ELSEVIER

Marine Geology 121 (1994) 105–119

MARINE GEOLOGY
INTERNATIONAL JOURNAL OF MARINE GEOLOGY, GEOCHEMISTRY AND GEOPHYSICS

Geochemistry of surface sediments from the mid-oceanic Kolbeinsey Ridge, north of Iceland

K.S. Lackschewitz [a], H.-J. Wallrabe-Adams [a], D. Garbe-Schönberg [b]

[a] *GEOMAR, Research Center for Marine Geosciences, Wischhofstraße 1-3, 24148 Kiel, Germany*
[b] *Geologisch–Paläontologisches Institut und Museum der Universität Kiel, Olshausenstraße 40, 24098 Kiel, Germany*

Received 30 January 1993; revision accepted 14 December 1993

Abstract

In order to assess recent submarine volcanic contributions to the sediments from the active Kolbeinsey Ridge, surface samples were analyzed chemically. The contribution of major and trace elements studied differ within the study area.

A statistical analysis of the geochemical variables using factor analysis and cluster method allows to distinguish possible sample groups. Cluster method identifies three distinct sediment groups located in different areas of sedimentation.

Group 1 is characterized by highest contents of Fe_2O_3, V, Co, Ni, Cu and Zn demonstrating the input of volcaniclastic material. Group 2 comprises high values of $CaCO_3$, CaO and Sr representing biogenic carbonate. Group 3 is characterized by the elements K, Rb, Cs, La and Pb indicating the terrigenous component.

The absolute percentage of the volcanic, biogenic and terrigenous components in the bulk sediments was calculated by using a normative sediment method. The highest volcanic component (>60% on a carbonate free basis) is found on the ridge crest. The biogenic component is highest (10–30%) in the eastern part of the Spar Fracture Zone influenced by the East Iceland Current. Samples from the western and southeastern region of the study area contain more than 90% of terrigenous component which appears to be mainly controlled by input of ice-rafted debris.

1. Introduction

In the North Atlantic Ocean, the non-carbonate fraction of the sediments generally consists of detrital, contintental derived material. The contribution of the processes related to the volcanically active ridge on the surrounding pelagic sediments is not well known.

Data on geochemistry of the sediments from the Mid-Atlantic Ridge of the North Atlantic are well known from the TAG area at 26°N (Cronan, 1972; Rona, 1976; Cronan et al., 1979; Shearme et al., 1983).

For the Reykjanes Ridge in particular, the first geochemical data were published by Horowitz (1974). Grousset et al. (1982) and Grousset and Chesselet (1986) gave information on geochemical characteristics of Late Quaternary marine sediments taken between the Azores and the Icelandic basin.

More recently, cores from the Greenland Sea including the Mohns Ridge were studied by Paetsch (1991), who showed the concentration variations of some elements with depth.

We have recently published preliminary results on the major and trace elements contents of the southern Kolbeinsey Ridge sediments (Lackschewitz and Wallrabe-Adams, 1991). The sedimentology of the surface samples from the Kolbeinsey Ridge were described in detail by

SSDI 0025-3227(94)00084-0

Lackschewitz et al. (1991) and Lackschewitz (1991). Oehmig and Wallrabe-Adams (1993) have given data on the depositional environment using settling velocity experiments of volcaniclastic deposits from the southern Kolbeinsey Ridge.

The focus of this study is to identify and evaluate the portion of different sedimentary processes within the deposits from the Kolbeinsey Ridge to provide information about the recent sedimentary environment in the ridge area. Our study is placed on determining the geochemical variability of surface sediments from the vicinity of the active spreading ridge. Thus, we will attempt to identify geochemical parameters which function as indicators of characteristic sediment facies types using a "geochemical facial analysis". This allows to quantify the composition and spatial distribution of local enrichment and impoverishment of metals and to characterize the geochemical and facial conditions of sedimentation.

2. Study area

The Kolbeinsey Ridge is the section of the Mid-Atlantic Ridge north of Iceland beginning at about 66°N and extending northward to the Jan Mayen Fracture Zone near 71°N. The southern Kolbeinsey Ridge is a recently active ridge segment (e.g. Spindler, 1989; Fricke et al., 1989).

The spreading velocity approximates 2 cm/yr (Vogt, 1983).

The study area includes the southern part of the active spreading ridge between Iceland (66°30′N) and the area of the Spar Fracture Zone (69°30′N) (Fig. 1).

The main surface current system in the western Iceland Sea is characterized by the East Greenland Current which carries cold (<0°C) polar water southward along the East Greenland shelf (Fig. 1). The East Iceland Current in the central Iceland Sea (0°–4°C) forms a mixture of the polar and the warm Atlantic waters.

3. Material and methods

Sediment was collected by box coring during R.V. *Poseidon* cruise 158 and R.V. *Polarstern* cruise ARK V/1b. Sampling and visual description of the surface sediments were carried out on board (Puteanus and Werner, 1989; Spindler, 1989). For the present study 25 surface samples recovered by box cores were selected.

A sample split was analyzed for the composition of its coarse fraction. The sediment samples were dried, weighed and washed on 63 μm sieve. The particle association of the 125–500 μm fraction seems to be most representative of coarse fraction composition. Thus, a split (>500 grains) of this size fraction was studied and counted for biogenic, terrigenous and volcanic components.

For major and trace element analysis, bulk sediment samples were oven-dried at 40°C and then pulverized. The major element composition was determined using a Philips (PW 1400) X-ray fluorescence spectrometer. For XRF analysis, the sediments were dried at 900°C and melted using lithiumtetraborate ($Li_2B_4O_7$) in a mixture consisting of 1 g sediment and 4 g lithiumtetraborate. For calibration of the XRF determinations, 12 international rock standards were used. The trace elements were analyzed by ICP/MS using a VG Plasma-Quad PQ 1. Total dissolution of bulk sediment was performed by pressurized HF–$HClO_4$–aqua regia attack (Garbe-Schönberg, 1993). The accuracy of the analytical results was controlled by measuring the international standard reference material "MESS 1" (see Table 3).

Calcium carbonate contents were measured using a LECO CS-125 infrared analyzer. Both, total carbon (TC) and total organic carbon (TOC) contents were determined by infrared measurements of CO_2 absorption. Organic carbon was calculated from CO_2 that was released by treatment with hydrochloric acid. The calcium carbonate content was calculated in weight percentages of sediment sample as:

$$CaCO_3\% = (TC\% - TOC\%) \times 8.33$$

The percentage of Ca on a carbonate-free basis is also given in Table 1 as $CaO_{silicate}$. The content of $CaO_{silicate}$ in the sediment was calculated by subtracting $CaO_{carbonate}$ (0.5604 $CaCO_3$) from CaO_{bulk} and assuming that the difference comprised only $Ca_{silicate}$.

