12. THE GEOCHEMISTRY OF HEAVY METALS IN UPPER CENOZOIC SEDIMENTS NEAR THE CREST OF THE MID-ATLANTIC RIDGE, LATITUDE 23°N, DRILLED ON DSDP LEG 45

I. M. Varentsov, Geological Institute of the USSR Academy of Sciences, Moscow

INTRODUCTION

This geochemical study was aimed at determining the distribution of heavy metals in sediments from Holes 395 and 396, drilled on Leg 45, their chemical and mineral associations, influences controlling their distribution, and how they originated. It should be emphasized that the near-axial zone of the Mid-Atlantic Ridge is characterized by a high degree of endogenic activity, and the supply of materials of continental run-off, the products of island and continental volcanism, as well as eolian components, are minor. Among the most important problems to be investigated in the petrologic and geochemical study of mafic rocks from oceanic seismic Layer 2 is the interaction between these volcanic rocks and heated solutions of seawater, a phenomenon that considerably affects the geochemistry of the oceans.

Several studies of the past few years (Boström, 1973; Boström et al., 1971, Lowell and Rona, 1976; Rona, 1976; Rona et al., 1976; Varentsov, 1971, 1976; Varentsov and Stepanets, 1970) emphasize the extreme importance of the interaction processes of basaltic volcanic rocks and thermal solutions, primarily seawater. The metals released as a result of this interaction probably accumulate among the sediments deposited near the axial zone of the Mid-Atlantic Ridge.

Thus, among the most essential objectives of geochemical study of the sediments recovered from the holes drilled on Leg 45 was evaluation of the role of the components (mainly heavy metals) supplied by hydrothermal solutions into upper Cenozoic sediments.

MATERIALS, METHODS

The geochemistry of sediments recovered on Leg 45 is reported in Timofeev et al. (this volume). These authors subdivided the two units in the sediments of each hole, described in the site chapters, into several sub-units. Their sub-unit nomenclature is adopted here, and is shown on several of the figures. The study of foraminifers and stratigraphic subdivision of the section was done by Krasheninnikov (this volume).

A significant part of the geochemical study involved mineralogical-petrographic examinations of thin sections under a microscope, use of X-ray structural analysis data, etc. The results of these studies serve as the basis for interpretation of chemical data.

Chemical analyses of sediments and silicate minerals were determined by spectral techniques in the analytical laboratory of GIN of the USSR Academy of Sciences, by comparison with international reference standards. The analyses carried out in this laboratory are thus comparable in accuracy and limits of sensitivity to data of other modern laboratories.

RECALCULATION OF CHEMICAL ANALYSES

The upper Cenozoic deposits of Holes 395 and 396, near Mid-Atlantic Ridge (22°N), are represented by relatively uniform carbonate units, mostly nannofossil oozes with varying amounts of foraminifer remains, dispersed iron hydroxides, and a slight admixture of clay minerals. In order to determine specific features of the geochemistry of these sediments–in particular, the distribution of heavy metals–it is necessary to exclude, by appropriate recalculations, the diluting influence of the following components: (a) terrigenous matter; (b) siliceous matter; (c) carbonates; (d) organic matter; (e) salts of seawater (sulfates, chlorides). Geochemical studies of oceanic sediments show that the remaining genetic specificity of rather uniform siliceous, carbonate, or terrigenous sediments can be clearly seen after removing the influence of these diluting components (Boström, 1973).

In this paper I have recalculated the chemical analyses on a clastic-free, silica-free, and carbonate-free basis (here called mineral-free, M.B., following the method of Varentsov and Blazhchishin [1976]). Note that determination of the terrigenous component was based on Al. The average composition of the sedimentary part of the lithosphere (clays, shales), after Vinogradov (1962), was taken as the normative terrigenous component, and subtracted from the bulk analysis until Al was exhausted. The difference obtained was recalculated to 100 per cent. Although recalculation of each analysis was based on the lithologic and mineralogical data, the recalculation scheme is to a certain extent formal; for instance, the true composition of clay components was not taken into consideration.

PECULIARITIES OF THE DISTRIBUTION OF HEAVY METALS

The paper by Timofeev et al. (this volume) devoted to problems of lithology, mineralogy, and geochemistry of the major components of upper Cenozoic deposits, and deals with the principal data on lithologic and stratigraphic subdivision of the sediment sections at Holes 395 and 396. These data were used in studying the distribution of heavy metals in sections of the holes drilled in the western (395) and eastern (396) flanks of the Mid-Atlantic Ridge. It should be emphasized that the study of lithology, mineralogy, and geochemistry of the major components does not enable us to recognize regional tendencies in the change of the material composition of sediments. The main difference lies in the fact that the turbidite layers, represented mostly by foraminiferal sands, accumulated in the western pond (Hole 395), chiefly in the Early Pleistocene to Late Pliocene, whereas similar sediments in the eastern pond (Hole 396) were deposited to a greater extent in the Early Pliocene.

The general diluting effect of nannofossil-foraminiferal material in the sediments blurs the detailed features of distribution of the major and minor elements (see Tables 1, 2, 3, 4). After recalculation of the chemical analyses data on a clastic-free, carbonate-free, and silica-free basis, one can clearly observe a slight tendency for the bulk iron to be higher uppermost Pliocene of both holes.

For the upper Cenozoic sediments penetrated by Hole 395 the heavy metal distribution is shown in Tables 5 and 6 (Figures 1, 2, and 3). These are the main peculiarities: relatively high concentrations (weight %, recalculated) of Fe, Mn, Co, Cu, V, Pb, and Mo occur between 21.04 meters and 33.29 meters (3-3, 101 cm down to 4-5, 72, cm: upper Pliocene, *Globoratalia Tosaensis*). The maximum contents of these elements occur in nannofossil ooze containing an appreciable admixture of basaltic volcaniclastic material. Another interval with higher concentrations of heavy metals is Unit II (80.03 to 83.43 m sub-bottom, 9-4, 110 cm down to 9-6, 150 cm, upper Miocene to Pliocene) represented by basal clays enriched in hydroxides of iron and manganese, and containing varying amounts of nannofossil ooze. These relatively thin beds were deposited within a few meters of altered and fresh basalts of seismic Layer 2.

The distribution of phosphorus follows that of the heavy metals (see Figure 1, Tables 5 and 6). For Ni (see Figure 2), rather high concentrations occur between 44.01 and 60.00 meters sub-bottom (5-6, 41 cm down to 7-4, 35 cm; lower Pliocene, *Globorotalia margaritae evoluta* Zone), where fragments of altered gabbros and serpentinites are present.

In Hole 396 (see Tables 7 and 8, Figures 4, 5, and 6), the highest concentrations (%, M.B.) of Fe, Mn, Ni, Co, Cu, V, Pb, Zn, Mo, and P occur between 20.18 meters and 43.87 meters sub-bottom, (5-1, 00 down to 6-1, 150 cm; upper Pliocene, *Globoratalia tosaensis* Zone).

The basal deposits occurring on altered basalts of seismic Layer 2 have an intense accumulation of heavy metals. These sediments, as in Hole 395, are represented by clays enriched in hydroxides of iron and manganese, and fragments of basaltic glass; the amounts of nannofossil ooze vary (Unit II, middle Miocene/upper Miocene-Pliocene; depth: 117.15-125.34 m sub-bottom; 13-6, 00 down to 14-5, 150 cm).

TABLE 1
Heavy-Metal Contents in Upper Cenozoic Sediments, North Atlantic, Hole 395, Leg 45 (n. 10^{-4}%, on air-dry weight)

Sample (Interval in cm)	Contents (wt. %, n. 10^{-4})									
	Cr	Ni	V	Cu	Co	Pb	Ga	Ge	Mo	Zn
1-3, 66-68	50	52	96	120	39	32	9	<1.5	9.7	–
1-4, 78-80	20	18	46	74	22	13	<5	<1.5	2.0	–
2-3, 30-32	17	18	36	43	14	≈10	<5	<1.5	2.7	–
2-4, 76-78	14	14	20	39	10	<10	<5	<1.8	1.7	–
2-6, 11-13	26	20	56	78	30	16	<5	<1.5	5.4	–
3-1, 70-72	<10	<10	<15	33	<10	<10	<5	<1.5	1.7	32
3-3, 27-29	26	18	53	79	24	16	<5	<1.5	7.0	–
3-3, 99-101	16	14	38	54	17	10	<5	<1.5	4.7	–
3-5, 93-95	≈10	12	35	52	14	16	<5	<1.5	4.2	–
4-5, 70-72	≈10	<10	29	46	12	≤10	<5	<1.5	2.0	–
5-2, 57-59	11	10	35	48	12	10	<5	<1.5	<1.5	–
5-4, 80-82	11	12	40	47	16	10	<5	<1.5	2.0	20
5-6, 39-41	11	11	35	55	14	10	<5	<1.5	3.2	26
6-1, 116-118	13	12	35	44	14	10	<5	<1.5	1.8	24
6-3, 47-49	12	14	41	43	17	12	<5	<1.5	2.8	–
7-2, 132-134	32	40	36	55	18	10	<5	<1.5	1.8	34
7-3, 14-16	63	90	36	57	26	10	<5	<1.5	1.6	–
7-4, 33-35	13	16	28	46	15	10	<5	<1.5	1.5	26
8-2, 74-76	11	12	44	43	14	10	<5	<1.5	4.7	–
8-4, 19-21	12	14	55	53	18	12	<5	<1.5	5.4	–
9-1, 86-88	56	33	35	36	14	10	<5	<1.5	3.6	28
9-3, 124-126	15	20	54	70	27	15	<5	<1.5	6.0	–
9-5, 62-64	33	39	110	120	45	26	<5	<1.5	9.8	70

ASSOCIATIONS OF HEAVY METALS

The distribution of heavy metals in upper Cenozoic deposits of Holes 395 and 396 (Tables 5, 6, 7, 8; Figures 1-6) shows that the principal geochemical features are controlled by the behavior of iron, represented mostly by hydroxides. This conclusion is confirmed by the specific character of correlative relationships of the elements concerned (Figure 7, A-R; Figure 8, A-R). It follows from the analysis of correlative relationships of metals that there is a distinct paragenetic bond between Fe and a number of metals. The concentrations of the given metals and P are considerably influenced by the ferric iron content. At the same time, no correlative relationship between Al_2O_3 and heavy metals was noted (see Figure 7, B, C, L, P; Figure 8, B, C, L, P). The similar character of bonds shows that the aluminosilicate phases (including additional components of terrigenous, eolian, and volcaniclastic origin) did not play any significant role in accumulation of heavy metals. The most important geochemical property of hydroxides of iron and manganese is their high sorbtion capacity. The compounds act as collectors, extracting dispersed concentrations of heavy metals from solutions (in this case, seawater; Varentsov, 1976).

Thus, absence of relationships between concentrations of heavy metals and Al_2O_3—the main component of aluminosilicate materials—and strict stratigraphic control in the sediment sections of two spatially separated ponds revealing correlative changes in the distribution of heavy metals associated with Fe and Mn hydroxides, suggests that these elements were supplied by hydrothermal solutions ascending from the rift valley of the near-axial zone of the Mid-Atlantic Ridge. The formation of hydroxides of iron and manganese was proceeding during interaction of hydrothermal solutions with seawater. This phenomenon was accompanied by a mass co-precipitation of dispersed heavy metals.

TABLE 2
Average Heavy-Metal Content in Upper Cenozoic Deposits, North Atlantic, Hole 395, Leg 45 (n. 10^{-4}%, recalculated to an air-dry weight)

Lithologic Subdivision			Depth Interval		Comp.	Content (wt. %)									
Unit	Sub-unit	Sequence	Core	(m)	Cont.	Cr	Ni	V	Cu	Co	Pb	Ga	Ge	Mo	Zn
	1-1		1-1-00 through 1-3-68	0.00-3.68		50	52	96	120	39	32	9	<1.5	9.7	–
		1-2A	1-3-68 through 1-4-80	3.68-5.30		20	18	46	74	22	13	<5	<1.5	2.0	–
		1-2B	1-4-80 through 2-1-76	5.30-8.26											
			2-1-76	8.26-13.32	No. of anal.	2	2	2	2	2	2	2	2	2	
		1-2C	through		Min. sequen.	14	14	20	39	10	<10			1.7	
			2-4-132		Max. sequen.	17	18	36	43	14	≈10			2.7	
					Aver. sequen	10	16	28	41	12	<10	<5	<1.5	2.2	
	1-2		2-4-132	13.32-21.04	No. of anal.	4	4	4	4	4	4	4	4	4	1
		1-2A	through		Min. sequen.	<10	<10	<15	33	<10	<10			1.7	
			3-1-101		Max. sequen.	26	26	56	79	30	16			7.0	
					Aver. sequen.	<20	<17	<40	61	<20	<13	<5	<1.5	4.7	32
			3-3-101	21.04-33.29	No. of anal.	2	2	2	2	2	2	2	2	2	
		1-2E	through		Min. sequen.		<10	29	46	12	≈10			2.0	
			4-5-72		Max. sequen.		12	35	52	14	16			4.2	
					Aver. sequen.	≈10	<11	32	49	13	13	<5	<1.5	3.1	
I			1-1-00	0.00-33.29	No. of anal.	9	9	9	9	9	9	9	9	9	
			through		Min. sub-unit	<10	<10	<15	33	<10	<10			1.7	
			4-5-72		Max sub-unit	26	26	56	79	30	16			7.0	
					Aver. sub-unit	<17	<16	36	55	<17	<12	<5	<1.5	3.5	
			4-5-72	33.29-44.01	No. of anal.	3	3	3	3	3	3	3	3	3	2
		1-3A	through		Min. sequen.		10	35	47	12				<1.5	20
			5-6-41		Max. sequen.		12	40	55	16				3.2	26
					Aver. sequen.	11	11	37	50	14	10	<5	<1.5	2.2	23
	1-3		5-6-41	44.01-60.00	No. of anal.	5	5	5	5	5	5	5	5	5	3
		1-3B	through		Min. sequen.	12	12	28	43	14	10			1.5	24
			7-4-38		Max. sequen.	63	90	41	57	26	12			2.8	34
					Aver. sequen.	27	34	35	49	18	10	<5	<1.5	1.9	28
		1-3C	7-6-35 through 8-1-129	60.00-65.94											
			4-5-72	33.29-65.94	No. of anal.	8	8	8	8	8	8	8	8	8	5
			through		Min sub-unit	11	10	28	43	12	10			1.5	20
			8-1-129		Max. sub-unit	63	90	41	57	26	12			3.2	34
					Aver. unit	21	25	37	49	17	10	<5	<1.5	2	26
			8-1-129	65.94-80.03	No. of anal.	4	4	4	4	4	4	4	4	4	1
	1-4		through		Min. sub-unit	11	12	35	36	14	10			3.6	
			9-4-110		Max. sub-unit	56	33	55	70	27	15			6.0	
					Aver. sub-unit	23	20	47	50	18	12	<5	<1.5	4.9	28
			1-1-00	0.00-80.03	No. of anal.	22	22	22	22	22	22	22	22	22	7
			through		Min. unit	<10	<10	<15	33	<10	<10	<5		<1.5	20
			9-4-110		Max. unit	63	90	96	120	39	32	9		9.7	34
					Aver. unit	21	22	<41	55	18	12	<5	<1.5	3.5	27
II			9-4-110 through 9-6-150	80.03-83.43		33	39	110	120	45	26	<5	<1.5	9.8	70

THE HISTORY OF ACCUMULATION OF HEAVY METALS IN UPPER CENOZOIC SEDIMENTS

Upper Cenozoic deposits accumulating in two small isolated ponds near the axial zone of the Mid-Atlantic Ridge are represented by rather uniform sediments of nannofossil ooze with varying amounts of foraminiferal remains and dispersed Fe hydroxides. Despite this similarity, however, sedimentation in the two ponds differed in hydrodynamic regime (Timofeev. this volume). This is confirmed by the different stratigraphic positions of turbiditic layers represented by foraminiferal sands. An inevitable question arises: to what extent

TABLE 3
Heavy-Metal Contents in Upper Cenozoic Sediments, North Atlantic, Hole 396, Leg 45 (wt. %, on air-dry weight)

