22. COARSE FRACTION OF PLIO–PLEISTOCENE SEDIMENTS FROM DEEP SEA DRILLING PROJECT HOLE 552A, NORTHEAST ATLANTIC[1]

Andrew C. Morton, British Geological Survey, Keyworth[2]

ABSTRACT

The acid insoluble coarse fractions of the glacial–interglacial sequence of Hole 552A in the NE Atlantic are made up of varying amounts of terrigenous detritus, biogenic silica, and pyroclastic material, principally volcanic glass. Volcanic ash content varies significantly over the entire interval, and the three North Atlantic ash horizons of Ruddiman and Glover (1972) can be recognized satisfactorily. The terrigenous detritus is of mixed metamorphic–basaltic type and probably originated on the Greenland landmass.

INTRODUCTION

The Plio–Pleistocene of Hole 552A is the most complete record to date of high latitude Northern Hemisphere glaciation. There were two principal objectives behind the undertaking of a coarse-fraction study on this material. The first was to establish the nature of the terrigenous fraction, with the intention of determining the possible sediment source. The second was to provide correlation points by means of volcanic ash abundance and, in particular, to locate the three ash levels noted by Ruddiman and Glover (1972) and Sigurdsson and Loebner (1981), which were dated, respectively, as 9,400 years ago, 64,700 years ago, and 340,000 years ago.

METHODS

Following carbonate determinations on whole-rock and coarse-fraction samples by 0.6 N acetic-acid treatment (Zimmerman et al., this volume) the remaining, acid-insoluble, 74 to 125 μm fractions of selected samples were examined petrographically. This took three forms. Relatively widely spaced samples from Cores 1 through 10 were examined in detail for major compositional variations. The volcanic glass abundances in Cores 1 and 2 were determined on a more closely spaced sample set. Finally, a small number of samples were analyzed for heavy mineral content, following separation from the light minerals by gravity-settling in bromoform of s.g. 2.80. The results of these analyses are shown in Tables 1 to 3. The chemistry of the volcanic glass was investigated by electron microprobe analysis, using an energy-dispersive X-ray analyzer. Results of this are shown in Table 4.

DISCUSSION

The individual constitutents of the samples group naturally into three—terrigenous, biogenic, and pyroclastic. The terrigenous component includes quartz, feldspar, mica, rock fragments, opaques (in part), and virtually all the heavy minerals; the biogenic group comprises spicules, diatoms, and radiolarians; and the pyroclastic component is largely made up of volcanic glass, with some opaques and very minor amounts of heavy minerals and plagioclase.

Detrital Components

The terrigenous fraction is of arkosic composition (quartz:feldspar:lithic grains average 62:32:6), the preponderance of polycrystalline and strained monocrystalline quartz suggesting a source largely of metamorphic basement. Rock fragments also indicate a metamorphic component, with phyllite and schist fragments common, but basalt and chert occur frequently, particularly the former, indicating some contribution from exposed lavas. Some radiating masses of quartz crystals, occurring as rounded grains, are possibly vesicle infills from the same source.

Heavy Minerals

Heavy mineral results also suggest a mixed metamorphic–basaltic terrain (Table 3). The major heavy minerals are augite, epidote, and hornblende, with garnet and hypersthene also significant. Both augite and hornblende and augite and epidote show strong negative correlations ($r = -0.90$ and -0.72, respectively), suggesting that the augite had a different provenance. On the other hand epidote and hornblende were probably derived from similar source rocks, since they show a moderate positive correlation ($r = +0.47$). The epidote–hornblende group indicates derivation from metamorphic basement: the augite indicates a basaltic terrain. Although some augite is undoubtedly of pyroclastic origin (Sample 552A-5-3, 135 cm), there is no correlation between the pyroclast content and the amount of augite in the whole-rock fraction (as determined by combining the data in Tables 1 and 3) ($r = 0.01$), indicating that by far the most important input of augite was by detrital means.

Both the whole-rock fraction and the heavy mineral fraction therefore indicate a mixed metamorphic–basaltic source, with their respective contributions varying through time, presumably dependent on the changing movement of land ice. Greenland satisfies these criteria, possessing both extensive tracts of metamorphic basement and large areas of exposed basalt (both in East and West Greenland). The presence of the rare heavy

[1] Roberts, D. G., Schnitker, D., et al., *Init. Repts. DSDP*, 81: Washington (U.S. Govt. Printing Office).