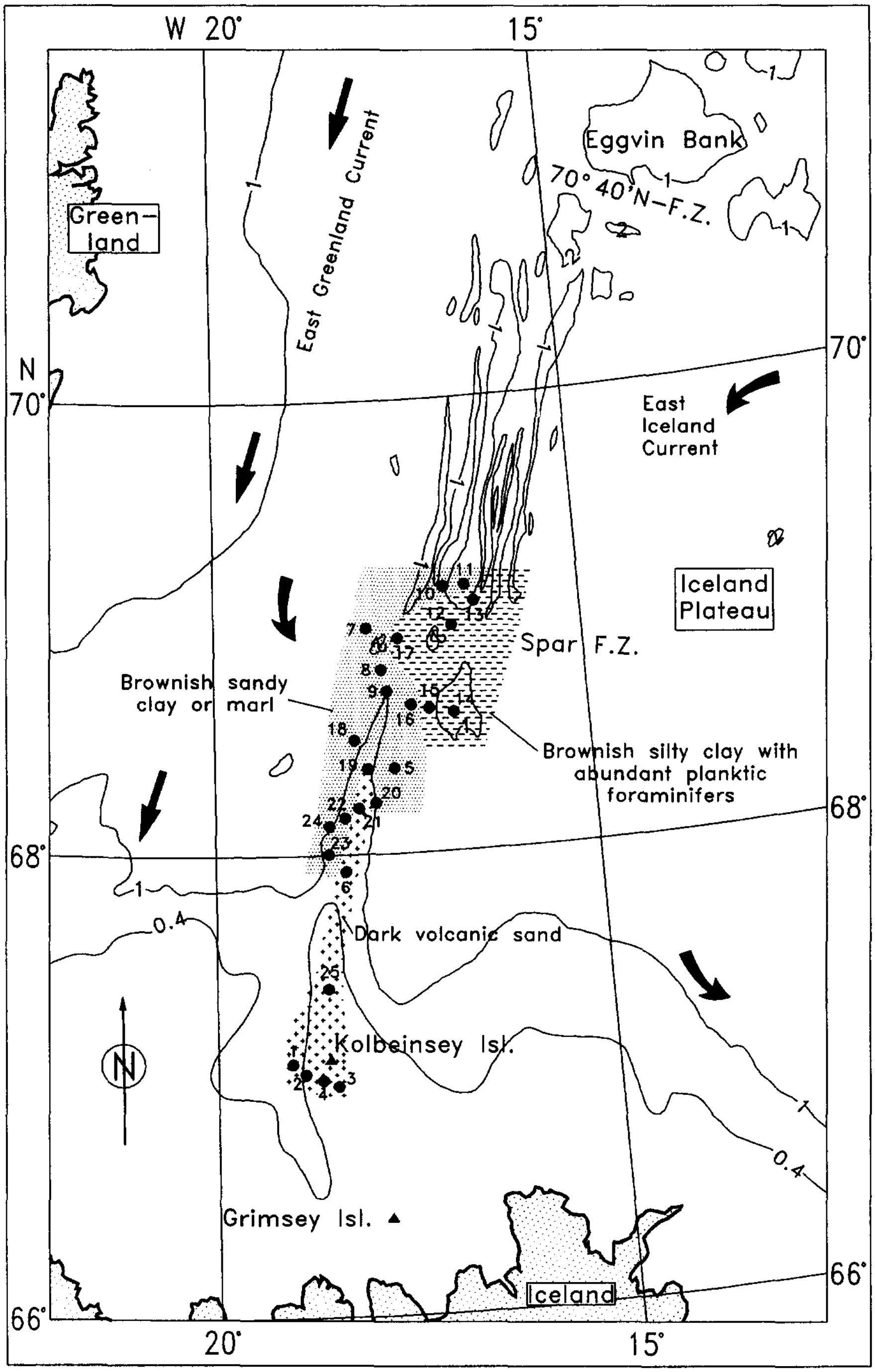

Fig. 1. Study area, lithology and location of surface samples in the Iceland Sea.

Table 1
Geochemical composition of basaltic glass from volcaniclastic sediments and from "zero age" basalts from Kolbeinsey Ridge

	Basaltic glass Kolbeinsey Ridge (Lackschewitz and Wallrabe-Adams, 1991)	Average basaltic rocks Kolbeinsey Ridge (Devey et al., 1994)
SiO_2	50.6	50.2
TiO_2	1.19	0.98
Al_2O_3	13.3	14.5
Fe_2O_3	13.0	12.9
MnO	0.20	0.21
MgO	7.60	7.76
CaO	11.7	11.9
Na_2O	1.72	1.83
K_2O	0.07	0.07
Cr		225
Co		59
Ni		105
Cu		124
Zn		95
Rb		1.4

4. Results and discussion

4.1. Surface sediment description and composition

Surface sediments from the basin west and east of the Kolbeinsey Ridge generally consist of brownish sandy silty clay (Fig. 1). The sand fraction of these sediments is mainly composed of terrigenous particles and small amounts of biogenic material. The terrigenous particle assemblages consist mainly of quartz and sedimentary and crystalline rock fragments.

East and northeast of the Spar Fracture Zone sediments are characterized by sandy silty clay with relatively high concentrations of planktic foraminifers. Generally, in all surface samples the fauna is made up of the subpolar species *Neogloboquadrina pachyderma* (sinistral). The temperate species *N. pachyderma* (dextral), which indicates warmer water masses were only observed in the samples east and northeast of the Spar Fracture Zone. The foraminifers are normally well preserved. Siliceous biogenic particles (mostly sponge spicules) are usually less than 2 weight-% (wt.-%). A higher content in siliceous particles (4.3–10.7 wt.-%) was observed in the surface sediments 10/2, 19/1, 20/1 and 21/1.

The most drastic changes in lithology occur on the southern Kolbeinsey Ridge. Here, sediments show an increase in the amount and size of dark volcanic sand (Fig. 1). These sediments consist of dark brown volcanic glass and dark volcanic rock fragments. The volcanic material is mostly fresh. The average major and trace element composition of the basaltic glass is given in Table 1. For comparison, the composition of basaltic rocks from Kolbeinsey Ridge are also shown (Devey et al., 1994). Some palagonitized glasses, fragments of volcanic rocks weathered in various degrees are only found in the southernmost samples near the Kolbeinsey Island.

4.2. Distribution of major and trace element concentration in the surface sediments

The percentages of major and trace elements are given in Tables 2 and 3. The statistical parameters are reported in Table 4.

Silicon (Si) is the dominant major element found in the sediments studied. For the western and northern portions of the study area mean SiO_2 values were approximately 60%. Highest SiO_2 values (70.5–72.7%) were observed in surface sediments taken in the vicinity of the Spar Fracture Zone. By contrast, sediments from the southern section of the study area have an average concentration of only 57%. Lowest SiO_2 values of 51–53% were determined in surface sediments from the ridge crest area. These sediments are also characterized by extremely low values of K_2O (<0.8%). Sediments from the central Kolbeinsey Ridge have the highest concentrations of Fe_2O_3 (11.4–14.6%), Co (43–52 ppm), V (223–384 ppm) and Cu (71–107 ppm). Increased concentrations of $CaO_{silicate}$ of 9–11.6% were also observed here. The content of $CaCO_3$ is generally very low (<2%) in the ridge crest sediments.