Sample (Interval in cm)	Contents (n. 10^{-4})									
	Zn	Cr	Ni	V	Cu	Co	Pb	Ga	Ge	Mo
1-1, 69-71	34	20	18	42	67	26	12	<5	<1.5	2.3
1-2, 32-34	44	46	42	65	102	36	22	6	<1.5	7.1
1-3, 72-74	26	14	14	36	50	18	10	<5	<1.5	2.8
1-5, 144-146	34	21	22	39	67	22	13	<5	<1.5	3.8
2-1, 123-125		10	13	22	43	13	≲10	<5	<1.0	2.0
2-2, 121-123		<10	11	21	42	11	<10	<5	<1.0	2.1
2-3, 93-95	30	20	23	40	61	24	18	<5	<1.5	5.9
2-5, 139-141		11	14	32	53	15	12	<5	<1.0	3.4
2-6, 76-78		≲10	11	23	37	11	≲10	<5	<1.0	2.2
3-1, 87-88		10	12	22	44	13	≲10	<5	<1.0	2.6
3-2, 94-96	22	11	13	24	42	16	10	<5	<1.5	2.8
3-4, 138-140	28	12	14	29	47	17	10	<5	<1.5	2.6
5-2, 73-75	22	10	13	29	45	14	≈10	<5	<1.5	3.0
5-3, 100-102	46	31	44	72	102	55	20	<5	<1.5	14.7
5-4, 80-82	22	9	11	24	38	10	≈10	<5	≤1.5	1.5
5-6, 61-63	20	22	12	23	37	10	~10	<5	<1.5	<2.0
6-2, 82-84		<10	≲10	20	44	<10	<10	<5	<1.0	<2.0
6-3, 67-69	20	13	12	23	35	12	~10	<5	<1.5	<2.0
6-5, 49-50	4	10	10	20	32	10	~10	<5	<1.5	<2.0
7-1, 99-101	8	13	12	23	38	16	10	<5	<1.5	3.9
7-3, 118-120	10	14	14	25	45	12	11	<5	<1.5	<2.0
7-4, 64-66		11	12	25	35	11	10	<5	<1.0	<2.0
7-5, 40-42		<10	≲10	22	41	<10	<10	<5	<1.0	<2.0
7-6, 74-76		<10	11	18	35	26	<10	<5	<1.0	<2.0
8-3, 41-43		12	12	22	31	14	~10	<5	<1.5	<2.0
8-5, 60-62		14	16	40	51	24	12	<5	<1.5	<2.0
8-6, 83-85		10	11	21	31	10	≲10	<5	<1.5	<2.0
9-1, 141-143	8	10	12	23	31	14	~10	<5	<1.5	2.6
9-3, 89-91	12	12	12	25	32	14	~10	<5	<1.5	2.6
9-5, 122-124	10	10	12	24	38	15	~10	<5	<1.5	2.7
10-2, 41-43	7	12	13	26	41	16	~10	<5	<1.5	2.7
10-3, 29-31	12	11	12	34	37	16	10	<5	<1.5	2.1
10-4, 86-88	2	≲10	<10	19	20	<10	<10	<5	<1.5	<2.0
10-6, 53-55		≲10	<10	19	24	<10	<10	<5	<1.5	<2.0
11-1, 113-115	6	10	11	23	36	17	≈10	<5	<1.5	≲2.0
11-3, 88-90	14	10	11	23	34	14	≈10	<5	<1.5	<2.0
11-4, 43-45		12	12	26	35	17	≈10	<5	<1.5	<2.0
11-4, 108-110	8	10	<10	19	24	<10	<10	<5	<1.5	<2.0
11-5, 34-36	20	13	14	34	47	18	11	<5	<1.5	2.4
12-2, 110-112	12	12	13	13	45	16	≈10	<5	<1.5	2.2
12-4, 110-112	16	12	13	31	40	17	≈10	<5	<1.5	≲2.0
12-5, 74-76		10	<10	16	33	<10	<10	<5	<1.0	<2.0
12-6, 62-64		13	16	26	48	19	11	<5	<1.5	≲2.0
13-2, 68-70	24	15	17	29	60	24	12	<5	<1.5	4.8
13-4, 66-68	14	11	12	37	34	14	10	<5	<1.5	3.2
13-5, 37-39	12	12	12	26	34	15	≈10	<5	<1.5	3.3
13-6, 66-68	10	14	16	29	42	17	11	<5	<1.5	4.3
14-0, 24-26	18	13	14	36	51	16	11	<5	<1.5	2.0
14-1, 21-23		75	120	180	205	86	43	17	<1.5	30.0
14-3, 69-71		59	102	155	168	83	41	12	<1.5	26.5
14-4, 72-74		≈10	18	44	66	18	12	<5	<1.5	5.3
14-5, 48-50		12	17	47	74	16	12	<5	<1.5	3.6

were the intervals of accumulation of heavy metals in the sediments local, and to what extent were they regional in character.

The data presented on Tables 1-8, and on Figures 1-8, plus the schematic distribution profiles of selected heavy metal contents in Holes 395 and 396 on the western and eastern flanks of the ridge, respectively (Figures 9-14), permit some conclusions.

Iron (Figure 9)

Abundant accumulations of iron took place in two stages:

a) Middle-late Miocene to Pliocene, when appreciable argillaceous sediments were formed. These contain varying amounts of nannofossil ooze and fragments of decomposed basaltic glass enriched in iron and manganese hydroxides. The sediments occur on fresh to moderately altered basalts of seismic Layer 2. It should be mentioned that metalliferous sediments occurring on basalts are distributed almost throughout the world ocean, and are mostly the products of hydrothermal activity in axial zones (Boström, 1973, Boström et al., 1971).

b) Late Pliocene (*Globorotalia tosaensis* Zone). At this time, noticeable concentrations of iron accumulated in both basins (see Tables 3, 4, 6, 7). After removing the diluting effect of terrigenous, carbonate, and siliceous material, it becomes obvious that hydroxides of iron form the major component of the sediment. Iron supply is inferred to be related to a strong outburst of hydrothermal activity on the rift zone of the Mid-Atlantic Ridge, or on its proximal flanks.

Besides these regional stages of iron accumulation, other intervals of local importance can be distinguished. Such intervals are representative of sedimentation in one basin only, and cannot be observed in the other. For example, after formation of basal metalliferous sediments in the western basin, nannofossil oozes poor in iron accumulated: sub-units 1-4 (weight %, M.B.): Fe nil to 47.60 (24.92) (see Table 6, Figure 9). In the eastern basin, the sediments succeeding metal-bearing deposits (sequence 1-2-D, lower Pliocene) are characterized by higher concentrations of Fe (%, M.B., see Table 8): 17.26 to 74.86 (37.74). Higher in both holes, distinct from the two regional stages, clear local differences in the history of accumulation of iron can be seen (Figure 9). Such differences appear to be related to local manifestations of hydrothermal activity in the region of each of the basins concerned, and to the pattern of paleocurrents.

Manganese (Figure 10)

In the history of accumulation of this metal two large regional stages occurred, corresponding to those of iron accumulation (see Figure 10, Tables 5, 6, 7, 8). The local intervals of formation of Mn accumulations differ considerably for each of the ponds concerned. The above-mentioned paragenetic relationships of manganese and iron and peculiarities of sedimentation in the late Cenozoic allow the following conclusion on a hydrothermal inflow of manganese: the distribution of manganese was to a considerable degree controlled by a genetically similar component; iron hydroxides acted as co-precipitating agent.

Vanadium (Figure 11)

As with iron, vanadium is characterized by two large regional stages of accumulation (see Tables 5, 6, 7, 8). The concentration of vanadium in the western pond is, however, much higher than in the eastern pond. It is noteworthy that the duration of the later regional stage of vanadium accumulation is equivalent to two foraminifer zones: *Globorotalia tosaensis* and *Globorotalia miocenica*, corresponding to the second half of the Pliocene. A relatively high vanadium content in the sediments of the western pond appears to reflect the specific endogenic activity of this area in the late Cenozoic. Higher concentrations of iron, manganese, and other metals (see Figures 9, 10, Tables 5, 6, 7, 8) characterize the sediments.

TABLE 4
Average Heavy-Metal Contents, Upper Cenozoic Sediments, North Atlantic, Hole 396, Leg 45 (n. 10^{-4} wt. %, air-dry weight)

Lithologic Subdivision			Depth Interval		Comp.	Contents									
Unit	Sub-Unit	Sequence	Core	(m)	Cont.	Zn	Cr	Ni	V	Cu	Co	Pb	Ga	Ge	Mo
I	1-1	1-1A	1-00-00	0.00-20.18	No. of anal.	7	12	12	12	12	12	12	12	12	12
			through		Min. seq.	22	≲10	11	21	37	11	≲10	<5	<1.0	2.0
			4-6-00		Max. seq.	44	46	42	65	102	36	22	6	<1.5	7.1
					Aver. seq.	31	16	17	33	55	19	≲12	<5	<1.3	3.3
		1-1B	5-1-00	20.18-43.87	No. of anal.	4	4	4	4	4	4	4	4	4	4
			through		Min. seq.	20	9	11	23	37	10	≈10			1.5
			6-1-150		Max. seq.	46	31	44	72	102	55	20			14.7
					Aver. seq.	28	18	20	37	56	22	12	<5	<1.5	5.3
					No. of anal.	11	16	16	16	16	16	16	16	16	16
					Min. sub-unit	20	9	11	21	37	10	⩽10	<5	<1.0	1.5
					Max. sub-unit	46	46	44	72	102	55	22	6	<1.5	14.7
					Aver. sub-unit	30	17	18	34	55	19	12	5	<1.3	3.8
	1-2	1-2A	6-2-00	43.87-67.16	No. of anal.	4	9	9	9	9	9	9	9	9	9
			through		Min. seq.	4	<10	≲10	18	31	<10	<10		<1.0	<2.0
			8-4-150		Max. seq.	20	14	14	25	45	26	11		<1.5	3.9
					Aver. seq.	10	<11	≲11	22	37	13	<10	<5	<1.3	<2.2
		1-2B	8-5-00	67.16-84.14	No. of anal.	4	6	6	6	6	6	6	6	6	6
			through		Min. seq.	7	10	11	21	31	10	≲10			<2.0
			10-2-150		Max. seq.	12	14	16	40	51	24	12			2.7
					Aver. seq.	9	11	13	27	37	16	~10	<5	<1.5	<2.4
		1-2C	10-3-00	84.14-89.18	No. of anal.	2	3	3	3	3	3	3	3	3	3
			through		Min. seq.	2	⩽10	<10	19	20	<10				<2.0
			10-6-150		Max. seq.	12	11	12	34	37	16				2.1
					Aver. seq.	7	<10	<11	24	27	<12	<10	<5	<1.5	<2.0
		1-2D	11-1-00	89.18-117.15	No. of anal.	10	13	13	13	13	13	13	13	13	13
			through		Min. seq.	6	<10	<10	13	24	<10	<10		<1.0	<2.0
			13-6-00		Max. seq.	24	15	17	37	60	24	12		<1.5	4.8
					Aver. seq.	14	12	13	25	39	16	≈10	<5	<1.5	<2.6
					No. of anal.	20	31	31	31	31	31	31	31	31	31
					Min. sub-unit	2	<10	<10	13	20	<10	<10		<1.0	<2.0
					Max. sub-unit	24	15	17	40	60	26	12		<1.5	4.8
					Aver. sub-unit	11	11	12	24	37	<15	<10	<5	<1.4	<2.4
					No. of anal.	31	47	47	47	47	47	47	47	47	47
					Min. unit	2	9	<10	13	20	<10	<10	<5	<1.0	1.5
					Max. unit	46	46	44	72	102	55	22	6	<1.5	14.7
					Aver. unit	18	13	14	28	43	16	11	<5	<1.4	2.9
II			13-6-00	117.15-	No. of anal.	1	5	5	5	5	5	5	5	5	5
			through	(121.41)-	Min. unit		≈10	14	36	51	16	11	<5		2.0
			14-5-150	125.34	Max. unit		75	120	180	205	86	43	17		30.0
					Aver. unit	18	34	54	92	113	44	24	<9	<1.5	13.5

Cobalt (Figure 12, Tables 5, 6, 7, 8)

Two large regional stages of accumulation of Co, corresponding of stages of Fe, Mn, and V accumulation, are suggested. It should be noted that for cobalt the geochronologic volume of the late regional stage is somewhat greater in the uppermost Pliocene, the upper *Globorotalia tosaensis* Zone. On the whole, the upper Cenozoic sediments of the western pond are characterized by much higher concentrations of cobalt than analogous deposits in the eastern pond.

Copper (Figure 13, Tables 5, 6, 7, 8)

The pattern of distribution of copper in Holes 395 and 396 coincides in many respects with the cobalt distribution (see Figure 12): again, there are two pronounced regional stages, and again, sediments of the western pond are richer in the given metal than sediments of the eastern pond.

Titanium (Figure 14, Tables 5, 6, 7, 8)

Titanium is a component whose accumulation history differs considerably from the group of heavy metals and aluminum (see Timofeev, this volume). For example, titanium concentrations in basal sediments are low. However, higher concentrations of TiO_2 were recognized at the upper Pliocene regional stage peculiar to the other heavy metals (Figure 14): the upper part of the *Globorotalia tosaensis* Zone. Such a regional continuity of deposits, rich in TiO_2, within a narrow geochronologic interval associated with relatively high concentrations of Fe, Mn, V, Co, etc.,

TABLE 5
Chemical Composition of Upper Cenozoic Deposits, North Atlantic, Hole 395
Leg 45 (wt. %, recalculated to the clastic-free, silica-free matter, M. B.)

Sample (Interval in cm)	Content																			
	TiO_2	CaO	MgO	Na_2O	K_2O	Fe^{2+}	Fe^{3+}	Fe_{total}	$Mn_{tot.}$	$P_{tot.}$	Cr	Ni	V	Cu	Co	Pb	Ga	Ge	Mo	Zn
1-3, 66-68	4.432	–	21.512	2.454	9.065	2.755	52.589	55.344	6.010	0.651	0.015	0.025	0.095	0.238	0.075	0.058	–	<0.001	0.022	–
1-4, 78-80	–	3.729	–	56.856	10.297	nil	26.854	26.854	1.300	0.547	0.007	0.003	0.079	0.219	0.065	0.034	–	<0.004	0.006	–
2-3, 30-32	2.002	26.260	16.014	7.362	5.835	nil	38.541	38.541	2.511	1.120	0.027	0.030	0.081	0.129	0.041	≈0.027	<0.007	<0.004	0.008	–
2-4, 76-78	5.169	–	40.432	13.100	10.267	2.124	23.084	25.208	3.328	1.841	0.064	0.064	0.099	0.255	0.064	<0.006	<0.025	<0.010	0.011	–
2-6, 11-13	4.742	–	8.920	39.359	7.593	nil	33.258	33.258	5.040	0.663	–	0.003	0.073	0.209	0.083	0.036	–	0.003	0.016	–
3-1, 70-72	5.407	24.886	16.290	13.032	9.843	–	26.757	26.757	1.872	1.178	<0.042	<0.042	<0.062	0.215	<0.062	<0.062	<0.028	<0.010	0.011	0.201
3-3, 27-29	5.889	5.802	5.802	10.906	10.251	4.798	48.640	53.438	6.325	1.003	0.017	–	0.105	0.288	0.087	0.052	–	<0.004	0.029	–
3-3, 99-101	0.237	–	2.755	54.667	6.412	–	–	31.727	2.517	1.140	0.028	0.024	0.119	0.228	0.071	0.038	<0.009	<0.006	0.021	–
3-5, 93-95	7.759	–	–	12.239	10.879	0.800	56.794	57.594	9.039	1.680	–	0.008	0.168	0.368	0.096	0.112	<0.016	<0.010	0.032	–
4-5, 70-72	3.898	17.961	–	35.890	4.833	nil	34.456	34.456	1.964	0.748	–	<0.003	0.050	0.125	0.031	≤0.025	<0.006	<0.004	0.006	–
5-2, 57-59	0.515	46.773	6,808	3.570	5.446	1.840	31.869	33.709	1.619	1.214	0.007	0.007	0.088	0.158	0.037	0.029	<0.007	<0.005	<0.005	–
5-4, 80-82	1.816	72.958	2.700	1.386	3.656	nil	14.267	14.267	2.461	0.502	–	0.002	0.062	0.098	0.033	0.019	<0.005	<0.003	0.004	0.026
5-6, 39-41	4.002	13.058	20.780	–	8.916	nil	42.965	42.965	7.933	1.544	–	0.007	0.147	0.344	0.084	0.056	<0.014	<0.009	0.021	0.119
6-1, 116-118	3.541	19.059	23.759	–	7.662	0.644	36.765	37.409	6.568	1.352	0.013	0.006	0.129	0.245	0.077	0.051	<0.013	<0.008	0.010	0.097
6-3, 47-49	2.079	27.281	16.165	1.485	6.109	nil	40.730	40.730	4.794	0.933	0.004	0.017	0.114	0.157	0.064	0.042	<0.008	<0.005	0.011	–
7-2, 132-134	1.771	13.610	44.141	1.312	3.771	0.098	30.368	30.466	3.673	0.689	0.069	0.095	0.069	0.157	0.052	0.026	<0.007	<0.004	0.005	0.082
7-3, 14-16	1.128	–	71.293	0.214	1.964	0.389	21.917	22.306	2.197	0.428	0.101	0.156	0.043	0.099	0.047	0.016	<0.004	<0.002	0.003	–
7-4, 33-35	2.351	33.012	16.455	1.431	6.081	2.044	31.172	33.216	5.775	1.124	0.015	0.036	0.077	0.204	0.066	0.041	<0.010	<0.007	0.007	0.092
8-2, 74-76	–	17.924	4.624	40.682	5.614	–	–	28.012	1.891	0.961	–	0.006	0.090	0.111	0.036	0.024	<0.006	<0.004	0.013	–
8-4, 19-21	0.702	–	89.752	6.464	–	–	–	–	2.656	–	–	–	0.105	0.190	0.065	0.035	–	<0.005	0.025	–
9-1, 86-88	1.869	13.737	43.971	7.803	3.976	2.077	21.986	24.063	3.382	0.682	0.139	0.074	0.068	0.092	0.036	0.024	<0.006	<0.004	0.010	0.062
9-3, 124-126	3.547	17.020	6.677	8.495	7.750	nil	47.604	47.604	7.094	1.401	–	0.012	0.092	0.179	0.071	0.036	–	0.003	0.017	–
9-5, 62-64	2.869	1.987	13.067	6.202	5.121	nil	59.906	59.906	8.432	1.766	0.002	0.020	0.150	0.225	0.086	0.044	–	<0.003	0.020	0.097

allows us to state that a mass impulse of supply of hydrothermal solutions from near the axial zone of the Mid-Atlantic Ridge occurred at that time. The solutions probably had low *p*H and possibly high temperatures. In the course of neutralization of these solutions in seawater, precipitation of titanium dioxide and iron and manganese hydroxides took place. This was accompanied by vigorous co-precipitation of other heavy metals present in solution. Hydrologic factors and a certain co-depositing role of the carbonate nannofossil material proved responsible for a subsequent redistribution of components and their accumulation in sediment ponds.