[2] Present address: British Geological Survey, Keyworth, Nottingham NG12 5GG, United Kingdom.

Table 1. Constitution of acid-insoluble 74 μm–125 μm fractions of selected samples from Hole 552A.

Sub-bottom depth (m)	Core-Section (level in cm)	Total carbonate[a]	Coarse fraction[a]	Carbonate in coarse fraction[a]	Quartz	Potash feldspar	Plagioclase feldspar	Mica	Rock fragments	Sponge spicules	Diatoms and radiolarians	Volcanic glass	Glauconite	Opaques	Heavy minerals	Heavy mineral analysis?
0.69	1-1, 68	20	16	62	39	15	3	1	5			20	2	12	3	–
1.90	1-2, 39	82	43	87	45	22	8	4	6	6		1		5	3	–
2.60	1-2, 109	42	18	91	54	23	4	1	4	tr		6	1	2	5	+
3.20	1-3, 19	50	41	77	45	20	6	5	3	2		13	1	1	4	+
6.32	2-2, 81	91	16	98	33	9	5	1	3	14	26	3		5	1	–
7.20	2-3, 19	12	12	29	33	23	3	5	3			26	1	2	4	+
10.88	3-2, 37	25	14	66	61	22	5	2	4			1	2	2	1	+
12.50	3-3, 49	83	54	96	59	28	4	1	1	1			tr	1	5	–
13.15	3-3, 119	4	6	17	68	23	2	tr	3				2	tr	2	+
14.52	4-1, 51	14	6	38	50	25	4	tr	12			1	1	2	5	+
15.12	4-1, 111	80	33	88	50	22	3	3	6	4		9	1	2	tr	–
16.01	4-2, 50	21	16	48	67	20	4	2	5				1	tr	1	+
17.71	4-3, 70	10	20	17	54	19	2	5	8			1	1	2	8	+
18.13	4-3, 112	18	10	45	58	26	2	2	6				tr	1	5	+
19.72	5-1, 71	33	25	77	56	25	3	3	8				tr	1	4	+
20.12	5-1, 111	83	44	91	63	26	2	tr	5	tr			1	2	1	+
20.92	5-2, 41	9	43	86	53	22	7	3	4	1		1	4	1	4	+
22.69	5-3, 68	16	10	37	47	24	5	2	11	1		tr	1	tr	9	+
23.36	5-3, 135		Not analyzed			3	1					86		9	1	+
23.71	5-4, 20	19	6	9	62	21	3	tr	5			5	3		1	+
30.61	7-2, 10	30	17	47	45	32	3	1	5			4	1	1	8	+
31.54	7-2, 103	33	21	74	61	26	1	1	6			2			3	–
31.82	7-2, 131	87	40	96	38	26	9	3	5	8		6	tr	1	4	–
32.38	7-3, 37	46	17	0	63	19	6	1	6			2	2	tr	1	+
34.09	8-1, 8	18	4	7	60	20	6	1	6	1		1	tr	1	4	+
35.92	8-2, 41	88	33	98	33	22	4	tr	4	25	2	3	3	1	3	–
37.09	8-3, 8	53	14	67	48	23	4	1	6	1		8		4	5	+
40.90	9-2, 39	35	20	46	52	28	1	1	8			7		1	2	+
41.35	9-2, 84	24	14	40	49	17	4	2	5	1	tr	13		3	6	+
42.14	9-3, 13	44	26	73	57	28	3	tr	3	1		4	1	tr	3	+
43.07	9-3, 106	96	26	100	29	11	1		5	12	37	1		2	2	–

[a] Data from Zimmerman et al., this volume.

Table 2. Variation in volcanic glass abundance in Cores 1 and 2, Hole 552A.