The highest $CaCO_3$ concentrations (10–28.5%) are found in surface sediments from the eastern part of the Spar Fracture Zone area and further north. Also, the highest concentrations of Sr with up to 680 ppm were found in these sediments.

The carbonate in the sediments is tied to tests

Table 2
Major element oxide concentrations in surface sediments in %

Sample	Core	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	Sum	$CaCO_3$	*$CaO_{silicate}$
1	13/015	52.0	0.36	12.4	12.8	0.19	9.76	10.9	1.29	0.30	100.0	0.18	10.8
2	13/016	53.1	0.53	12.4	12.8	0.16	8.80	9.46	1.43	0.74	99.4	0.78	9.02
3	13/018	52.6	0.31	12.1	12.7	0.17	9.40	10.1	1.38	0.57	99.3	0.25	9.96
4	13/019	50.8	0.41	13.0	11.4	0.14	10.6	12.3	1.07	0.19	99.9	1.17	11.6
5	0001/1	62.2	1.20	15.2	8.53	0.25	2.93	4.99	2.22	2.36	100.3	3.63	2.96
6	0002/2	52.7	1.26	13.6	13.5	0.24	5.95	10.8	1.89	0.53	100.7	2.54	9.38
7	0003/1	71.3	0.74	11.7	5.17	0.16	1.96	6.32	1.65	2.06	101.1	7.13	2.33
8	0004/1	70.5	0.73	11.6	5.13	0.16	1.93	6.28	1.80	2.16	100.3	7.17	2.26
9	0005/1	68.7	0.89	11.3	6.08	0.16	2.36	6.12	1.78	1.93	99.3	5.78	2.88
10	0006/1	63.5	0.94	13.7	6.68	0.22	2.27	7.75	2.38	2.45	100.1	9.22	2.59
11	0007/1	57.7	0.98	13.2	7.30	0.18	2.50	13.9	1.59	2.24	99.1	14.7	2.67
12	0008/1	63.0	0.70	10.8	5.61	0.13	2.68	13.3	1.56	1.57	99.5	18.0	3.20
13	0009/1	64.4	0.79	11.6	5.47	0.18	1.96	11.5	1.57	2.12	99.5	13.4	4.00
14	0010/2	51.4	0.89	13.0	7.19	0.34	2.31	20.2	1.28	2.19	99.1	28.5	4.20
15	0011/1	61.9	1.11	12.9	7.44	0.20	2.51	9.30	1.96	2.00	99.4	10.2	3.59
16	0012/1	68.1	0.88	12.3	6.44	0.18	2.35	5.50	1.85	2.14	99.7	5.05	2.67
17	0013/1	54.2	1.23	12.7	8.13	0.19	2.96	16.8	2.25	1.83	100.4	26.9	1.70
18	0015/1	67.0	0.96	13.0	7.21	0.17	2.65	5.19	1.74	2.19	100.1	5.50	2.11
19	0016/1	52.3	1.11	13.5	13.4	0.21	7.03	11.1	1.98	0.27	100.0	3.30	9.25
20	0017/1	72.7	0.84	10.2	5.98	0.13	2.34	4.27	1.54	1.84	100.2	2.51	2.86
21	0018/1	50.8	1.16	13.6	14.6	0.22	6.94	11.0	2.01	0.12	100.4	2.83	9.42
22	0019/1	62.3	1.27	12.4	8.62	0.23	2.94	8.01	1.90	1.61	99.3	5.42	4.97
23	0020/1	66.2	1.23	12.7	8.10	0.21	2.93	4.77	2.25	1.85	100.2	0.66	4.40
24	0021/1	63.1	1.34	14.5	9.30	0.37	3.13	4.16	2.11	2.11	100.1	0.95	3.63
25	0023/1	50.9	1.10	13.3	13.2	0.21	6.94	11.1	1.83	0.18	98.9	0.37	10.9

*$CaO_{silicate} = CaO_{bulk} - CaO_{carbonate}$; $CaO_{carbonate} = 0.5604\ CaCO_3$.

of calcareous foraminifers and coccoliths. These tests consist of low-magnesium calcite.

4.3. Statistical analysis

The results show distinct regional variations in the chemical composition of surface sediments. An interpretation of these results, however, is dependent on a clarification of the complex chemical conditions and on a classification of the surface sediments. Following this, a factor analysis of all available samples will make it possible to distinguish significant variations of individual parameters. These variations will be interpreted in terms of distinct facies types and sedimentary processes, respectively.

Cluster analysis was applied to find homogenous sample groups on the basis of the chemical composition of the surface sediments. These analyses will permit us to quantify the composition and distribution of different sedimentary facies.

The surface sediments of the Kolbeinsey Ridge are characterized by four factors which explain 87.7% of variance (Fig. 2).

Factor 1 (36.3% of the variance) has loadings of Al_2O_3, Fe_2O_3, MgO, MnO, V, Co, Ni, Cu and Zn and a somewhat lower loading of TiO_2. This factor is believed to represent dark volcanic glass and/or dark volcanic rock fragments. These elements are characteristic of mafic minerals. Thus, high levels of Fe_2O_3, MgO, Co, Cu and V, with high percentages of volcanic material, are found in sediments on the central ridge. Lackschewitz and Wallrabe-Adams (1991) exhibit that increased concentrations of Fe_2O_3, MgO, Co, Ni, Cu and Zn are indicators of submarine glass particles from sediments of the southernmost Kolbeinsey Ridge and Devey et al. (1994) take these to be

Table 3
Trace element concentrations in surface sediments in ppm. "MESS 1" is an international reference standard repeatedly analyzed during the ICP-MS analytical runs for controlling the accuracy of the analytical results