In interpreting the distribution of titanium in the sediments, we cannot disregard the possible role of fine gabbroic and ultramatic detritus. In the process of post-sedimentary alteration of such material, some products significantly enriched in TiO_2 could have formed. This might be the case in sequence 1-3-B (Hole 395, Figure 14), in which relatively high concentrations of TiO_2 are correlated with appreciable amounts of fragments of altered gabbros and serpentinite.

CONCLUSIONS

Upper Cenozoic sediments accumulating in small ponds on the flanks of the near-axial zone of the Mid-Atlantic Ridge (22°N) are represented by rather uniform nannofossil oozes with varying amounts of foraminifers, and admixtures of iron hydroxides, argillaceous material, and altered volcaniclastic material.

The study of residual features of the geochemistry of heavy metals in sediments of Holes 395 and 396 (after removing by recalculations the effects of carbonate, terrigenous, and siliceous dilution) enables us to demonstrate that they form in evident association with Fe. The high sorbtive activity of Fe and Mn hydroxides controls the distribution of heavy metals in these deposits. No clear correlative relationship with heavy metals has been found for Al_2O_3.

Two regional stages of rather high heavy-metal concentrations were established in the upper Cenozoic: (a) middle-upper Miocene-Pliocene and (b) the upper Pliocene (*Globorotalia tosaensis* Zone); nannofossil oozes which accumulated during the late Pliocene are characterized by rather high concentrations of heavy metals. The sources of heavy metals are inferred to be hydrothermal solutions supplied from near the axis of the Mid-Atlantic Ridge, and perhaps from the fracture zones of the flanks.

Perhaps because of local redistribution of the metals by means of currents and varying supply of hydrothermal solutions from local fracture zones, the sediments of the pond of the western flank of the ridge (Hole 395) are richer in heavy metals than deposits of the eastern pond (Hole 396).

REFERENCES

Boström, K., 1973. The origin and fate of ferromanganoan active ridge sediments, *Acta Universitatis Stockholmiensis. Stockholm Contrib. Geol.*, v. 27, no. 2, p. 149-243.

Boström, K., Farquharson, B., and Eyl, W., 1971. Submarine hot springs as a source of active ridge sediments, *Chem. Geol.*, v. 10, p. 189-203.

Lowell, R. P. and Rona, P. A., 1976. On the interpretation of near-bottom water-temperature anomalies, *Earth Planet. Sci. Lett.*, v. 32, p. 18-24.

Rona, P., 1976. Pattern hydrothermal mineral deposition: Mid-Atlantic Ridge crest at latitude 26°N, *Marine Geol.*, v. 21, p. M59-M66.

Rona, P., Harbison, R. N., Bassinger, B., Scott, R. B., and Nalwalk, A. J., 1976. Tectonic fabric and hydrothermal activity of Mid-Atlantic Ridge crest (lat. 26°N), *Geol. Soc. Am. Bull.*, v. 87, p. 661-674.

Varentsov, I. M., 1971. On the leaching of manganese in the course of interaction of basic volcanic materials with sea water, *Soc. Mining Geol. Japan. Spec.* Issue 3, p. 466-473.

———, 1976. Geochemistry of transitional metals in the process of ferromanganese ores formation in recent basins. *In* Smirnov, V. I. (Chief Ed.), *Mineral deposits, Rept. Soviet Geol. Internat. Geol. Cong., 25th Session:* Moscow, (Nauka), p. 79-96 (in Russian).

Varentsov, I. M. and Blazhchishin, A. I., 1976. Ferromanganese nodules. *In Geology of Baltic Sea*, Vilnus (Mokslas), p. 307-348 (in Russian).

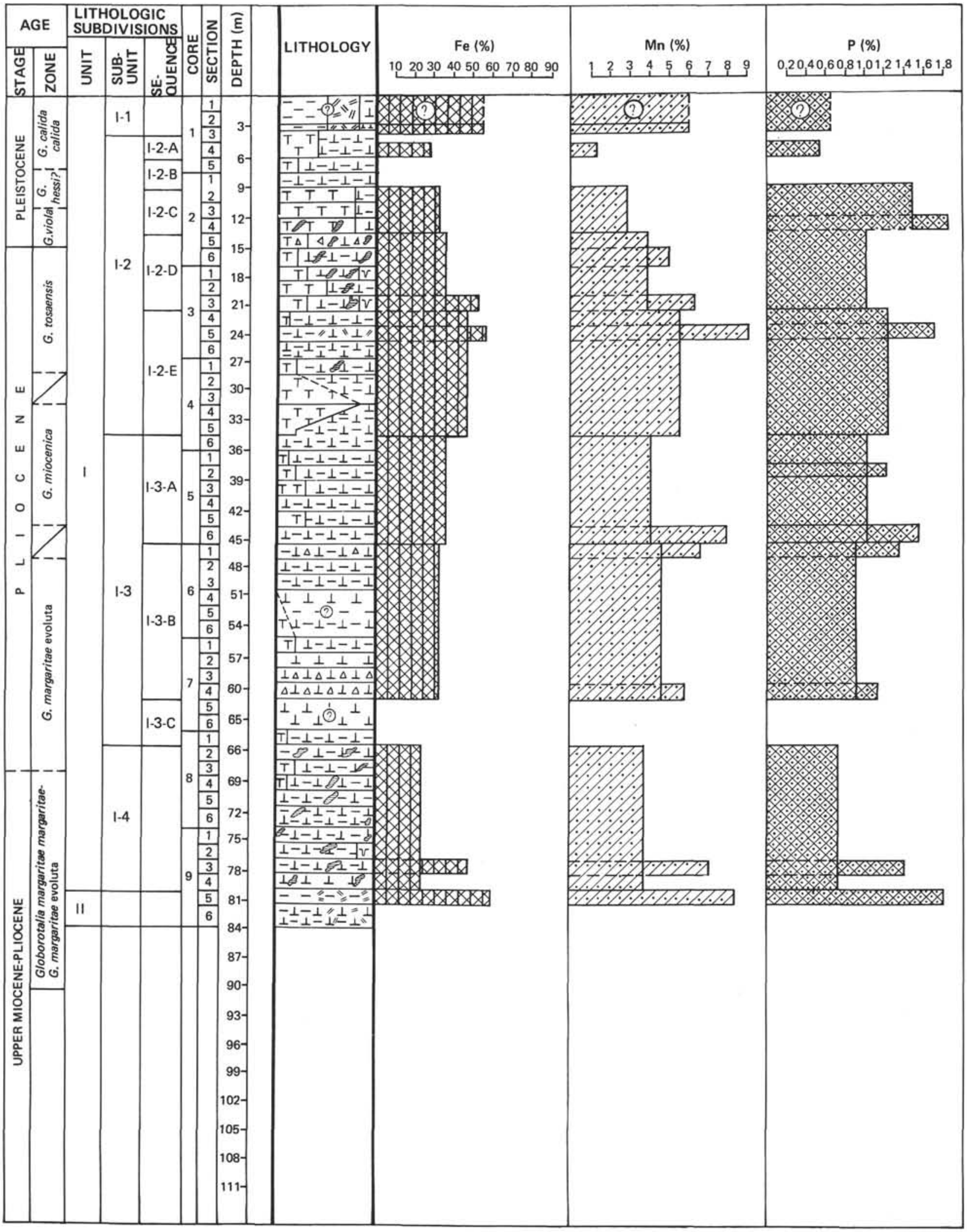

Figure 1. *Distribution of Fe, Mn, P (wt. %, recalculated to the clastic-free, carbonate-free basis (M. B.)) in the section of upper Cenozoic sediments, region of the Mid-Atlantic Ridge, Hole 395, Leg 45.*

Varentsov, I. M. and Stepanets, M. I., 1970. The experiments on modeling of the processes of manganese leaching by sea water from basic volcanic materials, Doklady Academii Nauk SSSR, v. 190, no. 3, p. 679-682 (in Russian).

Vinogradov, A. P., 1962. The average content of chemical elements in the major types of igneous rocks of the Earth's crust, *Geochemistry* (Moscow), no. 7, p. 552-572 (in Russian).

TABLE 6
Chemical Composition of Upper Cenozoic Sediments (average values), North Atlantic, Hole 395, Leg 45 (wt. % on M. B.)

Lithologic Subdivisions: Unit	Sub-unit	Sequence	Core	(m)	Comp. / Cont.	Content: TiO_2	CaO	MgO	Na_2O	K_2O	Fe^{2+}
	1-1		1-1-00 through 1-3-68	0.00-3.68		4.432	–	21.512	2.454	9.065	2.755
		1-2A	1-3-68 through 1-4-80	3.68-5.30		–	3.729	–	56.856	10.297	nil
		1-2B	1-4-80 through 2-1-76	5.30-8.26							
		1-2C	2-1-76	8.26-13.32	No. of anal.	2	2	2	2	2	2
	1-2		through		Min. seq.	2.002	nil	16.014	7.362	5.835	nil
			2-4-132		Max. seq.	5.169	26.260	40.432	13.100	10.267	2.124
					Aver. seq.	3.586	13.130	28.223	10.231	8.051	1.062
		1-2D	2-4-132	13.32-21.04	No. of anal.	4	4	4	4	4	4
			through		Min. seq.	0.237	nil	2.755	10.906	6.412	nil
			3-1-101		Max. seq.	5.889	24.886	16.290	54.667	10.251	4.798
					Aver. seq.	4.069	7.672	8.442	29.491	8.525	1.200
		1-2E	3-3-101	21.04-33.29	No. of anal.	2	2		2	2	2
			through		Min. seq.	3.898	nil		12.239	4,833	nil
			4-5-72		Max. seq.	7.759	17.961		35.890	10.879	0.800
					Aver. seq.	5.829	8.980	nil	24.064	7.856	0.400
			1-3-68	3.68-33.29	No. of anal.	9	9	9	9	9	9
			through		Min. subunit	nil	nil	nil	7.362	4.833	nil
			4-5-72		Max. subunit	7.759	26.260	40.432	56.856	10.879	4.798
					Aver. subunit	3.900	8.738	10.024	27.046	3.468	0.858
I		1-3A	4-5-72	33.29-44.01	No. of anal.	3	3	3	3	3	3
			through		Min. seq.	0.515	13.038	2.700	nil	3.656	nil
			5-6-41		Max. seq.	4.002	72.958	20.780	3.570	8.916	1.840
					Aver. seq.	2.111	44.263	10.096	1.652	6.006	0.613
	1-3	1-3B	5-6-41	44.01-60.00	No. of anal.	5	5	5	5	5	5
			through		Min. seq.	1.128	nil	16.165	nil	1.964	nil
			7-4-35		Max. seq.	3.541	33.012	71.293	1.485	7.662	2.044
					Aver. seq.	5.435	18.592	34.363	0.888	5.117	0.636
		1-3C	7-4-35 through 8-1-129	60.00-65.94							
			4-5-72	33.29-65.94	No. of anal.	8	8	8	8	8	8
			through		Min. subunit	0.515	nil	2.700	nil	1.964	nil
			8-1-129		Max. subunit	4.002	72.958	71.293	3.570	8.916	2.044
					Aver. subunit	2.150	28.219	25.263	1.175	5.451	0.628
	1-4		8-1-129	65.94-80.03	No. of anal.	4	4	4	4	4	4
			through		Min. subunit	nil	nil	4.624	6.464	nil	nil
			9-4-110		Max. subunit	3.547	17.924	89.752	40.682	7.750	2.077
					Aver. subunit	1.530	8.016	36.256	15.861	4.335	0.519
			1-1-00	0.00-80.03	No. of anal.	22	22	22	22	22	22
			through		Min. seq.	nil	nil	nil	nil	1.964	nil
			9-4-110		Max. seq.	7.759	72.958	71.293	56.856	10.879	4.798
					Aver. seq.	2.857	15.293	20.857	14.487	6.646	0.801
II			9-4-110 through 9-6-150	80.03-83.113		2.869	1.987	13.067	6.202	5.121	nil

TABLE 6 – *Continued*

Content													
Fe^{3+}	$Fe_{tot.}$	$Mn_{tot.}$	$P_{tot.}$	Cr	Ni	V	Cu	Co	Pb	Ga	Ge	Mo	Zn
52.589	55.344	6.010	0.651	0.015	0.025	0.095	0.238	0.075	0.058	–	<0.001	0.022	–
26.854	26.854	1.300	0.547	0.007	0.003	0.079	0.219	0.065	0.034	–	<0.004	0.006	–
2	2	2	2	2	2	2	2	2	2	2	2	2	
23.084	25.208	2.511	1.120	0.027	0.030	0.081	0.129	0.041	<0.006	<0.007	<0.004	0.008	
38.541	38.541	3.328	1.841	0.064	0.064	0.099	0.255	0.064	≈0.027	<0.025	<0.010	0.011	
30.812	31.874	2.920	1.480	0.046	0.047	0.090	0.192	0.052	<0.017	<0.016	<0.007	0.010	nil
4	4	4	4	4	4	4	4	4	4	4	4	4	4
nil	26.757	1.872	0.663	nil	nil	<0.062	0.209	<0.062	0.036	nil	0.003	0.011	nil
48.640	53.438	6.325	1.178	<0.042	<0.042	0.119	0.288	0.087	<0.062	<0.028	<0.010	0.029	0.201
27.164	36.295	3.939	0.996	<0.022	<0.017	<0.090	0.235	0.076	<0.047	<0.009	<0.006	0.019	0.050
2	2	2	2	2	2	2	2	2	2	2	2	2	
34.456	34.456	1.964	0.748		0.003	0.050	0.125	0.031	⩽0.025	<0.006	<0.004	0.006	
56.794	57.594	9.039	1.680		0.008	0.168	0.368	0.096	0.112	<0.016	0.010	0.032	
45.625	46.025	5.501	1.214	nil	0.006	0.114	0.247	0.063	0.069	<0.011	<0.007	0.019	nil
9	9	9	9		9	9	9	9	9	9	9	9	9
23.084	25.208	1.300	0.547	nil	nil	0.050	0.125	0.031	<0.006	nil	0.003	0.006	
56.794	57.594	9.039	1.841	0.064	0.064	0.168	0.368	0.096	0.112	<0.028	0.010	0.032	
32.043	36.426	3.766	1.102	0.020	0.020	0.093	0.226	0.067	<0.044	<0.010	0.006	0.016	0.022
3	3	3	3	3	3	3	3	3	3	3	3	3	3
14.267	14.267	1.619	0.502	nil	0.002	0.062	0.098	0.033	0.019	<0.005	<0.003	0.004	0.026
42.965	42.965	7.933	1.544	0.007	0.007	0.147	0.344	0.084	0.056	<0.014	<0.009	0.021	0.119
29.700	30.314	4.004	1.087	0.002	0.005	0.099	0.200	0.051	0.035	<0.009	<0.006	0.010	0.048
5	5	5	5	5	5	5	5	5	5	5	5	5	5
21.917	22.306	2.197	0.428	0.004	0.006	0.043	0.099	0.047	0.016	<0.004	<0.002	0.003	nil
40.730	40.730	6.568	1.358	0.101	0.156	0.129	0.247	0.077	0.051	<0.013	<0.008	0.011	0.097
32.190	32.825	4.601	0.906	0.040	0.062	0.086	0.172	0.061	0.035	<0.008	<0.005	0.007	0.054
8	8	8	8	8	8	8	8	8	8	8	8	8	8
14.267	14.267	1.619	0.428	nil	0.002	0.043	0.098	0.033	0.016	<0.004	<0.002	0.003	0.026
42.965	42.965	7.933	1.544	0.101	0.156	0.147	0.344	0.084	0.056	<0.014	<0.009	0.021	0.119
31.257	31.883	4.378	0.974	0.026	0.041	0.091	0.183	0.058	0.035	<0.009	<0.005	0.008	0.018
4	4	4	4	4	4	4	4	4	4	4	4	4	4
nil	nil	1.891	nil	nil	nil	0.068	0.092	0.036	0.024	nil	0.003	0.010	nil
47.604	47.604	7.094	1.401	0.139	0.074	0.105	0.190	0.071	0.036	<0.006	<0.005	0.025	0.062
17.398	24.920	3.756	0.761	0.035	0.023	0.080	0.143	0.067	0.030	0.003	0.004	0.016	0.016
22	22	22	22	22	22	22	22	22	22	22	22	22	22
nil	nil	1.360	nil	nil	nil	0.043	0.092	0.031	<0.006	nil	<0.001	0.003	nil
56.794	57.594	49.039	1.841	0.139	0.156	0.168	0.368	0.096	0.112	<0.028	0.010	0.032	0.201
30.028	33.542	4.089	0.973	0.025	0.028	0.092	0.196	0.064	0.039	<0.008	0.005	0.013	0.019
59.906	59.906	8.432	1.766	0.002	0.020	0.150	0.225	0.086	0.044	–	<0.003	0.020	0.097