Core-Section (level in cm)	Sub-bottom depth (m)	Volcanic glass in insoluble residue (%)	Insoluble residue in coarse fraction[a] (%)	Coarse fraction of whole rock[a] (%)	Volcanic glass in whole rock (%)
1-1, 20	0.21	3.5	16	51	0.29
1-1, 38	0.39	12.5	31	23	0.89
1-1, 68	0.69	20.0	38	16	1.02
1-1, 109	1.10	4.0	26	34	0.35
1-2, 10	1.62	2.5	18	35	0.16
1-2, 39	1.90	1.0	13	43	0.06
1-2, 79	2.30	1.0	21	25	0.05
1-2, 109	2.60	6.0	9	18	0.10
1-3, 19	3.20	13.0	23	41	1.23
1-3, 49	3.50	2.0	16	34	0.11
1-3, 69	3.70	7.0	20	25	0.35
1,CC (10)	4.05	4.5	35	21	0.33
2-1, 40	4.41	3.0	24	25	0.18
2-1, 81	4.81	4.0	14	32	0.18
2-1, 110	5.11	3.0	12	31	0.13
2-2, 1	5.52	2.5	7	44	0.08
2-2, 49	6.00	7.5	14	26	0.27
2-2, 81	6.32	3.0	2	16	0.01
2-2, 110	6.61	4.5	10	15	0.07
2-2, 130	6.81	1.0	20	15	0.03
2-3, 19	7.20	26.0	71	12	2.22
2-3, 50	7.51	0.0	40	15	0.00
2-3, 100	8.01	1.0	31	20	0.06
2-3, 139	8.40	0.0	36	10	0.00

[a] Data from Zimmerman et al., this volume.

mineral species piedmontite is a further indication of a Greenland source (Morton, this volume).

Biogenic Silica

There is a reasonably good positive correlation between biogenic silica and total carbonate ($r = +0.63$), indicating that its productivity matches that of the calcareous microfossils. Biogenic silica only becomes abundant where carbonate exceeds 90%. This is close to the threshold value for appearance of the more delicate biosiliceous organisms such as the diatoms and radiolarians, whereas spicules occur commonly in sediments with carbonate content down to 80%. This suggests that the sponges may be more tolerant of climatic conditions.

Pyroclastic Input

The pyroclastic input to the sediment is fairly sporadic with no apparent pattern to its distribution, although there appears to have been a relative lull in volcanic activity in the middle of the early Pleistocene (Core 3 to Core 5, Section 2). There is a suspicion of higher pyroclastic content in the glacial periods than in the interglacials, since samples with particularly high pyroclast content (>15%) never contain more than 50% carbonate, but in general there is a poor correlation between pyroclast and carbonate content ($r = -0.11$). Most of the pyroclastic material is glassy; both clear and brown types occur in variable proportions, varying between slightly and highly vesiculated. Some opaque grains are clearly of pyroclastic origin (Sample 552A-5-3, 135 cm), and are probably tachylyte. Minor components include augite and plagioclase.

The constituents of the volcanic ash are virtually identical to those of Site 404 (Harrison et al., 1979) and also

Table 3. Heavy mineral content of selected samples from Hole 552A (74–125μm fraction).

Sub-bottom depth (m)	Core-Section (level in cm)	Aegirine-augite	Anda-lusite	Apatite	Augite	Chlor-itoid	Clino-zoisite	Epidote	Garnet	Horn-blende	Hyper-sthene	Kyanite	Pied-montite	Rutile	Silli-manite	Sphene	Stau-rolite	Topaz	Tour-maline	Tre-molite	Zircon	Total grains counted
1.90	1-2, 109	0.5			67.0			6.5	2.5	18.0	2.0			0.5	0.5	1.0					1.5	200
3.20	1-3, 19				56.0			8.0	2.0	23.5	2.0	2.0		4.5		1.0					1.0	90
7.20	2-3, 19	1.0			68.0			7.0	4.0	17.0	0.5	0.5			0.5	1.0					0.5	200
10.88	3-2, 37		0.5	0.5	40.0			15.0	8.0	26.0	1.0	0.5		1.0	0.5	3.0	0.5		1.5		2.0	200
13.15	3-3, 119			1.0	21.5			21.5	14.0	35.0		1.0		3.0	1.0	1.0	1.0					80
14.52	4-1, 51				77.0			8.5	2.0	8.5	0.5	0.5				1.5					1.5	151
16.01	4-2, 50		R		28.5		0.5	19.5	5.0	38.0	2.0	1.0	R	0.5	0.5	2.5	1.0		0.5	0.5	R	200
17.71	4-3, 70		0.5		36.0		0.5	6.5	11.5	32.5	6.0	1.0	R	1.0	1.0	2.0	1.0		0.5		R	200
18.13	4-3, 112		0.5		35.0	R		13.5	9.0	34.0	2.5	0.5			1.0	2.5			0.5	0.5	0.5	200
19.72	5-1, 71		0.5		40.5			10.5	12.0	26.5	5.0	0.5				2.0	1.5			R	1.0	200
20.92	5-2, 41				42.0			13.5	6.0	31.5	3.5	0.5			0.5	2.0					0.5	141
22.69	5-3, 68			0.5	61.5		0.5	8.5	6.0	16.5	2.5	0.5		1.5		1.5					0.5	200
23.36	5-3, 135			2.0	98.0					R												200
23.71	5-4, 20	1.0		3.0	41.5			6.5	4.0	36.5	4.5								2.0		1.0	106
30.61	7-2, 10				56.5		0.5	5.0	4.5	28.0	2.5	1.0	R			1.0	0.5		0.5			200
32.38	7-3, 37			0.5	48.0			9.0	5.5	28.5	1.5	0.5			0.5	2.5		0.5	2.0		1.0	200
34.09	8-1, 8				17.5			14.5	11.5	41.5	8.0					2.0			1.0	1.0	3.0	103
37.09	8-3, 8			0.5	42.0			10.5	5.0	31.0	9.0			R		1.0			R		1.0	200
40.90	9-2, 39				38.5			16.5	9.0	23.5	4.0			0.5		2.0	3.0		1.0		2.0	200
41.35	9-2, 84				51.5		0.5	8.0	7.0	23.0	3.5	0.5		0.5		3.0	1.0		1.0		0.5	200
42.14	9-3, 13				35.0	R	1.0	13.5	9.0	30.0	7.0	1.0				1.0				0.5	1.0	200