Sample	Core	V	Co	Cu	Ni	Zn	Rb	Sr	Mo	Cs	La	Pb
1	13/015	253	45	92	55	93	13	104	n.d.	n.d.	n.d.	5
2	13/016	252	43	85	52	99	21	146	n.d.	n.d.	n.d.	7
3	13/018	244	43	71	60	100	18	100	n.d.	n.d.	n.d.	8
4	13/019	223	52	97	82	96	n.d.	84	n.d.	n.d.	n.d.	6
5	0001/1	200	26.7	38.5	44.7	106	93.2	314	1.84	4.87	37.8	31.9
6	0002/2	336	45.8	85.8	46.4	107	15.2	151	0.96	0.83	8.8	15.1
7	0003/1	119	18.1	22.7	28.2	69.7	64.5	244	1.72	2.91	25.5	18.6
8	0004/1	114	16.7	25.7	34.3	59.8	66.0	237	2.06	2.58	25.5	20.0
9	0005/1	135	18.8	29.1	29.9	77.6	57.9	236	1.09	2.42	23.2	19.9
10	0006/1	152	22.4	24.8	35.4	97.4	88.7	334	2.08	4.03	35.5	27.5
11	0007/1	144	20.9	36.4	35.0	74.2	65.7	379	1.10	3.80	28.1	22.2
12	0008/1	146	19.8	21.4	38.1	85.8	45.2	337	1.11	1.80	18.4	17.9
13	0009/1	126	17.3	23.4	30.2	69.5	64.4	373	1.06	2.92	25.3	21.7
14	0010/2	158	28.6	29.8	31.3	96.1	70.0	678	2.20	4.25	29.4	26.6
15	0011/1	175	23.1	35.5	32.0	88.6	61.7	313	1.86	2.95	25.3	19.8
16	0012/1	149	20.9	33.9	45.9	n.d.	66.4	237	1.89	3.18	28.8	27.6
17	0013/1	112	16.0	19.7	26.1	58.1	53.3	566	0.98	2.68	21.8	21.3
18	0015/1	219	21.5	34.2	36.0	91.8	69.4	261	1.66	3.23	28.6	24.1
19	0016/1	357	45.1	78.7	58.7	106	15.5	154	1.61	0.69	9.8	11.0
20	0017/1	149	20.4	35.8	35.8	76.5	52.7	214	0.95	1.98	21.8	24.4
21	0018/1	310	44.4	71.0	55.7	112	23.6	170	1.14	0.92	12.0	16.8
22	0019/1	199	26.1	50.5	39.7	107	46.7	290	1.90	2.37	24.4	40.3
23	0020/1	173	24.0	42.3	35.2	98	49.5	198	1.55	2.25	26.3	29.2
24	0021/1	434	56.5	91.5	92.6	216	132	415	4.37	6.63	57.9	55.9
25	0023/1	384	51.5	107	69.9	545	5.9	93	1.12	0.15	4.0	6.9
MESS 1		72.4	16.8	25.1	29.5	191	100	89.0	2.2	4.0	30.0	34.0
this work by ICP-MS ($n=4$)		65.2	14.3	25.4	28.4	177	92.7	87.6	2.5	4.3	35.6	31.2
SD		2.6	0.4	0.7	1.0	4.8	2.5	2.7	0.1	0.1	2.0	0.5

n.d. = no data. SD = standard deviation.

indicators of basalts from the Kolbeinsey Ridge (see Table 1).

Factor 2 (26.2% of variance) shows high negative loadings of K_2O, Rb, Mo, Cs, La and somewhat lower negative loadings for Sr and Pb. Here, the high rate of deposition of clay minerals and feldspars is reflected in the sediments. Rb and Cs are primarily absorbed by detritic, potassium-rich minerals such as illite and orthoclase (Wedepohl, 1969). Grousset et al. (1982) demonstrate a correlation between Rb and the clay minerals illite, kaolinite and chlorite within sediments from the North Atlantic and from the southern Norwegian–Greenland Sea. K and Rb are generally bound to the acidic lithogenic component in sediments from the Norwegian–Greenland Sea (Paetsch, 1991).

All these parameters designate factor 2 as a detrital factor.

Factor 3 (11.3% of variance) displays a high loading of CaO and somewhat lower loadings of $CaCO_3$ and Sr. Turekian (1964) showed a frequent correlation between Sr and biogenic $CaCO_3$. During the formation of $CaCO_3$ Sr is extracted from the surface water and inserted in the carbonate shell material due to its crystallochemical similarity to the carbonate phase (Broecker and Peng, 1982). These positive loadings represent biogenic carbonate.

Table 4
Statistical parameters for major and trace elements

Variable	Average*	SD	Minimum*	Maximum*
$CaCO_3$	7.10	7.63	0.18	28.5
C_{org}	0.53	0.23	0.07	1.16
SiO_2	60.1	7.30	50.8	72.7
TiO_2	0.92	0.29	0.31	1.34
Al_2O_3	12.7	1.09	10.2	15.2
Fe_2O_3	8.92	3.06	5.13	14.6
MnO	0.20	0.06	0.13	0.37
MgO	4.33	2.81	1.93	10.6
CaO	9.40	3.97	4.16	20.2
K_2O	1.50	0.81	0.12	2.45
Na_2O	1.77	0.33	1.07	2.38
V	211	88.9	112	434
Co	30.7	13.1	16.0	56.5
Ni	45.2	16.8	26.1	92.6
Cu	51.3	28.1	19.7	107
Zn	114	94.6	58.1	545
Rb	51.0	29.5	5.90	132
Sr	265	141	84.0	678
Mo	1.63	0.74	0.95	4.37
Cs	2.74	1.47	0.15	6.63
La	24.7	11.1	4.04	57.9
Pb	19.1	12.4	0.54	55.9

*Major element concentration in %; trace element concentration in ppm.

The factor 4 (13.9% of variance) has high negative loadings of C_{org}, Na_2O and Pb. This factor is believed to represent an organic component. We can't explain the meaning of TiO_2 in this factor.

4.4. *Cluster analysis*

The result of the cluster analysis is shown by the dendrogram in Fig. 3. Three groups of samples are visible.

With respect to average concentrations in all samples studied, group 1 is characterized by highest contents of Fe_2O_3, MgO, V, Co and Cu. The concentration of $CaCO_3$ and K_2O are lower. The other elements are close to the arithmetic mean from total data base (Table 4). A comparison with factor 1, which documents the volcaniclastic facies, points to a connection of the group with this factor.

Group 2 contains the samples with the highest values of $CaCO_3$, CaO and Sr in the surface sediment, thus demonstrating the high loading of geochemical parameters of the carbonate factor 3. The lowest Fe_2O_3 values are found in the samples from this group. As a result of the diluting effect of carbonate, the elements or element oxides TiO_2, Al_2O_3, MgO, V, Co, Ni, Cu and Zn are also relatively diluted and lie below the mean values of the total data base (Table 3).

Most samples were grouped together in group 3, which is characterized by a heterogeneity of all parameter with the exception of generally lower CaO values. Mean values for the individual elements/element oxides of this group were compared with the respective average values of the total data base for the purpose of further characterization. The mean values for TiO_2, Fe_2O_3, MgO, CaO, V, Co, Cu, Zn and Sr lie below the average values. In this group the mean values of Rb, Cs, La and Pb are highest and correspond to the detritic factor 2.

4.5. *Normative analysis*

A quantification of individual characteristic sediment components in the bulk sediment is essential for an estimate of submarine volcanic activity on the Kolbeinsey Ridge.

Bischoff et al. (1979) and Dymond (1981) calculated the absolute percentage of various components in the bulk sediment using normative sediment models. An assessment of biogenic, lithogenic and hydrothermal components was carried out by Metz et al. (1988) using calcium carbonate and aluminium data.