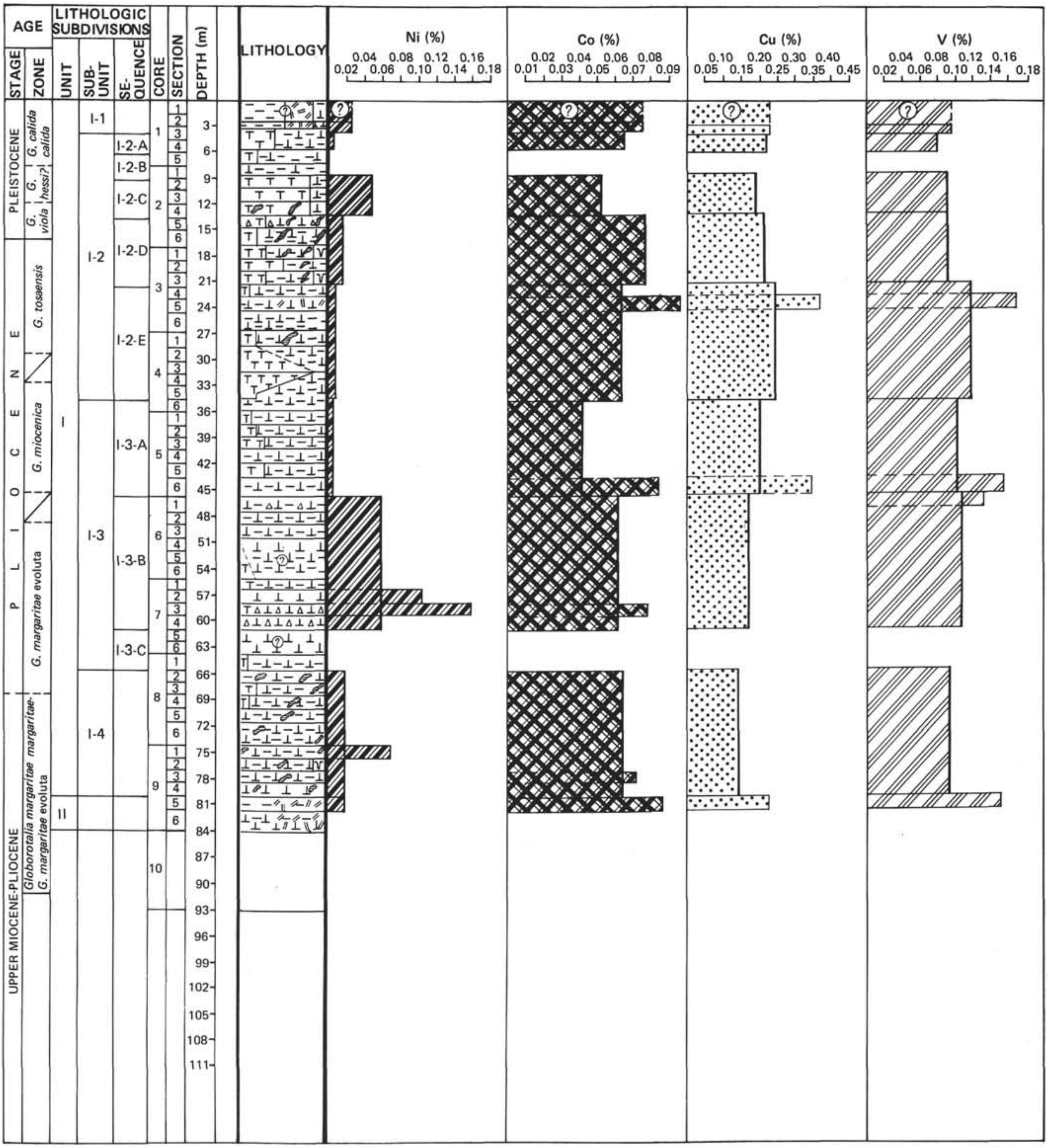

Figure 2. *Distribution of Ni, Co, Cu, V (wt. %, recalculated to M.B.) in the section of upper Cenozoic sediments, region of the Mid-Atlantic Ridge, Hole 395, Leg 45.*

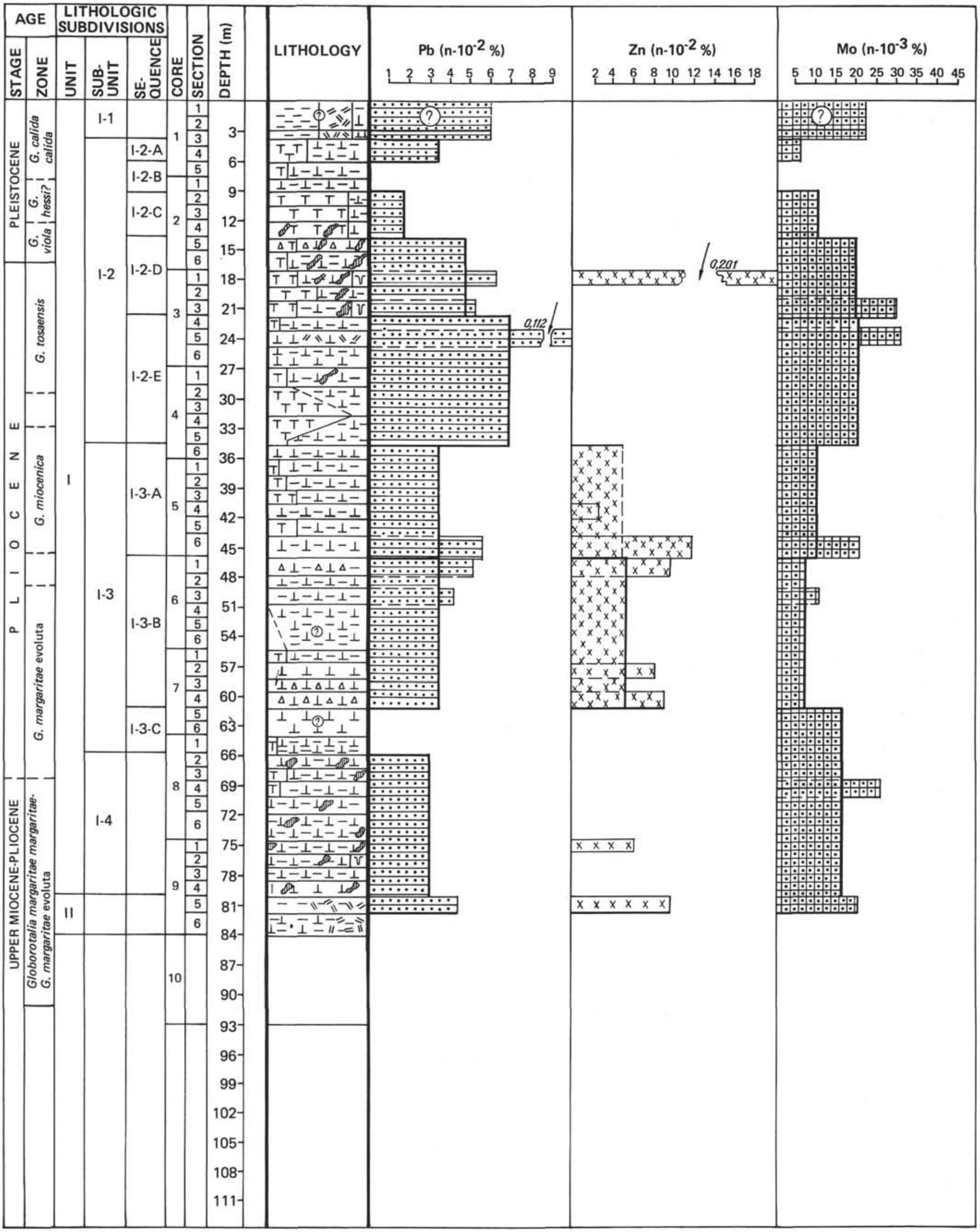

Figure 3. *Distribution of Pb, Zn, Mo (wt. %, recalculated to clastic-free, silica-free, carbonate-free basis (M.B.)) in the section of upper Cenozoic sediments, region of the Mid-Atlantic Ridge, Hole 395, Leg 45.*

TABLE 7
Chemical Composition of Upper Cenozoic Sediments, North Atlantic, Hole 396, Leg 45 (wt. %, on M. B.)

Sample (Interval in cm)	TiO_2	CaO	MgO	Na_2O	K_2O	Fe^{2+}	Fe^{3+}	$Fe_{tot.}$	$Mn_{tot.}$	$P_{tot.}$	Zn	Cr	Ni	V	Cu	Co	Pb	Ga	Ge	Mo
1-1, 69-71	3.825	29.947	12.495	9.548	7.621	2.833	29.126	31.959	3.400	0.793	0.062	0.014	0.009	0.062	0.164	0.065	0.025	–	<0.003	0.006
1-2, 32-34	4.924	–	20.356	10.148	10.118	3.303	43.925	47.328	6.125	0.600	0.039	0.021	0.012	0.042	0.240	0.084	0.042	–	<0.002	0.019
1-3, 72-74	4.310	18.923	14.914	11.035	10.259	2.155	33.276	35.431	3.879	0.819	0.060	–	–	0.073	0.181	0.065	0.030	<0.004	<0.005	0.011
1-5, 144-146	3.581	13.374	19.761	6.361	8.190	1.252	42.176	43.428	4.408	4.408	0.043	–	0.005	0.030	0.138	0.045	0.022	–	<0.003	0.009
2-1, 123-125	–	28.921	1.053	37.759	7.221	–	22.904	22.904	1.918	–	–	–	–	0.015	0.132	0.038	<0.026	<0.004	<0.003	0.006
2-2, 121-123	2.989	6.595	5.361	45.309	8.730	–	29.273	29.273	1.471	–	–	–	–	0.019	0.166	0.038	<0.033	<0.005	<0.003	0.008
2-3, 93-95	4.335	23.918	11.101	7.983	9.729	3.430	34.458	37.889	3.929	0.748	0.040	–	0.009	0.037	0.153	0.062	0.044	–	<0.003	0.017
2-5, 139-141	–	19.025	–	44.332	8.944	–	25.733	25.733	1.704	–	–	–	–	0.028	0.153	0.039	0.028	–	<0.002	0.011
2-6, 76-78	–	22.029	–	48.018	6.980	–	21.039	21.039	1.634	–	–	–	–	0.040	0.153	0.045	≲0.040	<0.010	<0.004	0.010
3-1, 87-88	–	22.716	3.954	42.444	7.382	–	21.178	21.178	2.021	–	–	–	0.004	0.031	0.163	0.048	≲0.035	<0.009	<0.003	0.010
3-2, 94-96	2.196	27.207	–	14.091	10.065	3.050	37.272	40.322	4.392	1.220	0.073	–	0.006	0.049	0.213	0.085	0.049	<0.006	<0.008	0.016
3-4, 138-140	9.790	–	20.037	6.594	7.558	–	49.458	49.458	5.123	0.964	0.086	–	0.005	0.056	0.198	0.071	0.035	<0.005	<0.006	0.012
5-2, 73-75	3.314	7.999	9.542	12.742	8.914	–	49.654	49.654	5.942	1.314	0.080	–	0.023	0.097	0.229	0.069	≈0.046	<0.011	<0.007	0.016
5-3, 100-102	3.021	–	17.278	5.582	8.506	–	54.179	54.179	8.482	2.368	0.056	0.005	0.041	0.085	0.208	0.118	0.034	–	<0.002	0.034
5-4, 80-82	5.967	–	18.053	14.351	12.010	8.309	36.408	44.716	3.323	0.982	0.106	–	0.015	0.091	0.249	0.060	≈0.060	<0.015	–	–
5-6, 61-63	3.949	37.197	–	3.469	5.443	5.870	40.132	46.002	2.295	1.174	0.064	0.064	0.011	0.053	0.165	0.043	~0.043	<0.011	<0.007	<0.010
6-2, 82-84	1.264	27.585	5.953	43.713	7.788	–	13.130	13.130	0.245	–	–	<0.016	≲0.016	0.049	0.163	<0.037	<0.037	<0.012	<0.004	<0.008
6-3, 67-69	5.443	16.419	14.876	1.723	11.248	14.514	29.844	44.357	3.991	1.179	0.118	0.036	0.027	0.100	0.272	0.091	≈0.073	<0.018	<0.012	<0.016
6-5, 49-50	7.641	53.671	7.152	10.881	11.125	–	–	5.807	2.873	0.367	–	0.031	0.037	0.086	0.177	0.055	~0.055	<0.022	<0.009	<0.012
7-1, 99-101	4.571	36.055	18.456	5.200	11.028	6.285	14.685	20.970	2.514	0.743	0.006	0.023	0.017	0.063	0.189	0.080	0.046	<0.011	<0.007	0.021
7-3, 118-120	3.844	19.557	2.408	5.618	8.068	4.646	52.758	57.404	1.816	0.929	0.008	0.017	0.017	0.046	0.165	0.042	0.038	<0.008	<0.005	<0.008
7-4, 64-66	–	–	–	58.635	10.347	–	30.773	30.773	–	–	–	–	–	0.016	0.135	0.043	0.038	–	<0.004	<0.009
7-5, 40-42	3.059	25.519	1.936	37.717	6.699	–	24.706	24.706	0.116	–	–	–	–	0.031	0.135	<0.031	<0.031	<0.008	<0.003	<0.007
7-6, 74-76	0.100	35.724	3.788	32.534	5.616	–	20.903	20.903	1.097	–	–	–	0.008	0.017	0.096	0.080	<0.027	<0.007	<0.003	<0.006
8-3, 41-43	3.959	–	4.990	60.744	5.640	–	21.748	21.748	1.302	1.247	–	0.016	0.022	0.054	0.141	0.065	~0.043	<0.011	<0.007	<0.010
8-5, 60-62	1.435	–	9.649	43.006	8.931	–	35.330	35.330	0.897	0.466	–	–	–	0.039	0.136	0.072	0.029	–	<0.004	<0.006
8-6, 83-85	3.945	29.684	–	45.183	0.942	–	18.693	18.693	0.188	1.080	–	0.005	0.014	0.047	0.122	0.038	≲0.038	<0.009	<0.006	<0.008
9-1, 141-143	5.078	38.338	7.594	1.876	6.634	5.032	30.103	35.136	4.346	0.640	0.009	0.009	0.023	0.059	0.123	0.059	~0.041	<0.014	<0.006	<0.011
9-3, 89-91	3.980	43.653	–	5.547	9.146	2.117	30.570	32.687	3.599	1.016	0.025	0.021	0.021	0.063	0.119	0.055	~0.038	<0.013	<0.006	<0.011
9-5, 122-124	3.373	24.828	12.946	35.129	4.406	3.343	12.702	16.045	2.279	0.729	0.012	0.006	0.015	0.042	0.103	0.039	~0.024	<0.009	<0.004	0.008
10-2, 41-43	2.948	40.885	5.098	5.791	20.148	1.734	19.385	21.119	3.260	0.451	–	0.010	0.017	0.052	0.125	0.048	~0.028	<0.007	<0.004	0.009
10-3, 29-31	1.878	53.962	4.532	5.903	5.784	1.491	23.284	24.775	2.206	0.686	0.015	0.006	0.012	0.066	0.095	0.042	0.024	<0.006	<0.004	0.006
10-4, 86-88	1.520	55.324	4.336	6.928	4.236	1.246	24.821	26.067	0.698	0.698	–	≤0.020	<0.020	0.040	0.047	<0.024	<0.024	<0.010	<0.004	<0.005
10-6, 53-55	0.611	29.598	3.668	51.535	5.574	–	7.804	7.804	0.288	0.647	–	≤0.025	<0.025	0.054	0.079	<0.032	<0.032	<0.014	<0.005	<0.007
11-1, 113-115	3.940	0.557	34.976	7.545	10.556	–	40.328	40.328	1.412	0.297	0.015	0.026	0.030	0.071	0.126	0.059	≈0.033	<0.015	<0.005	0.007
11-3, 88-90	2.301	12.074	31.517	4.912	5.947	–	41.394	41.394	1.189	0.414	0.026	0.013	0.015	0.041	0.080	0.036	≈0.023	<0.008	<0.004	<0.005
11-4, 43-45	8.693	–	4.866	10.552	14.324	2.734	55.877	58.610	2.460	–	–	0.027	0.033	0.093	0.169	0.087	≈0.049	<0.016	<0.008	<0.010
11-4, 108-110	2.327	43.853	16.662	4.249	8.830	1.847	21.280	23.127	0.332	0.296	0.022	0.030	<0.030	0.059	0.085	<0.035	<0.035	<0.016	<0.005	<0.007
11-5, 34-36	4.606	–	6.540	1.442	10.232	1.758	73.100	74.858	1.863	0.070	0.042	0.010	0.014	0.070	0.144	0.056	0.032	<0.007	<0.005	0.008
12-2, 110-112	2.926	37.463	12.444	3.008	5.224	3.008	34.487	37.495	1.208	–	0.014	0.011	0.014	0.005	0.109	0.038	≈0.022	<0.008	<0.003	0.005
12-4, 110-112	5.908	21.629	25.228	3.973	10.763	–	31.170	31.170	0.917	–	0.041	0.024	0.027	0.085	0.126	0.054	≈0.031	<0.014	<0.005	≤0.006
12-5, 74-76	4.731	12.700	7.898	33.974	2.455	–	37.069	37.069	0.925	–	–	<0.014	<0.014	0.028	0.107	<0.032	<0.032	<0.011	<0.003	<0.007
12-6, 62-64	0.706	28.928	1.137	42.921	3.606	–	21.010	21.010	0.745	0.666	–	–	0.004	0.020	0.153	0.063	0.031	–	<0.005	≤0.007
13-2, 68-70	2.238	8.700	43.855	6.513	6.739	–	29.748	29.748	1.232	0.704	0.028	–	0.005	0.020	0.128	0.053	0.023	–	<0.003	0.011
13-4, 66-68	4.595	46.191	18.006	6.876	5.650	–	17.258	17.258	1.123	–	0.020	0.003	0.010	0.082	0.095	0.041	0.027	<0.007	<0.004	0.010
13-5, 37-39	3.742	33.311	7.215	7.249	10.553	–	35.739	35.739	1.585	0.236	0.030	0.027	0.027	0.071	0.108	0.047	0.030	<0.013	<0.005	0.011
13-6, 66-68	2.405	15.399	25.961	4.471	7.033	–	42.771	42.771	1.307	0.471	–	–	0.003	0.023	0.086	0.037	0.021	–	<0.003	0.010
14-0, 24-26	6.027	–	28.655	8.865	13.103	–	41.331	41.331	1.361	0.155	0.047	0.023	0.027	0.101	0.183	0.058	0.039	≤0.012	<0.005	0.007
14-1, 21-23	0.963	–	19.320	13.269	2.867	–	55.264	55.264	6.459	1.382	–	–	0.054	0.093	0.184	0.080	0.032	–	–	0.032
14-3, 69-71	–	–	–	19.477	4.030	–	63.821	63.821	9.856	2.200	–	–	0.069	0.121	0.220	0.117	0.047	–	–	0.042
14-4, 72-74	–	–	3.571	37.752	5.657	–	48.562	48.562	2.685	1.462	–	–	0.017	0.069	0.141	0.038	0.024	<0.005	<0.003	0.012
14-5, 48-50	3.300	–	29.253	6.221	6.173	–	52.949	52.949	1.686	0.071	–	0.007	0.019	0.083	0.164	0.033	0.024	<0.005	<0.003	0.008