Note: R denotes presence in abundances less than 0.5%.

Table 4. Volcanic glass compositions from Sample 552A-5-3, 135 cm as determined by electron microprobe.

Oxide (%)	Pale brown glass	Colorless glass
Si	53.6	69.1
Al	13.1	12.3
Ti	1.6	0.4
Cr	0.1	0.0
Fe[a]	11.7	2.7
Mg	1.9	0.0
Mn	0.4	0.0
Ca	4.8	0.7
Na	1.4	1.6
K	2.4	4.7
P	0.5	0.0
S	0.2	0.1
Total	91.7	91.6

[a] All Fe calculated as FeO.

to ashes of Plio–Pleistocene age of Site 346 on the Icelandic Plateau (Sylvester, 1976). The glass is distinctly bimodal in composition (Table 2), with the SiO_2 content of the brown glass between 50 and 55% and that of the colorless glass between 65 and 70%. These values closely accord with those determined by Harrison et al. (1979) by refractive index methods for the Site 404 ash. Electron microprobe analysis indicates that the glass has been extensively hydrated, as shown by the low total of the analysis (Table 2).

It is generally accepted that the volcanic ash of Plio–Pleistocene age in the North Atlantic and Norwegian–Greenland Sea originated from eruptions on Iceland (Ruddiman and Glover, 1972; Sylvester, 1976; Harrison et al., 1979; Donn and Ninkovich, 1980; Sigurdsson and Loebner, 1981). The explosive nature of the volcanism is ascribed to the interaction of the magma with water, particularly, in this case, with glacial meltwater, in the manner described by Heiken (1975).

The more detailed investigation of the volcanic ash abundance of Cores 1 and 2 has revealed three levels at which volcanic glass is particularly abundant (Table 2, Fig. 1). These are of particular importance in that they equate with the three levels reported by Ruddiman and Glover (1972). The first maximum lies between Samples 552A-1-1, 38 cm and 1-1, 68 cm, with an extrapolated peak at Sample 552A-1-1, 50 cm. This level was therefore deposited some 9,400 years ago. The second occurs at Sample 552A-1-3, 19 cm, equivalent to the 64,700 year-ago level, and the third is at Sample 552A-2-3, 19 cm, deposited some 340,000 years ago.

CONCLUSIONS

The bulk of the terrigenous, ice-rafted material in the Plio–Pleistocene of Hole 552A was transported south or southeast from Greenland. Two distinct source areas contributed in varying proportions, one contributing metamorphic basement material, the other basaltic detritus. Biogenic silica plays a relatively unimportant role except in the most calcareous levels, where radiolarians and