Factor analysis permits only qualitative estimates of the distribution of sediment components. For quantitative estimates, other methods have been developed. An overall balance of surface sediments on the Kolbeinsey Ridge was drawn up here in accordance with the methods developed by Metz et al. (1988).

To calculate the percentage of biogenic, terrigenous and volcanic components in the bulk sediment, we used weight percentages (wt.-%) of siliceous biogenic particles, wt.-% $CaCO_3$ and wt.-% K_2O data.

Since, according to sedimentological studies, C_{org} and siliceous biogenic particles combined generally make up <2% of the total sediment, the biogenic content was equated with the $CaCO_3$

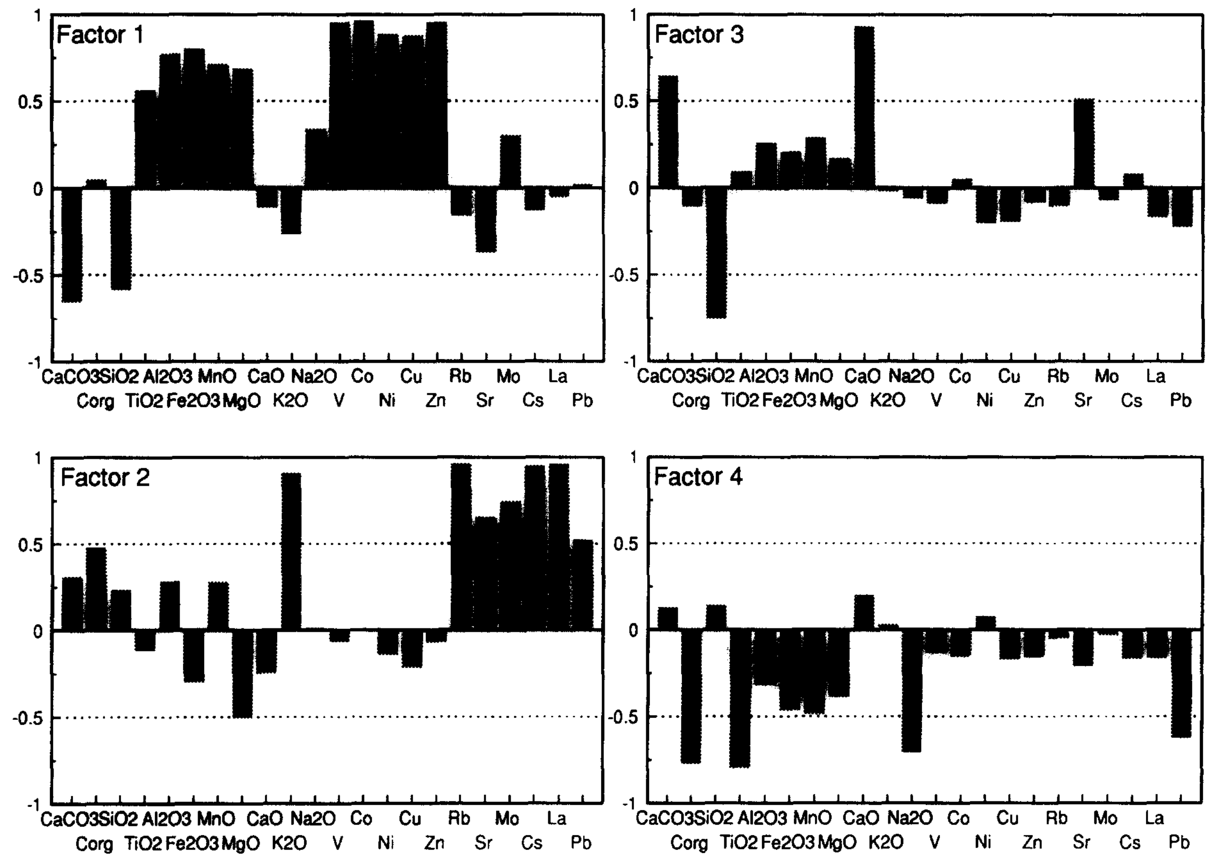

Fig. 2. Rotated factor loadings and varimax factor scores.

content of the surface sediments. An exception are the surface sediments (10/2, 19/1, 20/1 and 21/1) which show markedly higher percentages of siliceous biogenic particles. The biogenic content of these samples is computed using the equation:

$$\%_{\text{biogenic component}} = \text{wt.-}\%_{\text{CaCO3}} + \text{wt.-}\%_{\text{siliceous biogenic particles}}$$

In the volcanic group, the terrigenous content can be calculated on the basis of the K_2O concentration in the bulk sediment, provided that the entire K_2O is bound to terrigenous material.

The potassium content in carbonate sediments is nearly exclusively bound to the non-carbonate fraction (Wedepohl, 1969). Bowen (1966) describes no detectable potassium concentrations for calcareous foraminifers, calcareous sponges, corals, molluscs and echinoderms recording a mean potassium content of 5.8 ppm for siliceous sponges.

The average K_2O content for "zero age" basaltic components from the Kolbeinsey Ridge is 0.07% (Lackschewitz and Wallrabe-Adams, 1991; Devey et al., 1994).

The K_2O of clayey sediments is primarily bound to clay minerals, potassium feldspars and mica, although mica generally has a high correlation with clay mineral content (Welby, 1958). Weaver (1965) reports high concentrations of potassium in illites. Chester (1965) records an average K_2O of 2.3% for pelagic deep-sea sediments.

For this reason, nearly the entire concentration of K_2O in our surface samples from the volcanic group must be traced back to the terrigenous content. The K_2O content was first determined from the non-carbonate fraction of the surface

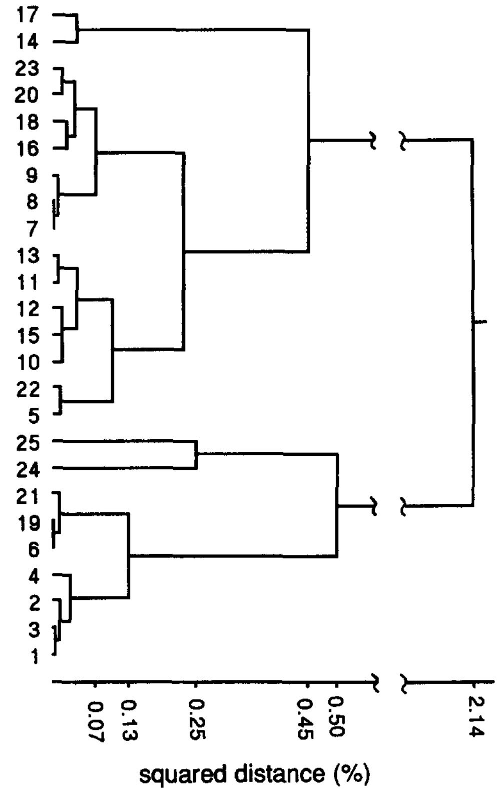

Fig. 3. Dendrogram from cluster analysis (Tanimoto distance, Ward's method) of geochemical data. Dendrogram sample numbers are identical to Table 2.

samples in the terrigenous group. The arithmetic mean of potassium in this group is 2.2%. Generally, this value is in good agreement with the average K_2O of 2.3% for pelagic deep-sea sediments.

