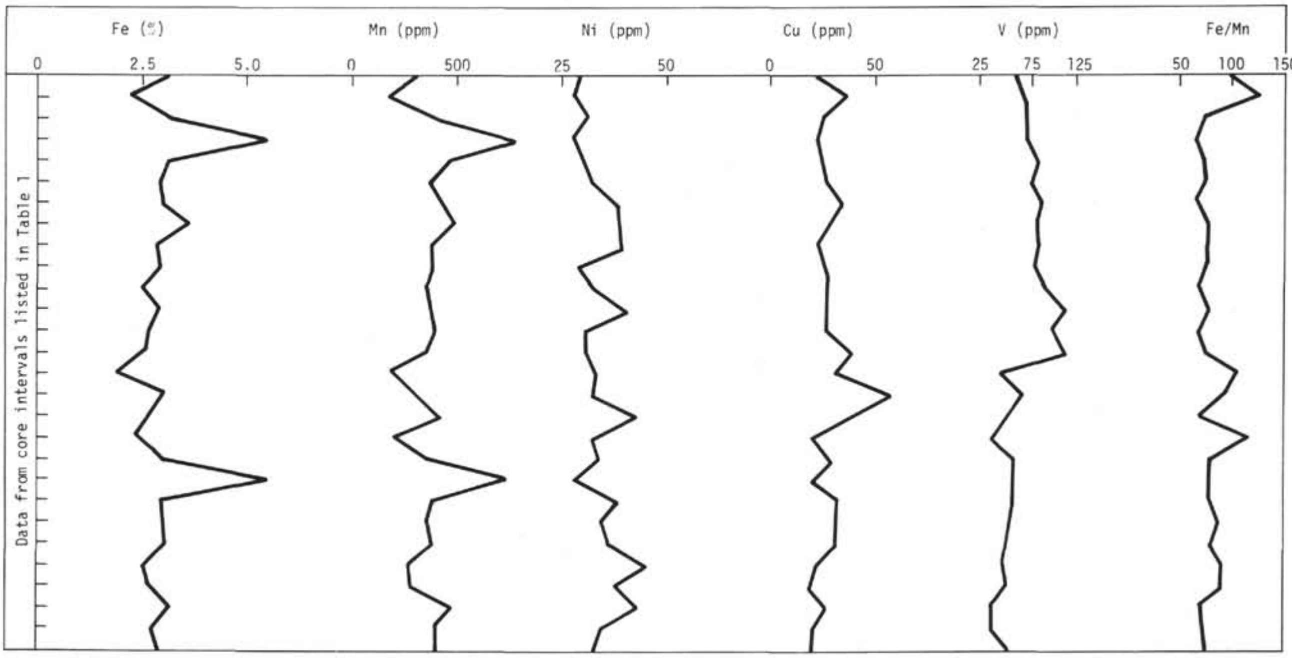

Figure 3. *Some elemental abundances and Fe/Mn for Site 273, plotted stratigraphically.*

TABLE 2
Mean Values for Ross Sea Diamicts and Other Related Sediments

	Fe (%)	Mn (ppm)	Ni (ppm)	Cu (ppm)	V (ppm)
Ross Sea Diamicts	2.85	385	33	28	64
Modern Glacial Marine					
Angino, 1966	3.72	1401	37	137	200
Frakes and Crowell, in press.	3.88	1251	75	93	115
Tills					
Roaldset, 1972	8.4	1254	–	–	–
Deep-Sea Sediments					
Turekian and Wedepohl,	6.5	6700	225	250	120
1961; Cronan, 1969	5.07	4784	211	323	215
Crustal Abundance					
Taylor, 1964	5.63	950	75	55	135