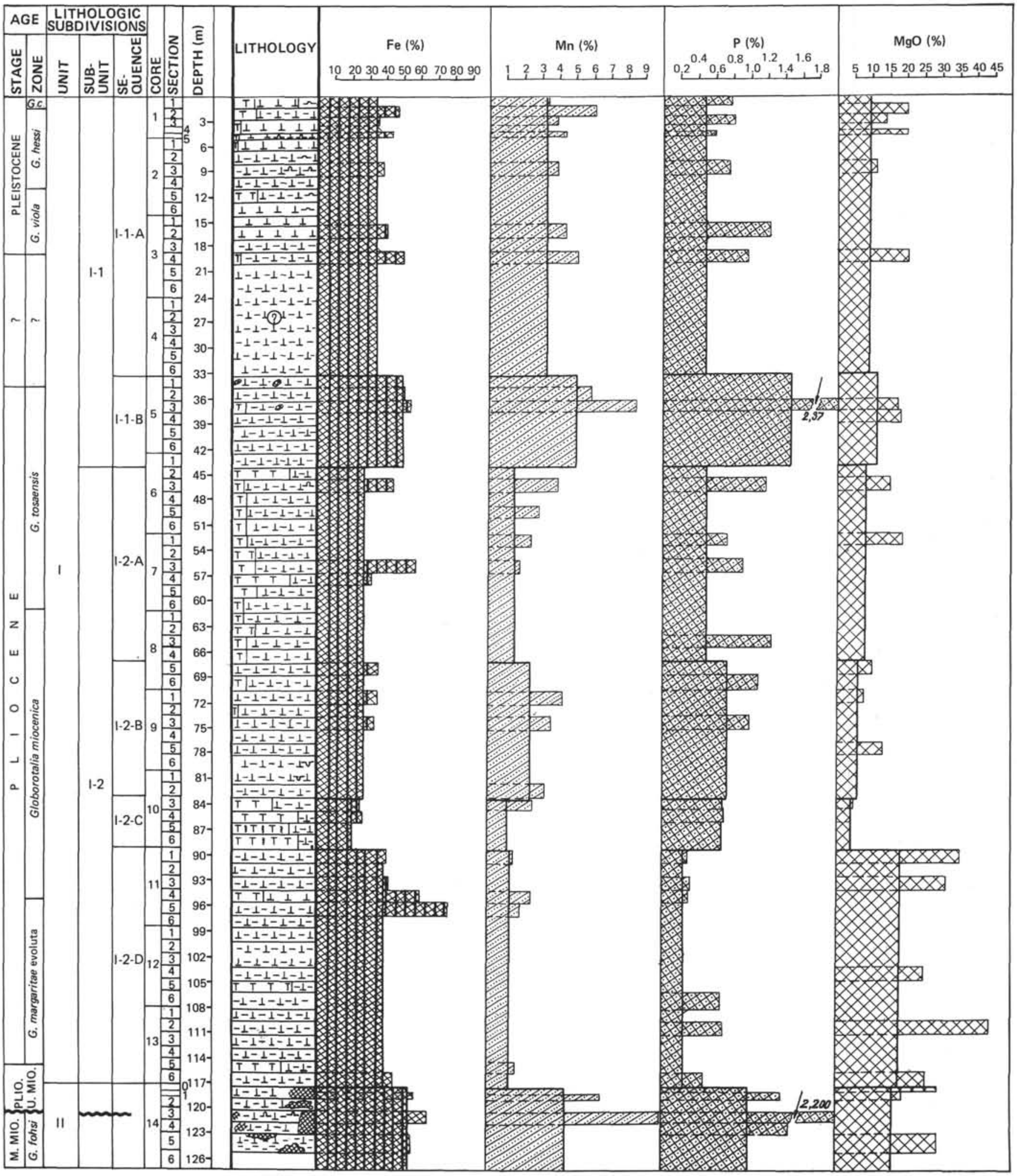

Figure 4. *Distribution of Fe, Mn, P, and MgO (wt. %, recalculated to M. B.) in the section of upper Cenozoic sediments, region of the Mid-Atlantic Ridge, Hole 396, Leg 45.*

TABLE 8
Chemical Composition of Upper Cenozoic Sediments (average values), North Atlantic, Hole 396, Leg 45 (wt. % on M. B.)

Lithologic Subdivision			Depth Interval		Comp.	Content (wt. %)					
Unit	Sub-Unit	Sequence	Core	(m)	Cont.	TiO_2	CaO	MgO	Na_2O	K_2O	Fe^{2+}
		1-1A	1-00-00	0.00-20.18	No. of anal.	12	12	12	12	12	12
			through		Min. seq.	nil	nil	nil	6.361	6.980	nil
			4-6-00		Max. seq.	9.790	29.947	20.356	48.018	10.259	3.430
					Aver. seq.	2.996	17.721	9.086	23.635	8.566	1.335
I	1-1	1-1B	5-1-00	20.18-43.87	No. of anal.	4	4	4	4	4	4
			through		Min. seq.	3.021	nil	nil	3,469	5.433	nil
			6-1-150		Max. seq.	5.967	37.197	18.053	14,351	12.010	8.309
					Aver. seq.	4.063	11.299	11.218	9.036	8.718	3.545
					No. of anal.	16	16	16	16	16	16
					Min. sub-unit	nil	nil	nil	3.469	5.443	nil
					Max. sub-unit	9.790	37.197	20.356	48.018	12.010	8.309
					Aver. sub-unit	3.263	16.116	9.619	19.985	8.604	1.888
	1-2	1-2A	6-2-00	43.87-67.16	No. of anal.	9	9	9	9	9	9
			through		Min. seq	nil	nil	nil	1.723	5.616	nil
			8-4-150		Max. seq.	7.641	53.671	18.456	60.744	11.248	14.514
					Aver. seq.	3.320	23.834	7.729	28.529	8.617	1.215
		1-2B	8-5-00	67.16-84.14	No. of anal.	6	6	6	6	6	6
			through		Min. seq.	1.435	nil	nil	1.876	0.942	nil
			10-2-150		Max. seq.	5.078	43.653	12.946	45.183	20.148	5.032
					Aver. seq.	3.460	29.565	5.881	22.755	8.368	2.038
		1-2C	10-3-00	84.14-89.18	No. of anal.	3	3	3	3	3	3
			through		Min. seq.	0.611	29.598	3.668	5.903	4.236	nil
			10-6-150		Max. seq.	1.878	55.324	4.532	51.535	5.784	1.491
					Aver. seq.	1.336	46.295	4.179	21.455	5.198	0.912
		1-2D	11-1-00	89.18-117.15	No. of anal.	13	13	13	13	13	13
			through		Min. seq.	0.706	nil	1.137	1.442	2.455	nil
			13-6-00		Max. seq.	8.693	46.191	43.855	42.921	14.324	3.008
					Aver. seq.	3.778	20.068	18.177	10.591	7.839	0.719
					No. of anal.	31	31	31	31	31	31
					Min. sub-unit	nil	nil	nil	1.442	0.942	nil
					Max. sub-unit	8.693	55.324	43.855	60.744	11.248	14.514
					Aver. sub-unit	3.347	25.535	11.409	19.205	7.912	1.137
					No. of anal.	47	47	47	47	47	47
					Min. unit	nil	nil	nil	1.442	0.942	nil
					Max. unit	9.790	55.324	43.855	60.744	12.010	14.514
					Aver. unit	3.318	7.435	10.800	19.470	8.148	1.392
			13-6-00	117.15-	No. of anal.	5	5	5	5	5	5
II			through	(124.41)	Min. unit	nil		nil	6.221	2.867	
			14-5-150	125.34	Max. unit	6.027		29.253	37.752	13.103	
					Aver. unit	2.058	nil	16.160	17.117	6.366	nil

TABLE 8 – *Continued*

Content (wt. %)													
Fe^{3+}	$Fe_{tot.}$	$Mn_{tot.}$	$P_{tot.}$	Zn	Cr	Ni	V	Cu	Co	Pb	Ga	Ge	Mo
12	12	12	12	7	12	12	12	12	12	12	12	12	12
21.039	21.039	0.748	nil	0.039	nil	nil	0.015	0.132	0.038	0.022	nil	<0.002	0.006
49.458	49.458	6.125	1.220	0.086	0.021	0.012	0.073	0.240	0.085	0.049	<0.010	<0.008	0.019
32.485	33.820	3.334	0.479	0.058	0.003	0.004	0.040	0.171	0.057	0.034	<0.004	<0.004	0.011
4	4	4	4	4	4	4	4	4	4	4	4	4	4
36.408	44.716	2.295	0.982	0.056	nil	0.011	0.053	0.165	0.043	0.034	nil	nil	nil
54.179	54.179	8.482	2.368	0.106	0.064	0.041	0.097	0.249	0.118	0.060	<0.015	<0.007	0.034
45.093	48.638	5.010	1.460	0.077	0.017	0.022	0.081	0.213	0.072	0.046	0.009	0.004	0.015
16	16	16	16	11	16	16	16	16	16	16	16	16	16
21.039	21.039	0.748	nil	0.039	nil	nil	0.015	0.132	0.038	0.022	nil	nil	nil
54.179	54.179	8.482	2.368	0.106	0.064	0.041	0.097	0.249	0.118	≈0.060	<0.015	<0.007	0.034
35.637	37.526	3.753	0.724	0.064	0.007	0.009	0.050	0.182	0.061	0.037	<0.005	<0.004	0.012
9	9	9	9	9	9	9	9	9	9	9	9	9	9
nil	5.807	nil	nil	nil	nil	nil	0.016	0.135	<0.031	<0.027	nil	<0.003	<0.006
52.758	57.404	3.991	1.247	0.118	0.036	0.037	0.100	0.272	0.091	≈0.073	<0.022	<0.012	0.021
23.172	26.644	1.550	0.496	0.015	0.015	0.015	0.051	0.164	0.058	0.043	0.011	0.007	0.011
6	6	6	6	3	6	6	6	6	6	6	6	6	6
12.702	16.045	0.188	0.466	nil	nil	nil	0.039	0.103	0.038	~0.024	nil	<0.004	<0.006
35.330	35.330	4.346	1.080	0.009	0.021	0.023	0.063	0.136	0.072	0.041	<0.014	<0.006	0.011
24.464	26.502	2.428	0.730	0.015	0.009	0.015	0.050	0.121	0.052	0.033	<0.009	<0.005	<0.009
3	3	3	3	2	3	3	3	3	3	3	3	3	3
7.804	7.804	0.288	0.647	nil	0.006	0.012	0.040	0.047	<0.024	<0.024	<0.006	<0.004	<0.005
24.821	26.067	2.206	0.698	0.015	⩽0.025	<0.025	0.066	0.095	0.042	0.032	0.014	<0.005	<0.007
18.636	19.549	1.064	0.677	0.008	<0.017	<0.019	0.053	0.074	0.033	0.027	<0.010	<0.004	<0.006
13	13	13	13	10	13	13	13	13	13	13	13	13	13
17.258	17.258	0.332	nil	nil	nil	0.004	0.005	0.080	<0.032	≈0.021	nil	<0.003	<0.005
73.100	74.858	2.460	0.704	0.042	0.030	0.033	0.033	0.169	0.087	<0.049	<0.016	<0.005	0.011
37.010	37.737	1.253	0.243	0.024	0.012	0.017	0.051	0.117	0.049	<0.030	0.009	<0.004	<0.008
31	31	31	31	24	31	31	31	31	31	31	31	31	31
nil	5.807	nil	nil	nil	nil	nil	0.005	0.047	<0.024	≈0.021	nil	<0.003	<0.005
73.100	74.858	4.346	2.247	0.118	0.036	0.037	0.100	0.272	0.091	≈0.073	<0.022	<0.012	0.021
28.786	29.936	1.549	0.453	0.018	0.013	0.016	0.051	0.127	0.051	0.032	0.009	<0.005	0.009
47	47	47	47	35	47	47	47	47	47	47	47	47	47
nil	5,807	nil	nil	nil	nil	nil	0.005	0.047	<0.024	≈0.021	nil	nil	nil
73.100	74.858	8.482	2.368	0.118	0.064	0.041	0.100	0.272	0.118	≈0.073	<0.022	<0.012	0.034
31.118	32.520	2.229	0.545	0.032	0.011	0.014	0.051	0.146	<0.054	0.035	<0.008	<0.005	0.010
5	5	5	5	1	5	5	5	5	5	5	5	5	5
41.331	41.331	1.361	0.071		nil	0.017	0.069	0.141	0.033	0.024	nil	nil	0.007
63.821	63.821	9.856	2.200		0.023	0.069	0.121	0.220	0.117	0.047	⩽0.012	<0.005	0.042
42.385	52.385	4.409	1.054	0.047	0.006	0.037	0.093	0.178	0.065	0.033	<0.005	<0.002	0.020

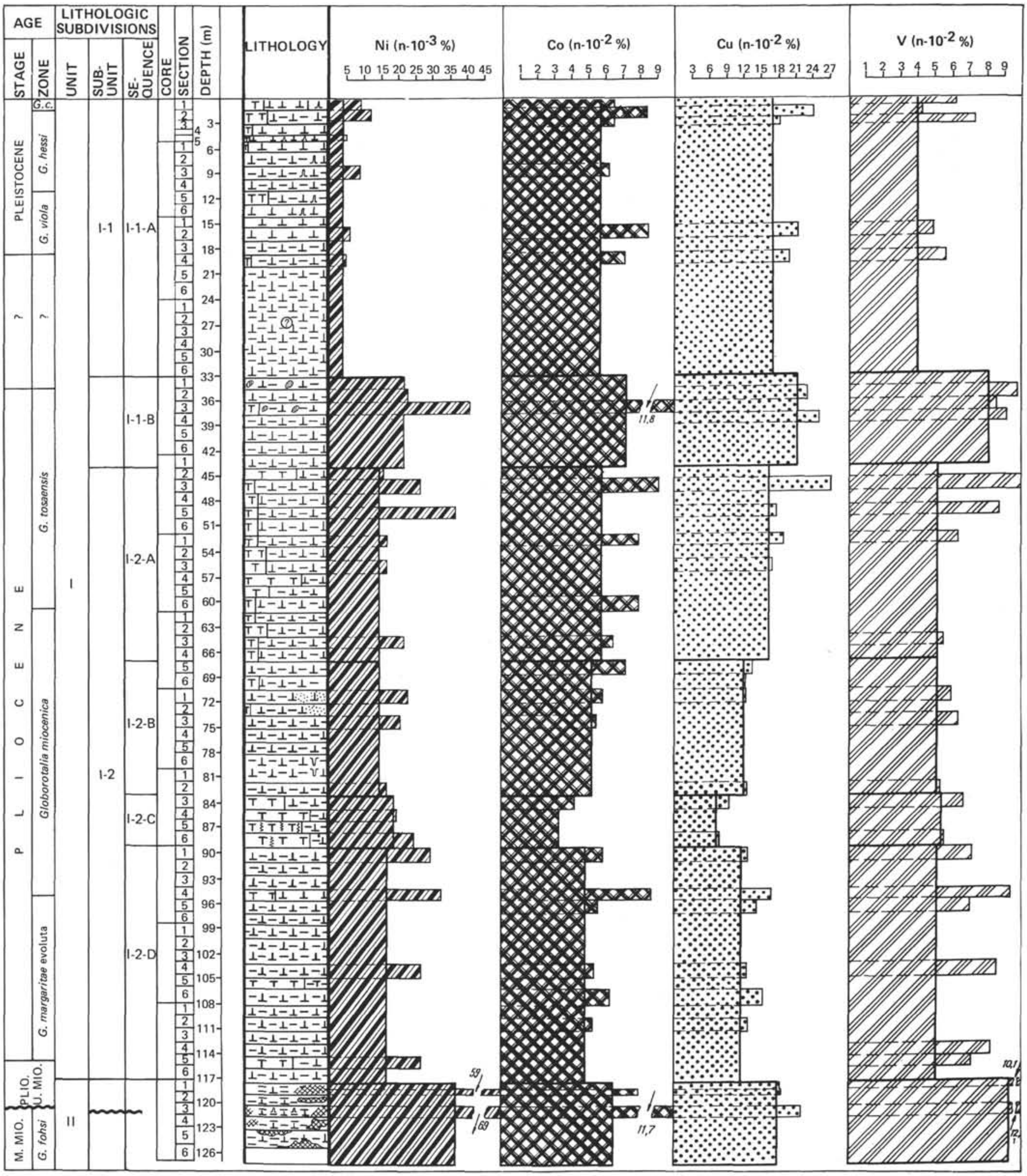

Figure 5. *Distribution of Ni, Co, Cu, and V (wt. %, recalculated to M.B.) in the section of upper Cenozoic sediments, region of the Mid-Atlantic Ridge, Hole 396, Leg 45.*