On the basis of the calculated average K_2O content, the percentage of the terrigenous component was calculated for the samples in the volcanic group as follows:

$$\%_{\text{terrigenous component}} = \frac{(100\% - \%_{\text{biogenic component}}) \times K_2O_{\text{volcanic}}}{2.2\%}$$

Thus, the volcanic content can be calculated using:

$$\%_{\text{volcanic component}} = 100\% - \%_{\text{terrigenous component}} - \%_{\text{biogenic component}}$$

4.6. Distribution of the biogenic, terrigenous and volcanic components

The distribution of volcanic, terrigenous and biogenic sediment components in surface sediments is shown in Figs. 4–6.

The highest percentages (>60%) of the volcanic component occur in the vicinity of the ridge crest. This pattern shows a marked similarity with the lithology presented in Fig. 1. These sediments obviously derived from submarine volcanism which produce lava flows, volcanic glass, and volcanic rock fragments. An indication of hydrothermal activity along the Kolbeinsey Ridge is only documented near Kolbeinsey Island showing boiling water and shaking basalt fragments caused by gas bubbles (Fricke et al., 1989). Generally, the terrigenous and the biogenic component is relatively low in the area of the ridge crest reflecting enhanced dilution by volcaniclastic material. Sediments with still abundant volcanic material but a large amount of terrigenous component are also found in samples from the adjacent ocean floor. According to Lackschewitz and Wallrabe-Adams (1991) and Oehmig and Wallrabe-Adams (1993), bottom currents and mass flows are responsible for downslope transport of volcanic material.

The regional distribution of the biogenic component in the western Iceland Sea is shown in Fig. 5. The highest percentages of the biogenic sediment component (20–30%) have been determined in the eastern and northeastern area of the Spar Fracture Zone, whereas this component decreases significantly to the west. According to the normative analysis calcium carbonate is the best indicator for the biogenic component (foraminifers and coccoliths). Bulk calcium carbonate contents of surface samples provide a good approximation to differentiate surface water masses in the Iceland Sea (Baumann et al., 1993). The amounts of planktic foraminifers and coccolithophorids are found in samples from the East Iceland water masses indicating a relatively high calcium carbonate shell production (Samtleben and Schröder, 1992). In contrast, low production of $CaCO_3$ towards the Greenland continental margin can be related to the polar water masses of the East

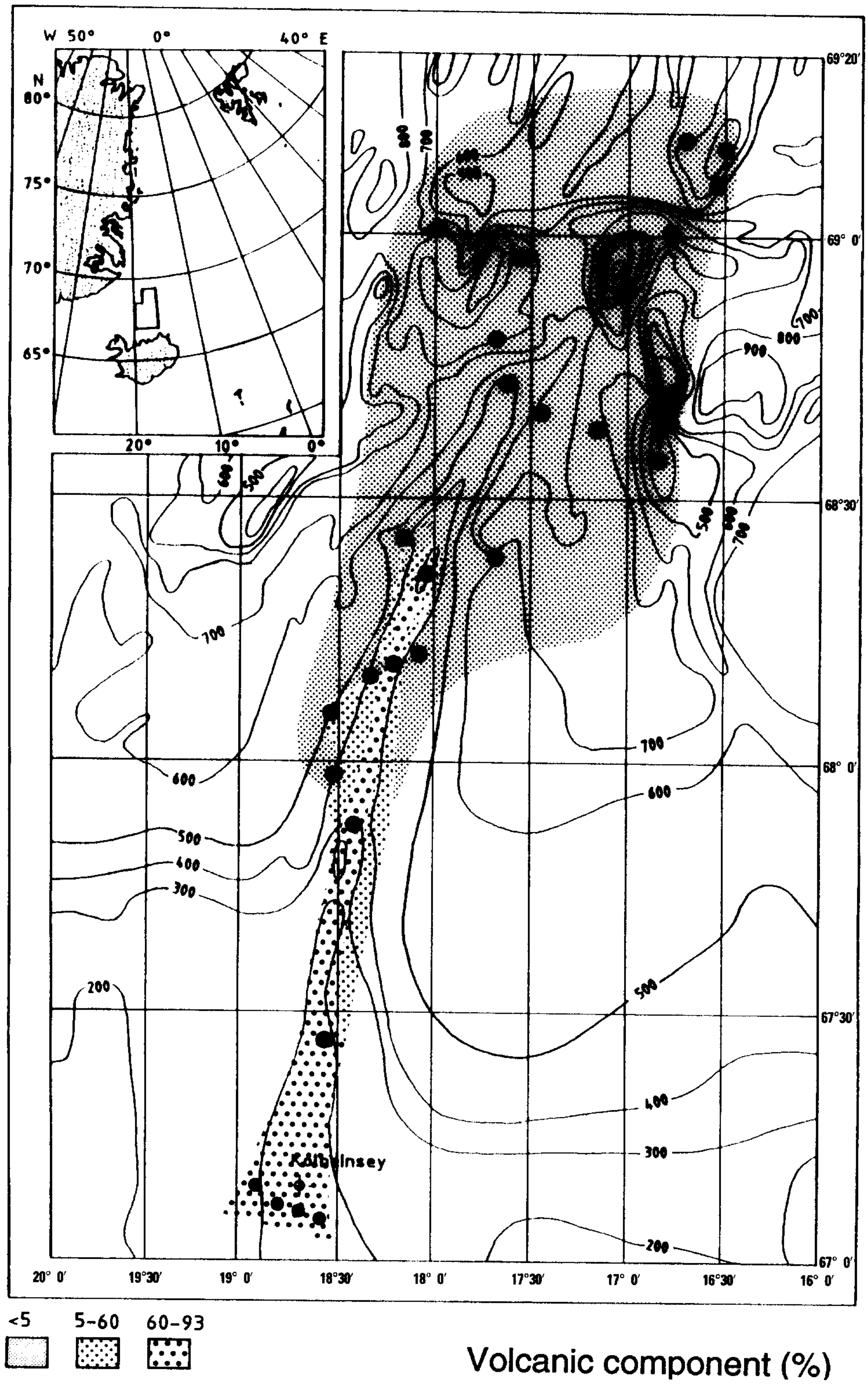

Fig. 4. Distribution and percentages of the volcanic component on the basis of normative sediment analysis.