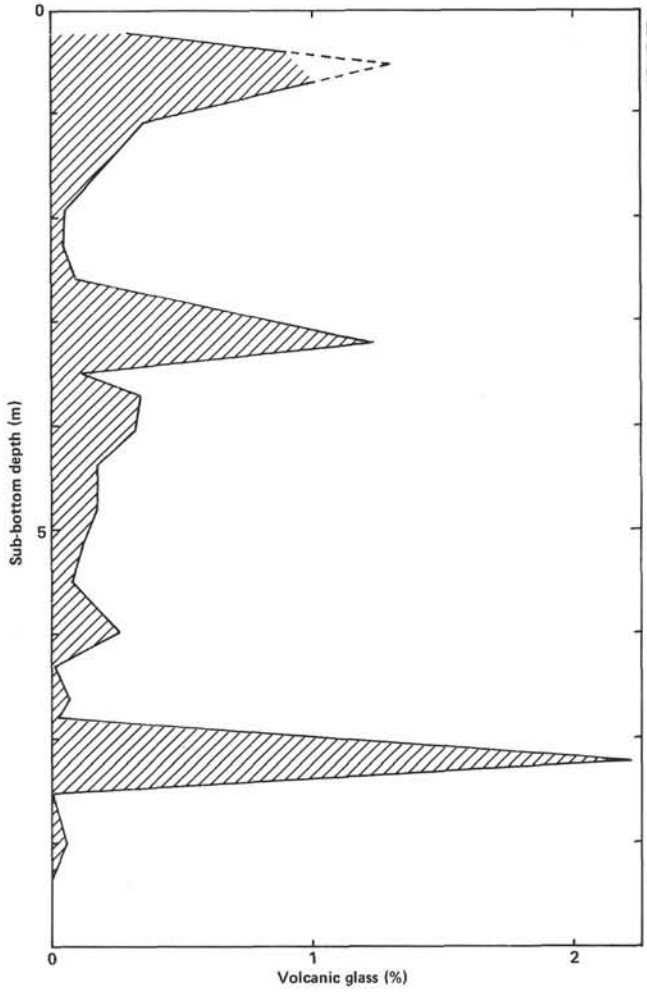

Figure 1. Variation in abundance of volcanic glass in Cores 1 and 2 of Hole 552A, showing the presence of three levels of high ash abundance.

diatoms also flourish. Pyroclastic input is variable, being a consistent but relatively low-key influence in the lower part of the sequence (Cores 5 to 9), virtually disappearing in Cores 3 and 4, and consistently present in Cores 1 and 2. Only one undisturbed ash layer is present (5-3, 86 cm) and correlates with the one found at Hole 404 (2-6, 80 cm). The three levels of high ash abundance in Cores 1 and 2 correspond to the ash levels of Ruddiman and Glover (1972) and are therefore dated as 9,400 years ago, 64,700 years ago, and 340,000 years ago.

ACKNOWLEDGMENTS

The author is grateful to the U.K. Department of Energy for funding shipboard and shore-based research. This paper is published with the approval of the Director of the British Geological Survey (N.E.R.C.).

REFERENCES

Donn, W. L., and Ninkovich, D., 1980. Rate of Cenozoic explosive volcanism in the North Atlantic Ocean inferred from deep sea cores. *J. Geophys. Res.*, 85:5455–5460.

Harrison, R. K., Knox, R. W. O'B., and Morton, A. C., 1979. Petrography and mineralogy of volcanogenic sediments from DSDP Leg 48, southwest Rockall Plateau, Sites 403 and 404. *In* Montadert,

L., Roberts, D. G., et al., *Init. Repts. DSDP,* 48: Washington (U.S. Govt. Printing Office), 771–785.

Heiken, G., 1975. An atlas of volcanic ash. *Smithsonian Contrib. Earth Sci.,* 12:1–101.

Ruddiman, W. F., and Glover, L. K., 1972. Vertical mixing of ice-rafted volcanic ash in North Atlantic sediments. *Geol. Soc. Am. Bull.,* 83:2817–2836.

Sigurdsson, H., and Loebner, B., 1981. Deep-sea record of Cenozoic explosive volcanism in the North Atlantic. *In* Self, S., and Sparks, R. S. J. (Eds.), *Tephra Studies:* London (D. Riedel Publishing Co.), pp. 289–316.

Sylvester, A. G., 1976. Petrography of volcanic ashes in deep-sea cores near Jan-Mayen Island: Sites 338, 345–350 DSDP Leg 38. *Init. Repts. DSDP,* Suppl. to Vols. 38, 39, 40, and 41: Washington (U.S. Govt. Printing Office), 101–106.

Date of Acceptance: August 29, 1983