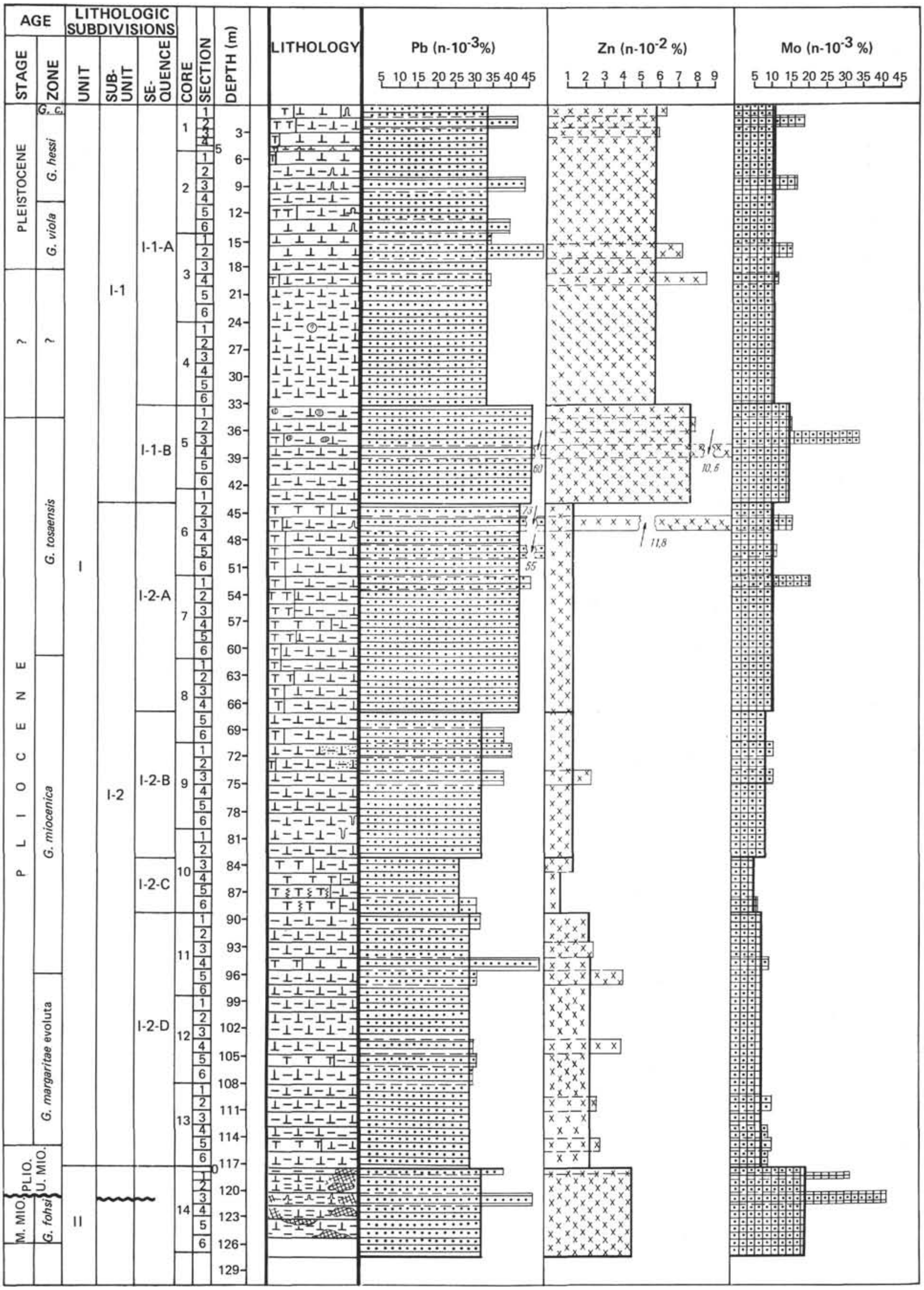

Figure 6. *Distribution of Pb, Zn, Mo (wt. %, recalculated to M.B.) in the section of upper Cenozoic sediments, region of the Mid-Atlantic Ridge, Hole 396, Leg 45.*

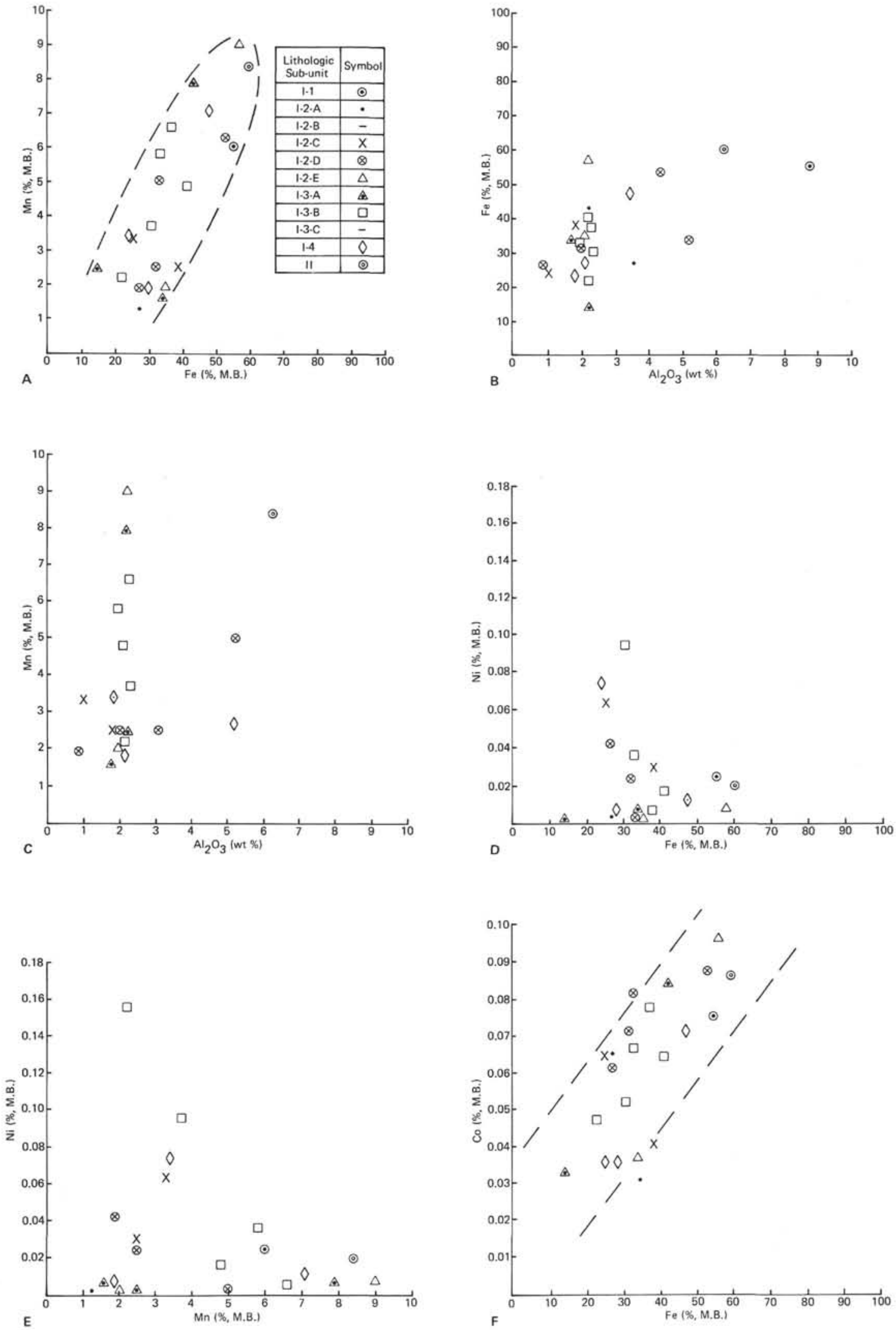

Figure 7. *Correlative relationships of some heavy metals in upper Cenozoic sediments, region of the Mid-Atlantic Ridge, Hole 395, Leg 45. Contents of heavy metals: wt. %, recalculated to M. B. elastic-free, silica-free, carbonate-free matter;* Al_2O_3*: wt. %, recalculated to an air-dry weight.* (A) *Mn-Fe;* (B) *Fe-*Al_2O_3*;* (C) *Mn-*Al_2O_3*;* (D) *Ni-Fe;* (E) *Ni-Mn;* (F) *Co-Fe;* (G) *Co-Mn;* (H) *P-Fe;* (I) *V-Fe;* (J) *Cu-Fe;* (K) *Cu-Mn;* (L) *Pb-*Al_2O_3*;* (M) *Ob-Mn;* (N) *Zn-Fe;* (O) *Zn-Mn;* (P) *Zn-*Al_2O_3*;* (Q) *Mo-Fe;* (R) *Mo-Mn.*