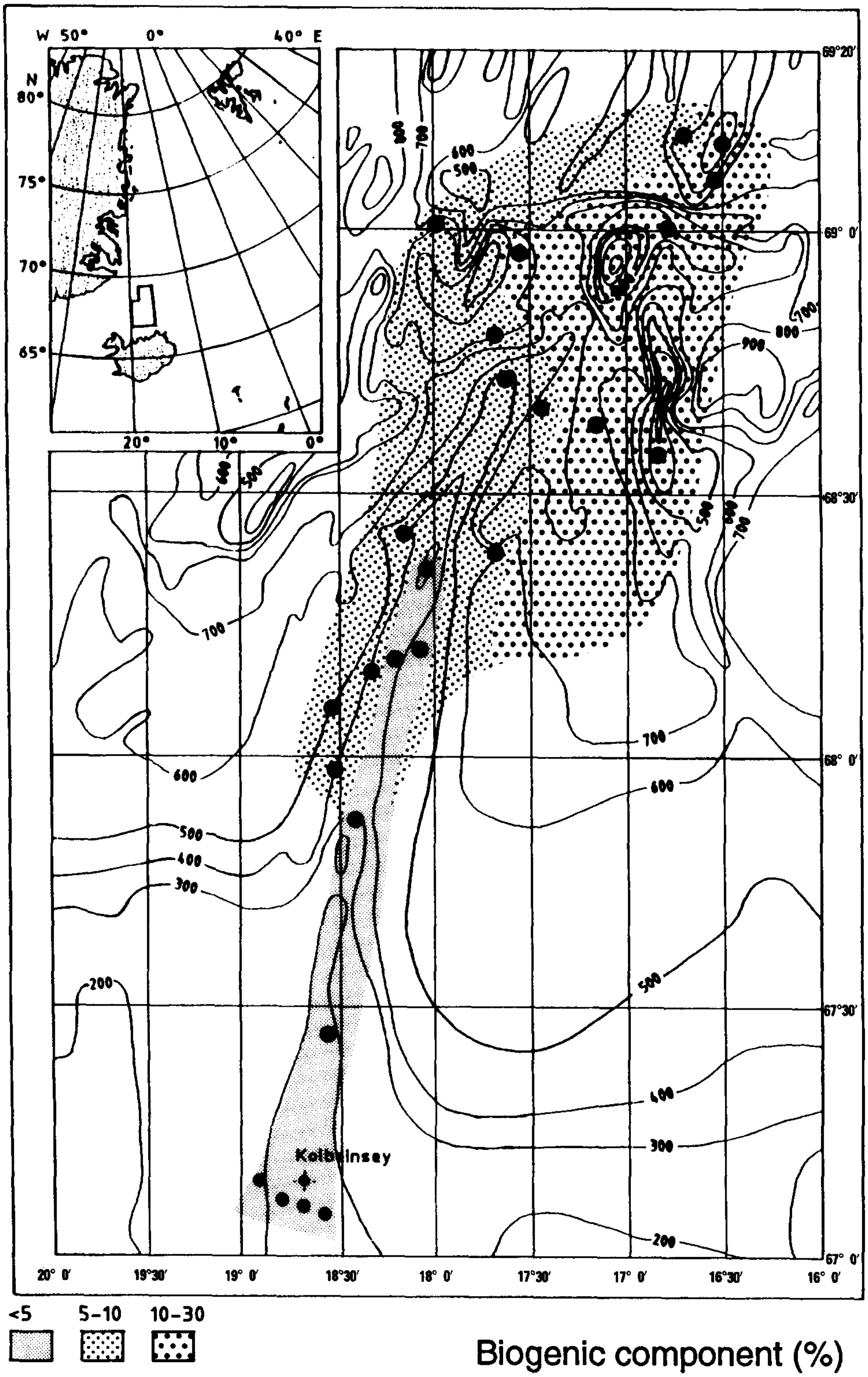

Fig. 5. Distribution and percentages of the biogenic component on the basis of normative sediment analysis.

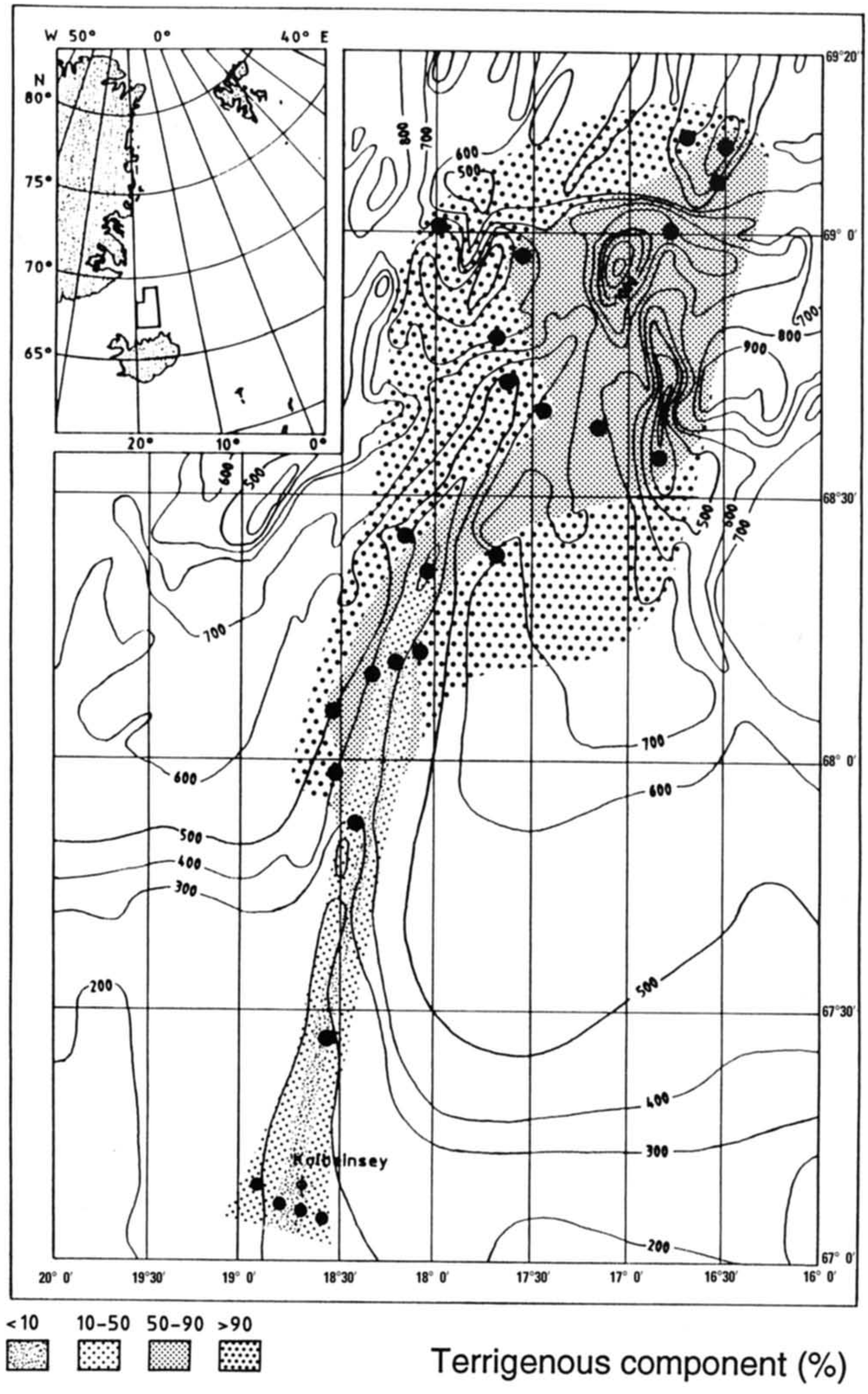

Fig. 6. Distribution and percentages of the terrigenous component on the basis of normative sediment analysis.

Greenland Current. Thus, the relatively high amounts of $CaCO_3$ in surface sediments east of the Kolbeinsey Ridge are probably caused by a higher production in the East Iceland Current influenced by warmer Atlantic water masses.

Generally, our results are in good agreement with the data of Peatsch et al. (1992) and Baumann et al. (1993).

In addition, a distinct increase in Sr concentrations is observed in relation with relatively high calcium carbonate contents reaching the sediment over the calcium carbonate production. Cornblad and Malmgren (1981) show that the incorporation of Sr into the carbonate shells of planktic foraminifers correlate positively with the surface water temperature.

Fig. 6 shows the amount of the terrigenous sediment component. Generally, the surface sediments in the west and southeast of the study area exhibit 90% of the terrigenous component. These sediments are characterized by highest concentrations of K_2O and Rb. Grousset and Chesselet (1986) note an increase in Rb towards the Greenland continent. The main source of the metals in the marine sediments near the continent seems to be weathered terrestial material from Greenland. The transport mechanism for this material cannot be determined clearly owing to its geographical distribution. Grain size distribution shows no pattern of turbidity current or contour current activity. But previous studies of marine sediments from the high latitudes have shown that the high amounts of coarse terrigenous particles (>63 μm) in the Norwegian–Greenland Sea can be interpreted as ice-rafted material (Bischof, 1990; Henrich, 1990; Spielhagen, 1991). Enhanced deposition of ice-rafted detritus indicate that extensive melting of ice occurs in this area. Because sea ice sediments are mostly fine-grained and contain little or no terrigenous grains >63 μm (Pfirman et al., 1989a,b; Wollenburg, 1993), icebergs from land and fjord glaciers are proposed as transport agents for the bulk of the sand-sized terrigenous material (Molnia, 1972; Clark and Hanson, 1983). In addition, input of clayey and/or silty terrigenous material in the Norwegian–Greenland Sea can be caused by density currents from the continental shelfs (Elverhøi et al., 1989; Blaume, 1992). A drastic decrease in the terrigenous component was observed on the ridge crest indicating increased dilution by volcanic material.

In summary, the area of the mid-oceanic Kolbeinsey Ridge monitors the interaction between the terrigenous sediment input, submarine volcanic processes and the biogenic particle production (Fig. 7).

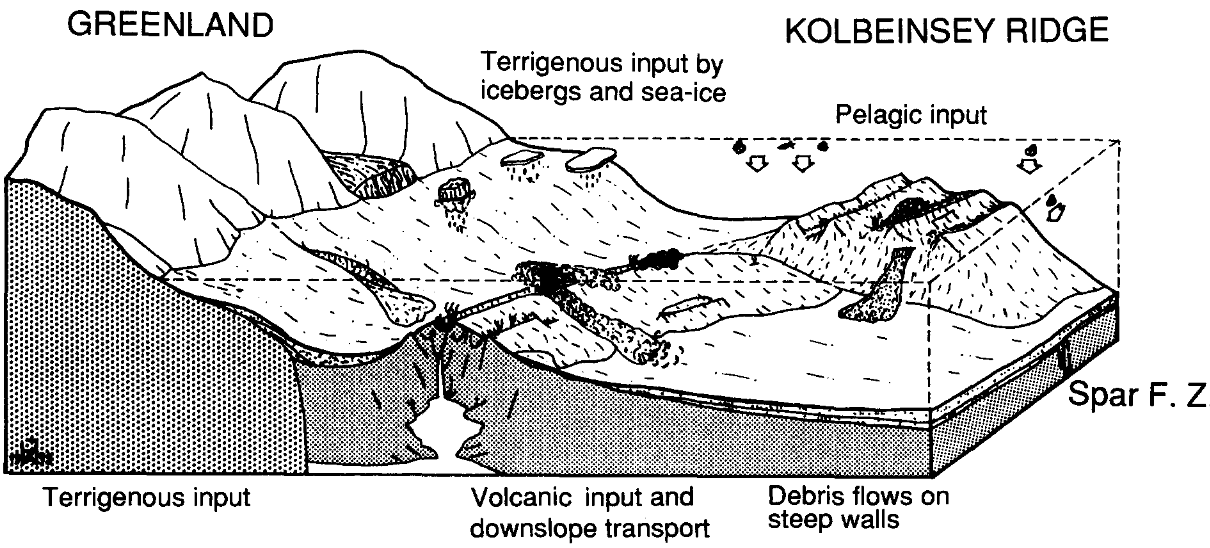

Fig. 7. Scheme of the recent sedimentation processes in the area of the Kolbeinsey Ridge.

5. Conclusions

High compositional gradients in sediments between Iceland and Jan Mayen result from a variability in sedimentary sources of different geographic regions.

Bulk chemical composition in surface sediments and normative sediment analysis allow quantitative estimates of three distinct components:

(1) a volcanic component;

(2) a terrigenous component; and

(3) a biogenic component.

A straightforward approach to calculating the terrigenous contribution to the sediments was made using calcium carbonate and K_2O data.

The terrigenous component is generally >90% in basins lying west and east of the Kolbeinsey Ridge presumably caused by deposition of terrigenous debris into regions with small contributions from other sources. The terrigenous facies is defined by the association of the elements K, Rb, Cs, La and Pb.

Fe, V, Co, Ni, Cu and Zn are the elements analyzed that most strongly reflect the volcanic input. Highest volcanic deposition is recorded in surface sediments from the ridge crest containing 60 to 90% of this component. This range indicates that submarine volcanic activity has had a substantial influence on sedimentation in the region.

The distribution of the biogenic component indicated by the content of calcium carbonate reflects the importance of warmer Atlantic water masses east of the Spar Fracture Zone.

Acknowledgements

We thank J. Thiede for supervising the project. We gratefully acknowledge two anonymous reviewers for their critical discussion and valuable comments. Thanks are due to P. Stoffers for access to the ICP/MS and to C. Devey to operate the X-ray fluorescence spectrometer. For technical assistance, we thank H.-C. Reimers. C. Hoffmann and J. Welling corrected the English. We also thank Capt. Andresen and his crew of the R.V. *Poseidon* on cruise 158 and Capt. Greve and his crew of the R.V. *Polarstern* on cruise ARK V/1. This investigation forms part of the research project "The Greenland–Scotland-Ridge" and was funded by the *Bundesministerium für Forschung und Technologie* (Grant MFG 00664).

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