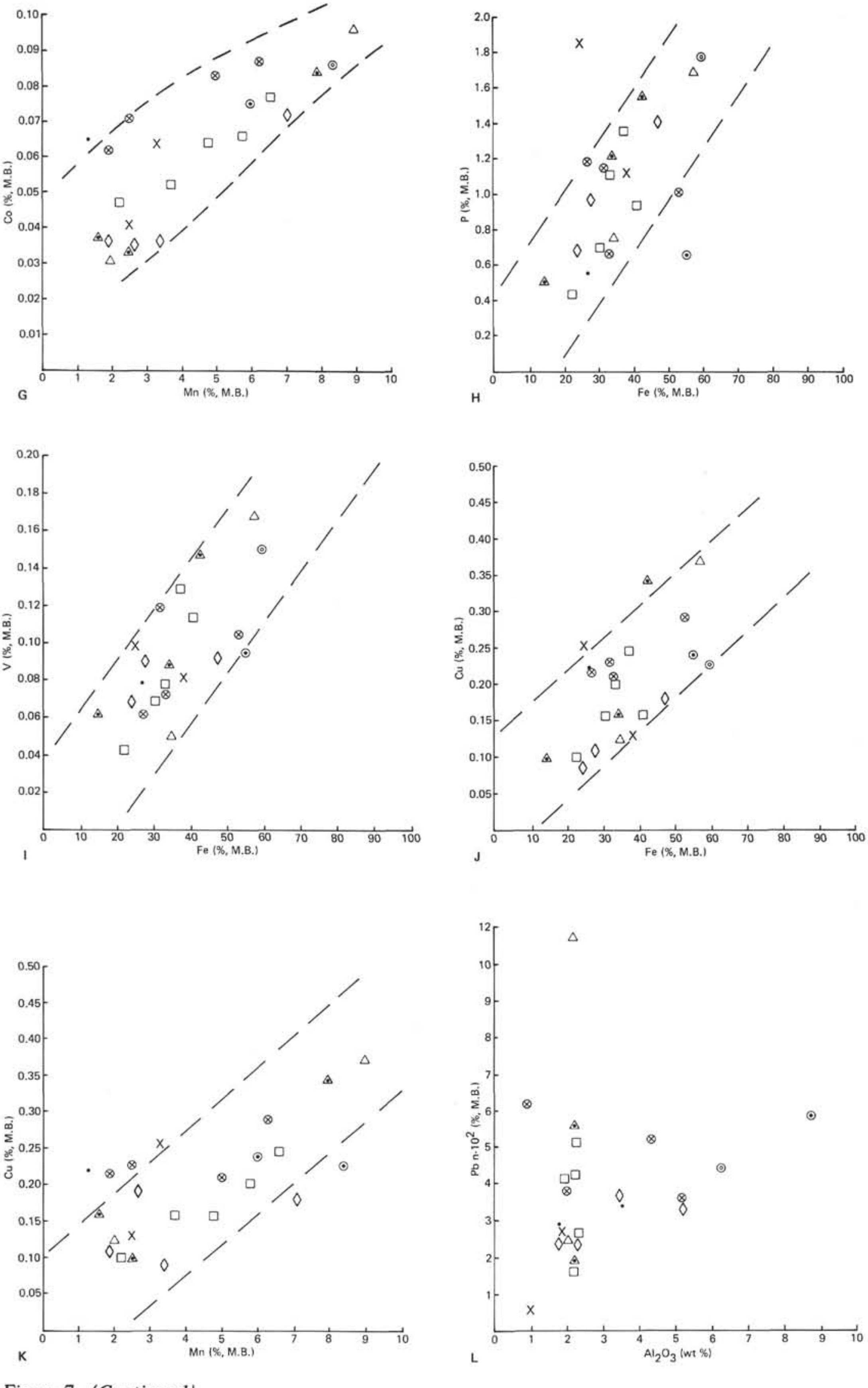

Figure 7. *(Continued)*

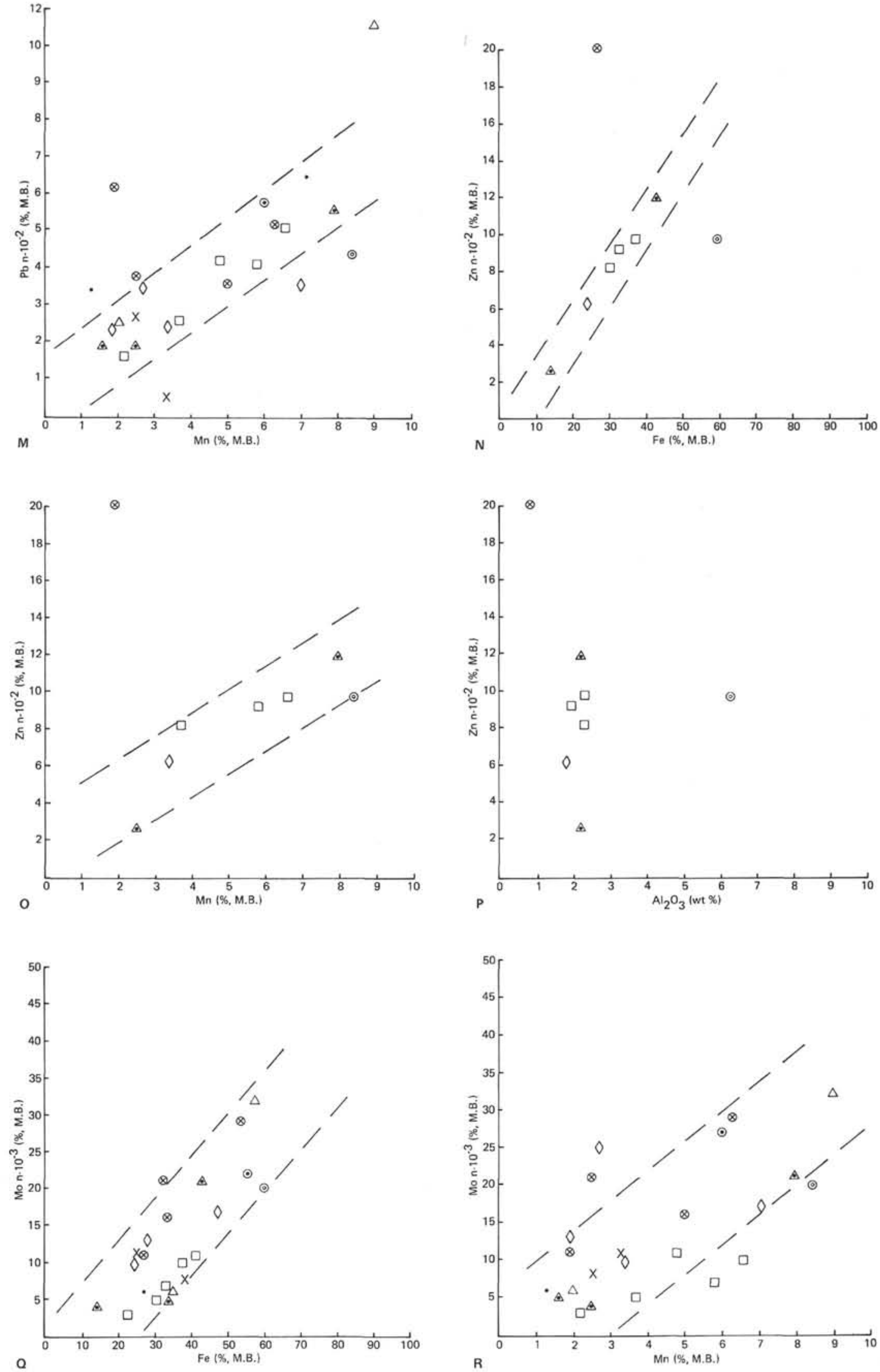

Figure 7. *(Continued).*

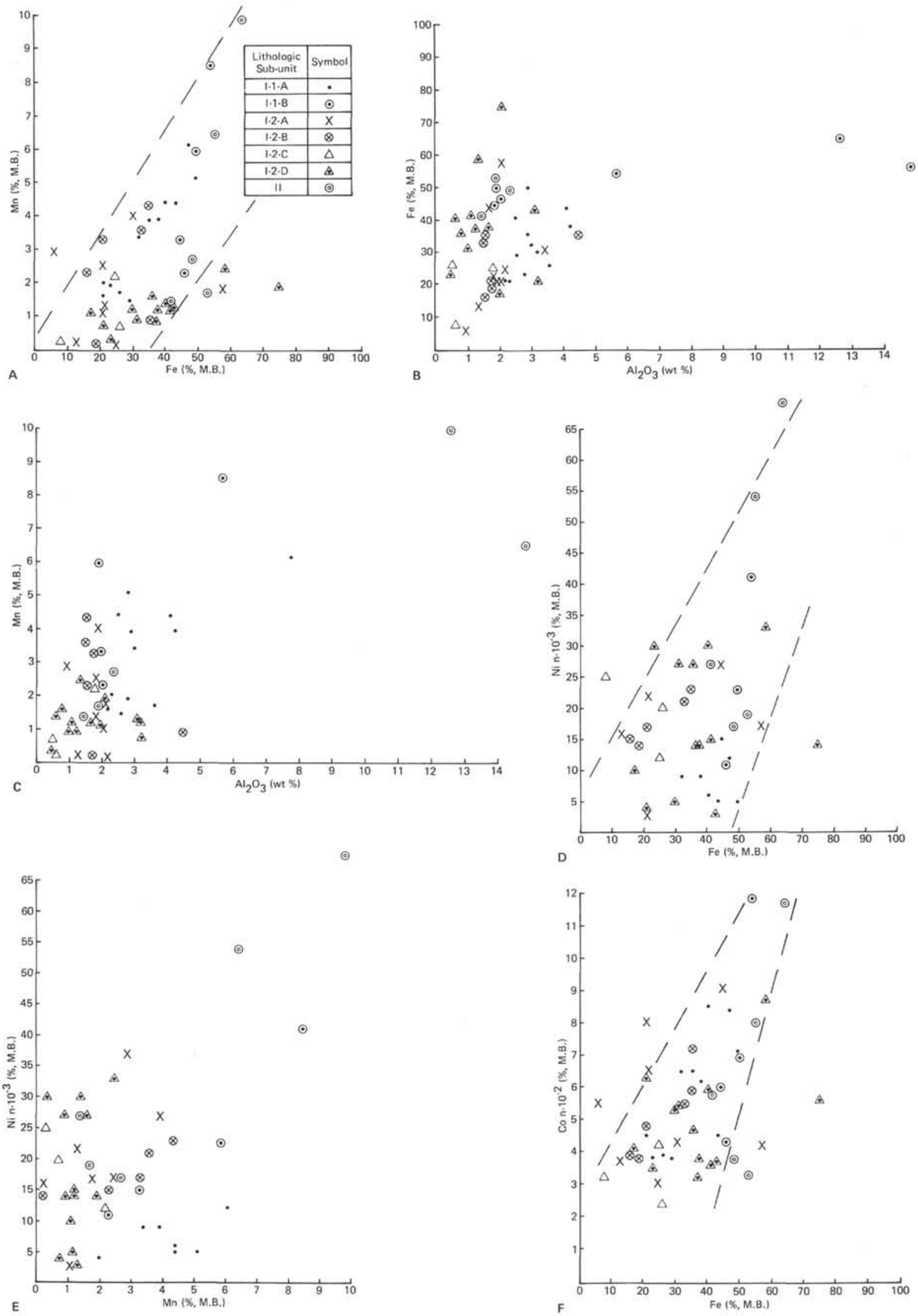

Figure 8. *Correlative relationships of some heavy metals in upper Cenozoic sediments, region of the Mid-Atlantic ridge, Hole 396, Leg 45. Contents of heavy metals: wt. %, recalculated to M. B., Al_2O_3; wt. %, recalculated to an air-dry weight.* (A) *Mn-Fe;* (B) *Fe-Al_2O_3;* (C) *Mn-Al_2O_3;* (D) *Ni-Fe;* (E) *Ni-Mn;* (F) *Co-Fe;* (G) *Co-Mn;* (H) *P-Fe;* (I) *V-Fe;* (J) *Cu-Fe;* (K) *Cu-Mn;* (L) *Pb-Al_2O_3;* (M) *Pb-Mn;* (N) *Zn-Fe;* (O) *Zn-Mn;* (P) *Zn-Al_2O_3;* (Q) *Mo-Fe;* (R) *Mo-Mn.*

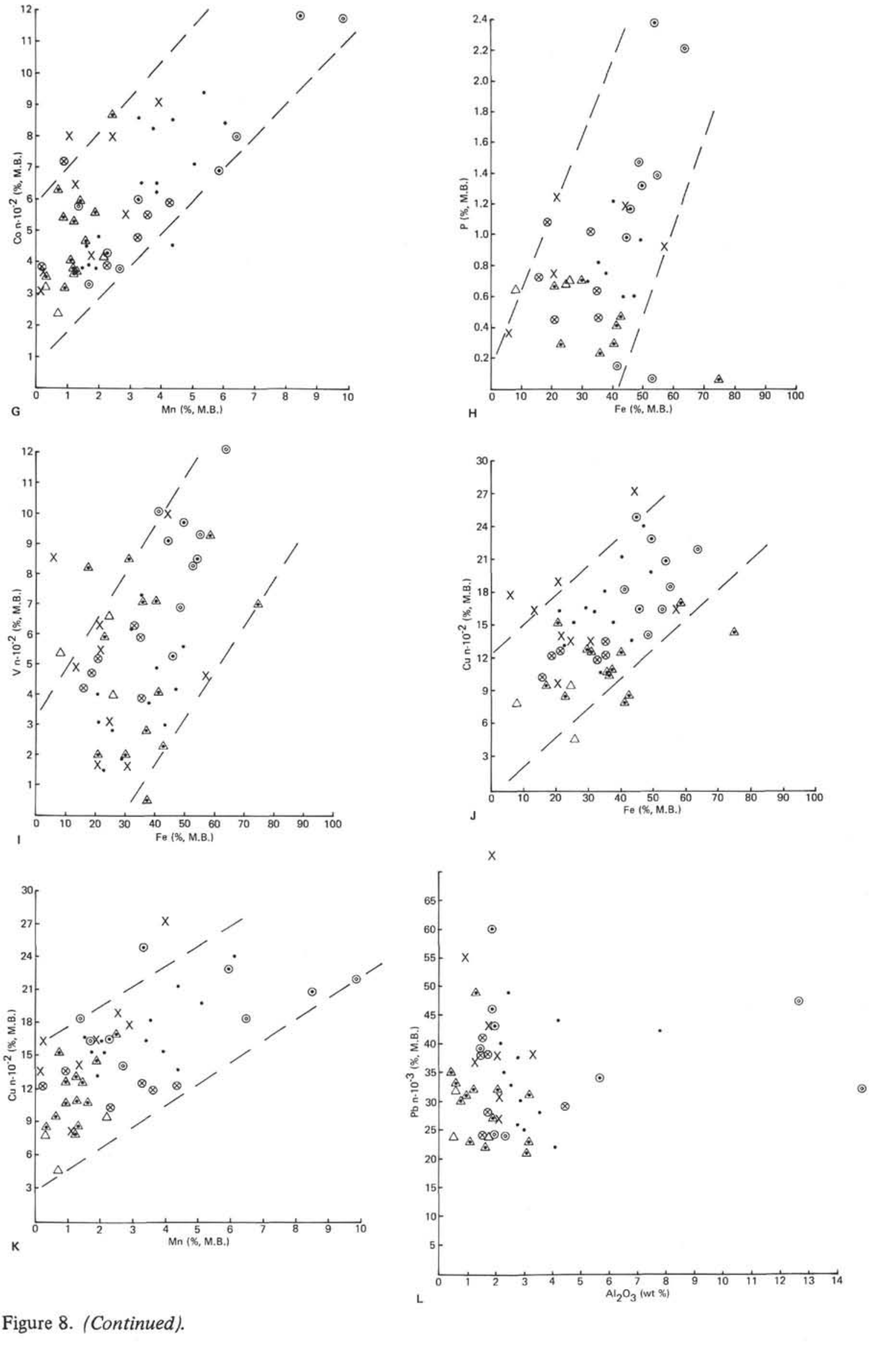

Figure 8. *(Continued).*

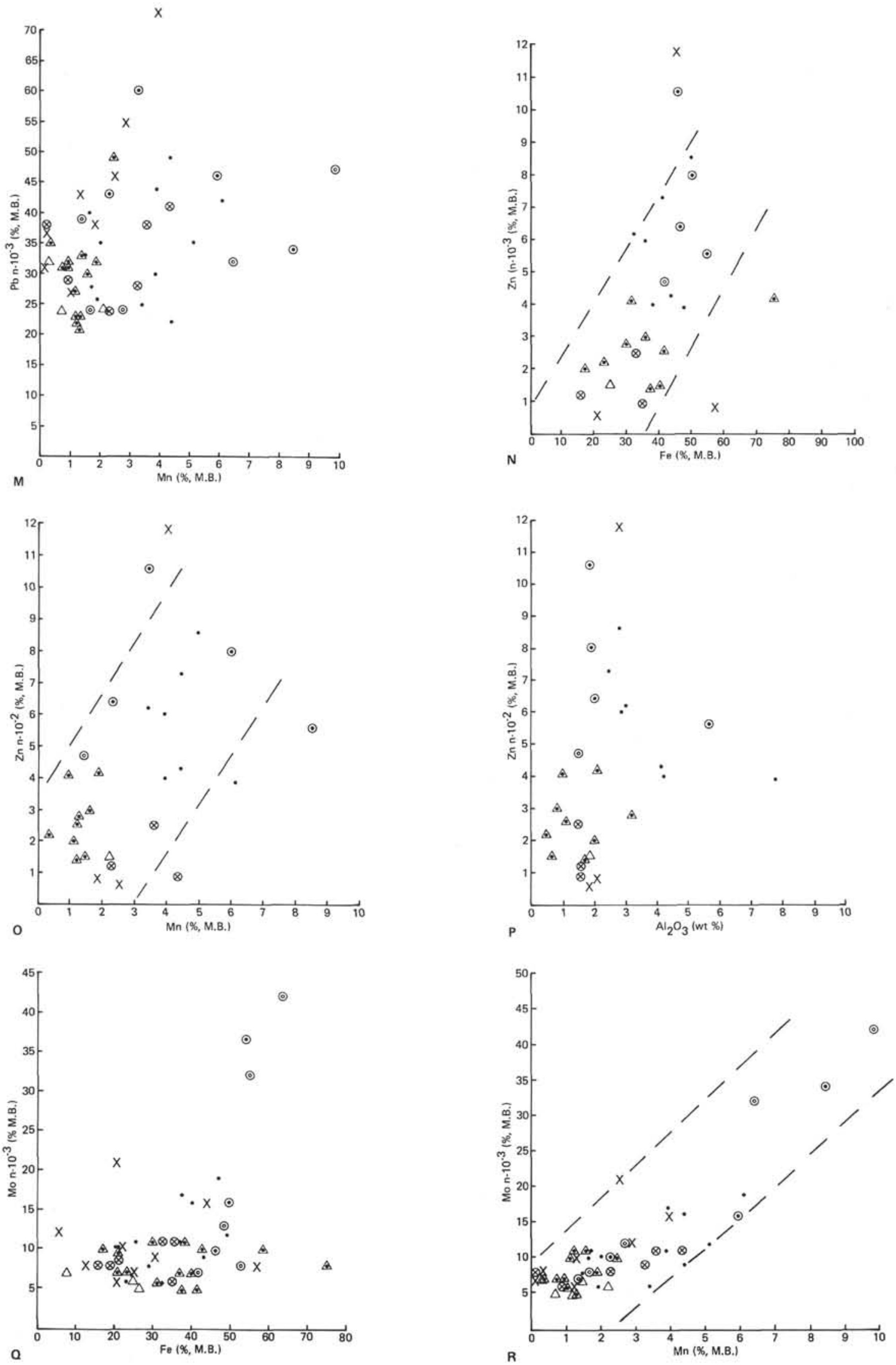

Figure 8. *(Continued).*

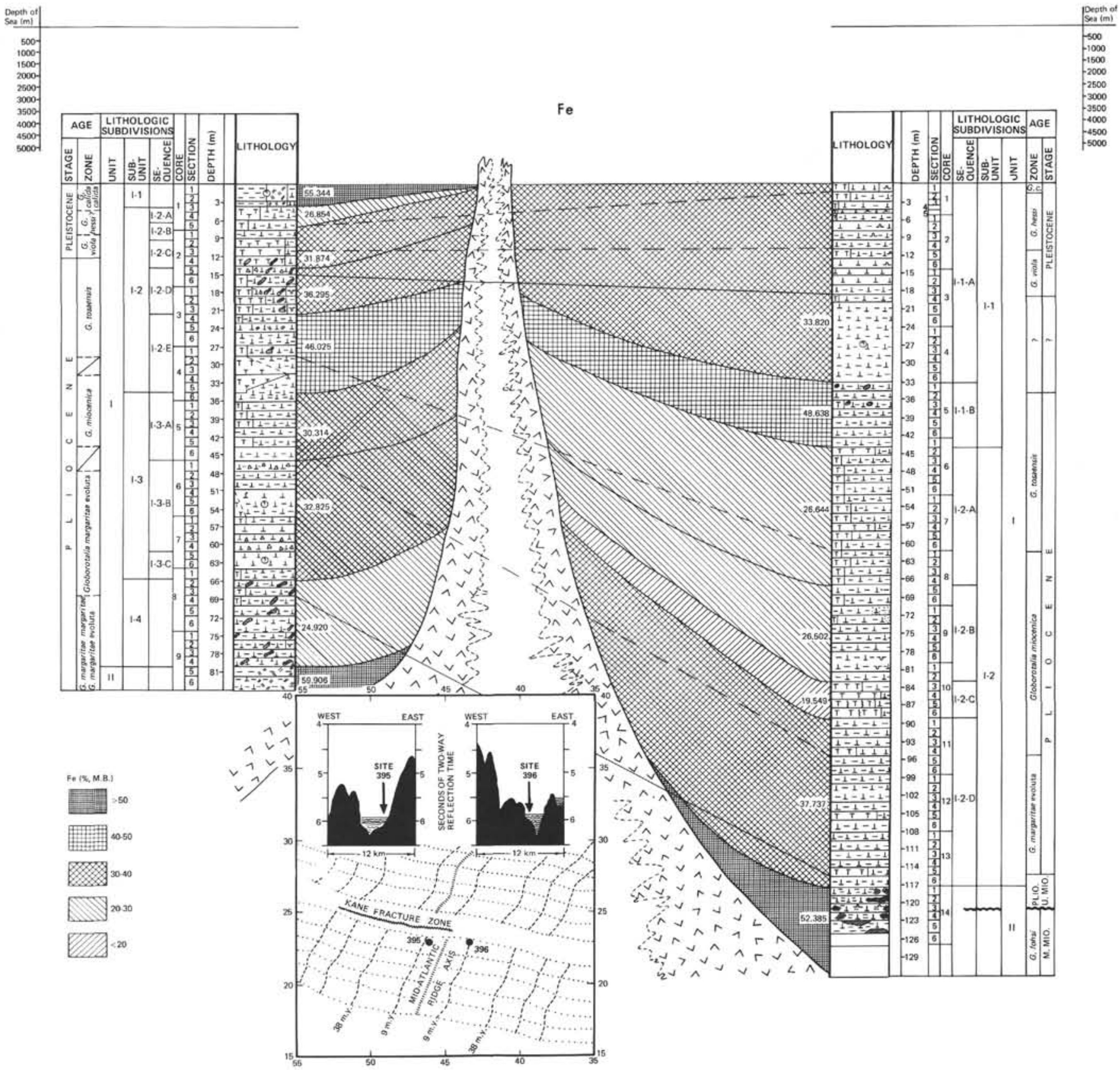

Figure 9. *Schematic profile of Fe distribution in upper Cenozoic sediments, region of the Mid-Atlantic Ridge, Leg 45 (wt. %, M.B.).*

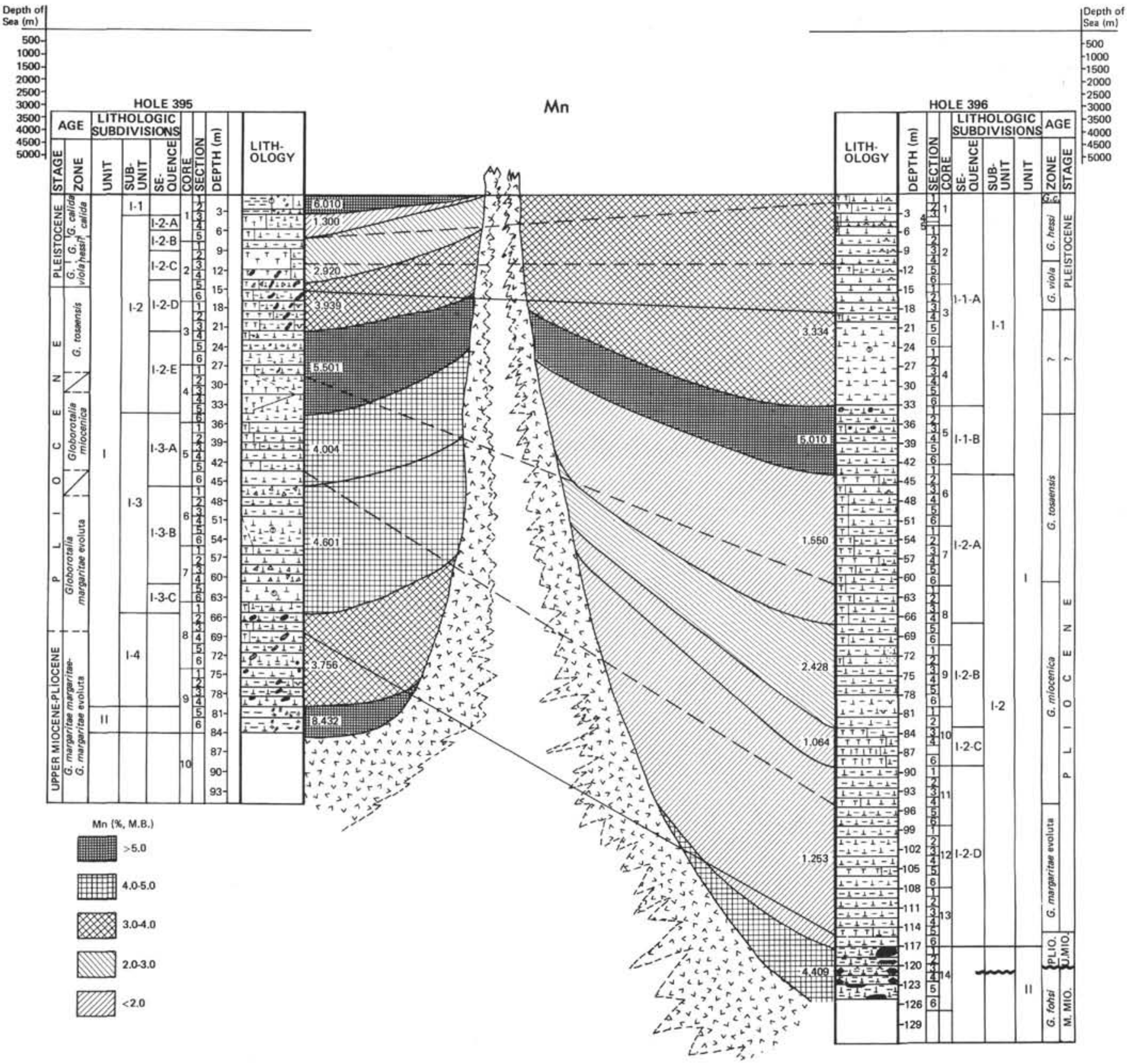

Figure 10. *Schematic profile of Mn distribution in upper Cenozoic sediments, region of the Mid-Atlantic Ridge, Leg 45 (wt. %, M.B.).*

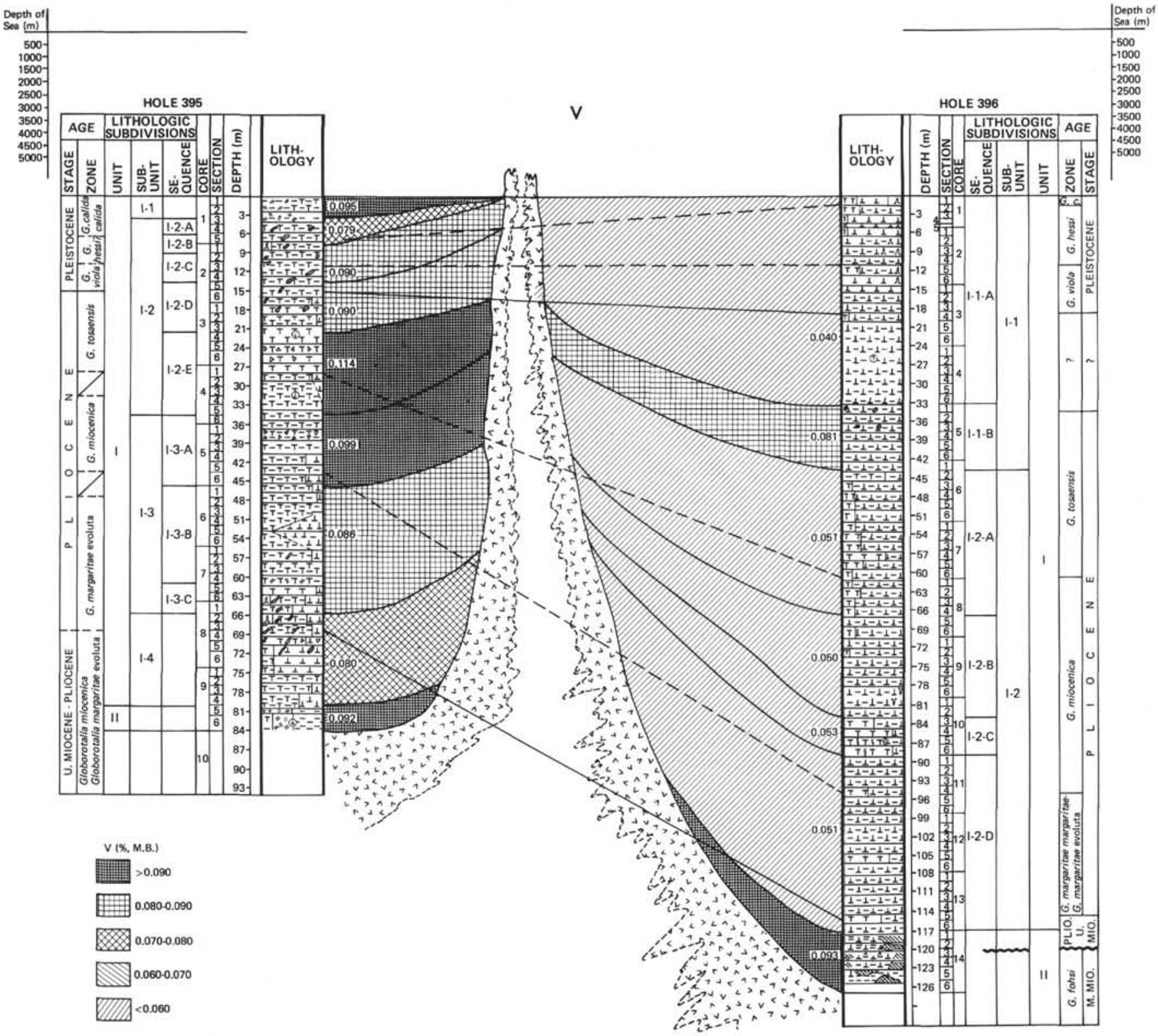

Figure 11. *Schematic profile of V distribution in upper Cenozoic sediments, region of the Mid-Atlantic Ridge, Leg 45 (wt. %, M.B.).*

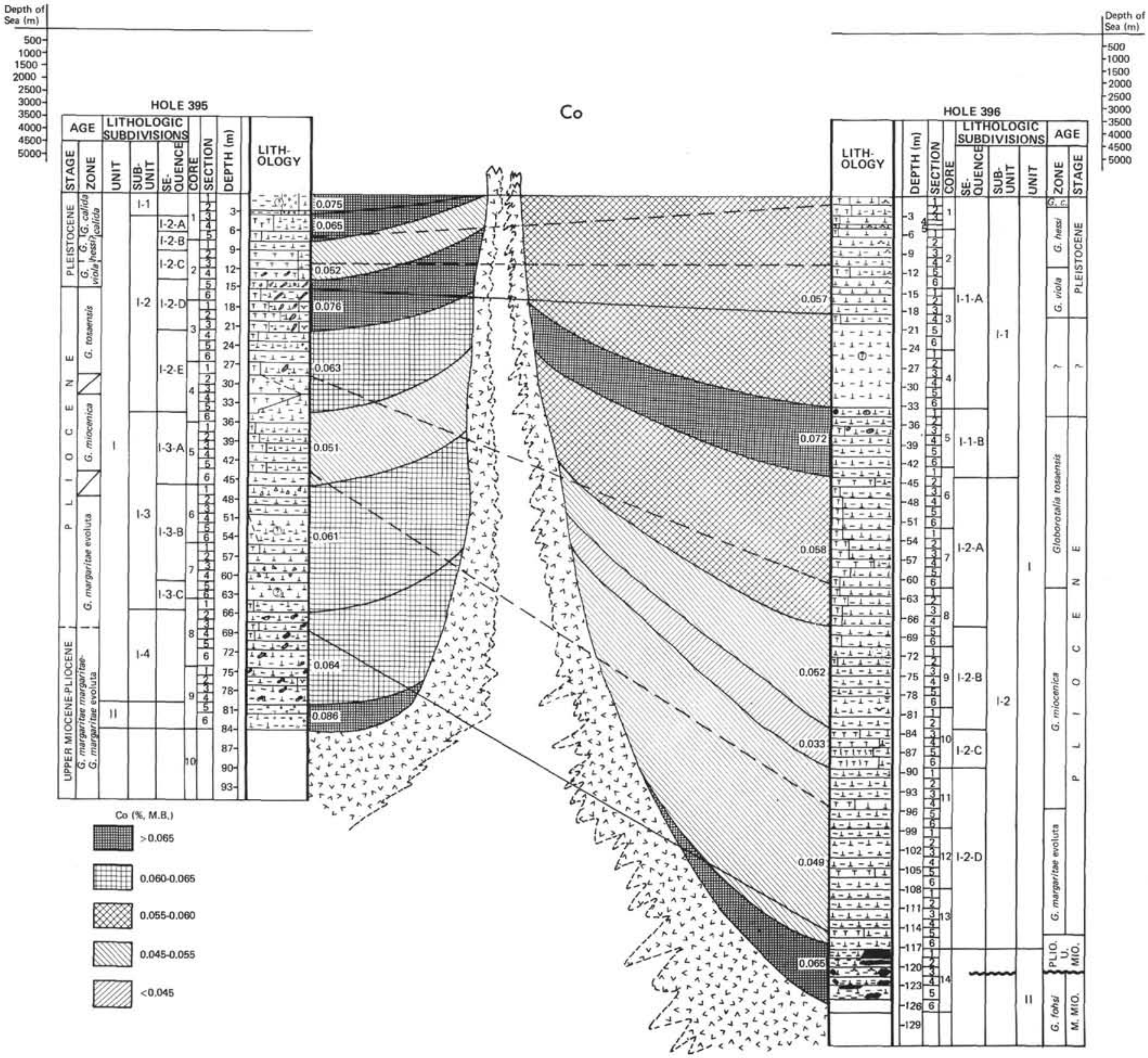

Figure 12. *Schematic profile of Co distribution in upper Cenozoic sediments, region of the Mid-Atlantic Ridge, Leg 45 (wt. %, M.B.).*

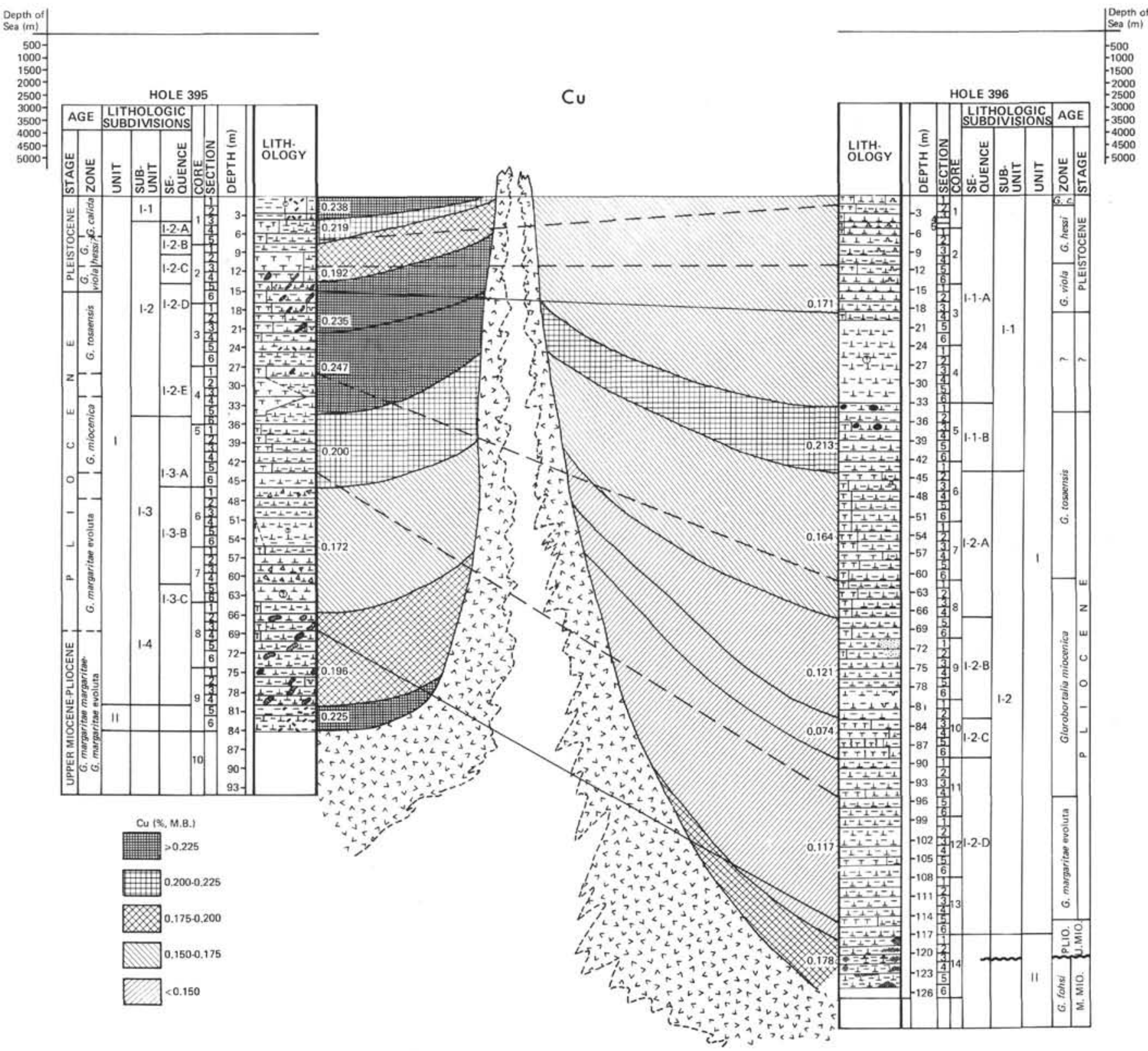

Figure 13. *Schematic profile of Cu distribution in upper Cenozoic deposits, region of the Mid-Atlantic Ridge, Leg 45 (wt. %, M.B.).*

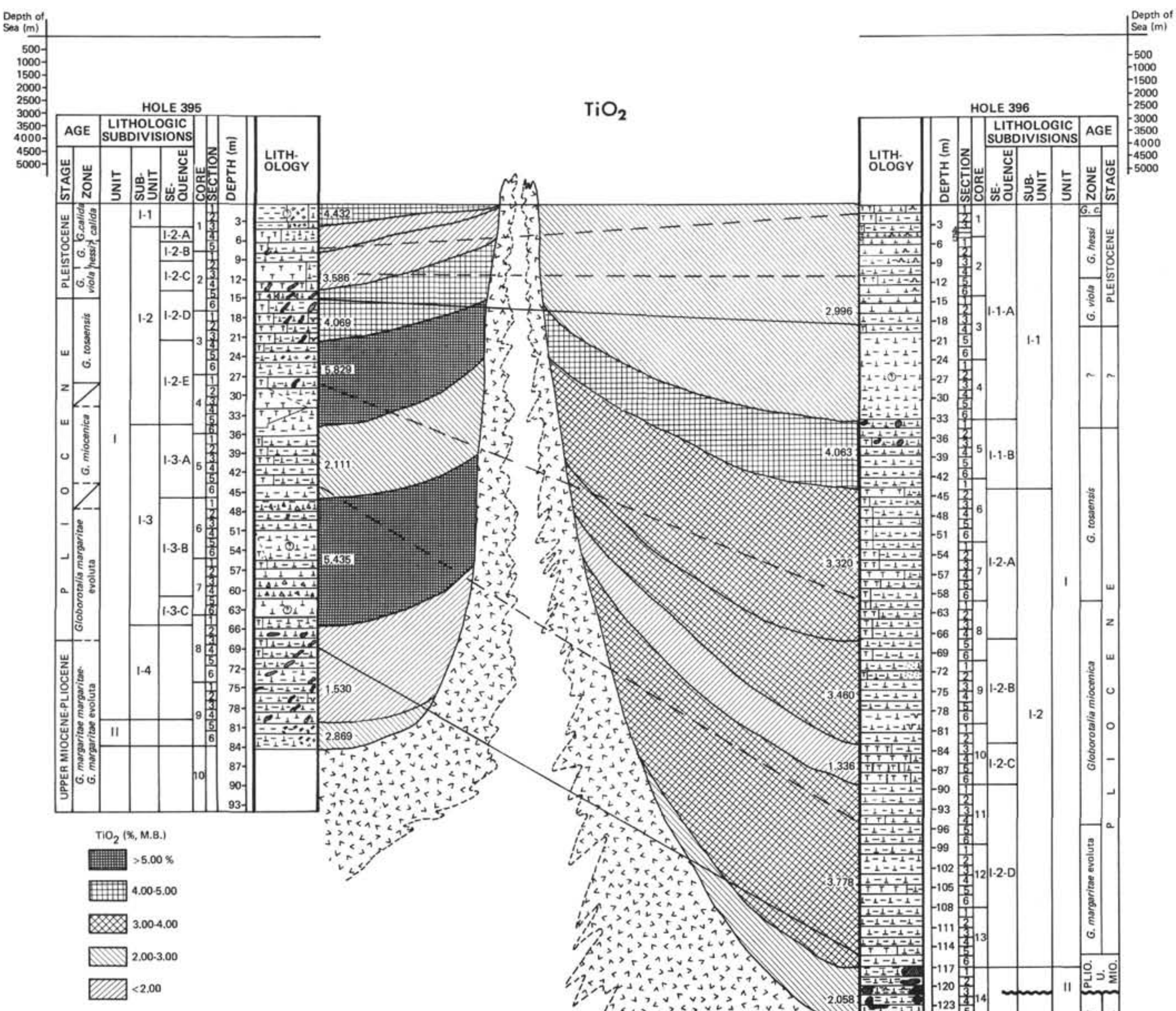

Figure 14. *Schematic profile of TiO_2 distribution in upper Cenozoic sediments, region of the Mid-Atlantic Ridge, Leg 45 (wt. %, M.B.).*