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SHEET INTRUSIONS ASSOCIATED WITH THE REYKJADALUR VOLCANO, WESTERN ICELAND; STRUCTURE AND COMPOSITION

By

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ABSTRACT

The sheet swarm of the Tertiary Reykjadalur volcano comprises a large number of inclined sheets associated with the central part of the volcanic edifice. These inclined sheets show a large variation in dip and strike. They occur as two lithological groups of aphyric and porphyritic tholeiites. Regional dykes, formed in the now extinct rift zones outside the volcanic edifice, are thicker and dip more steeply than the inclined sheets. Seventy samples of inclined sheets and regional dykes were analyzed for main and trace elements and show that the sheet intrusions are mainly tholeiites but a few ol-tholeiites and icelandites occur. The most evolved inclined sheets are found in the central part of the caldera associated with the volcano, whereas the most primitive sheets are found along the caldera margin. Although inclined sheets and dykes are somewhat different in lithology, it is not possible to chemically distinguish between inclined sheets and regional dykes with standard XRF methods of main and trace elements.

CONTENTS

INTRODUCTION

The aim of this report is to present the most important structural and chemical data on the sheet intrusions in the Reykjadalur volcano and surrounding areas, in addition to those reported in Gautneb[1].

The investigation was made during six weeks field work in the summer of 1988. Around 500 dykes and sheets were studied, 45 thin sections were made and 60 whole rock chemical analyses was performed. The chemical analyses was made in order to obtain data to test whether there was chemical difference between sheet intrusions inside and outside the Reykjadalur volcano.

GEOLOGICAL SETTING

The Reykjadalur area is situated about 90 km north of Reykjavik in a Tertiary lava pile (Fig. 1). Most of the investigated area is easily accessible from the main roads along Nordurdalur[2] and Midhdalir. The area offers good outcrops along numerous river and stream sections. It is, however, difficult to cross most rivers since the currents are strong and the water depth normally exceeds 0.5 m. The valley sides are mostly covered with scree or peat and offer poor exposures.

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[1]Gautneb H. 1989 The structure of the Reykjadalur sheet swarm, MS submitted to Tectonophysics.
[2]The reader is referred to the topographic maps Laxardalur and Nordurdalur 1:100000 (Iceland Geodetic Survey) for location of place names.

The Reykjadalur area was investigated by Johannesson[3] who described the general structure and petrochemistry of alldescribed the general structural and petrochemistry of all extrusive and intrusive rocks, as well as observing faults and geothermal springs. According to Johannesson[3] the main geological units are the following:

1) A 12-13 Ma old basement of flood basalts, tilted and faulted.

2) The 7 Ma old Hredavatn sedimentary horizon. This horizon is situated unconformably on the underlying basement.

3) Hallarmuli central volcano which was active form 6.7-7.0 Ma ago and contains ignimbrites, intermediate rocks and thin tholeiitic lava flows. This is a rather small central volcano which did not develop the structural and chemical features characteristic of larger mature central volcanoes.

4) Reykjadalur central volcano, active from about 6.0 to 4.0 Ma. It is situated unconformably on the Hallarmuli volcano. This volcano has the following series of extrusives:

   a) Thick layered serie consisting of tholeiitic to icelanditic lava flows.

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[3]Johannesson H. 1975 Structure and petrochemistry of the Reykjadalur central volcano and surrounding areas, midwest Iceland. Ph.D thesis, University, of Durham 273pp.

b) The main phase of differentiated extrusives, mainly intermediate to acid lavas.

c) Thin layered series of mainly tholeiitic composition.

d) The caldera in-fill.

A collapse caldera, 10 km in diameter and with vertical displacement in excess of 800 m, occupies the central part of the volcano. Before the Reykjadalur volcano became extinct the whole area was covered with a icecap 4.3-4.4 Ma ago and the Holthavorduheidi sedimentary horizon was deposited.

In the volcano the following intrusions occur:

a) Basaltic to rhyolitic dykes

b) Basaltic to rhyolitic inclined sheets

c) Gabbroic to rhyolitic plugs and stocks

Based on the methods of Walker[4] the maximum level of erosion is about 1000 m. The highest mountain peaks are about hundred meters below the initial lava pile.

Fault activity

The faults are closely associated with the sheet and dyke intrusions. According to Johannesson[5] the faults can be divided

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[4]Walker G.P.L. 1960. Zeolite zones and dyke distribution in relation of the structure of Eastern Iceland. J. Geol. 68, 518-528.

[5]Johannesson H. 1975 Structure and petrochemistry of the Reykjadalur central volcano and surrounding areas, midwest Iceland. Ph.D. thesis Univ. Durham 273pp.

into the following groups:

1. NE-SW faults

These occur only in the area south of the Reykjadalur volcano. Few faults occur in the southeastern part of the area, but they are abundant in the Grothals area and in the western part of Nordurdalur. The trend changes from NE-SW to ENE-WSW northwards along the Grothals ridge. Most faults dissect the lavas at right angles, indicating that the faulting took place prior to the tilting of the lavas.

2. N-S faults

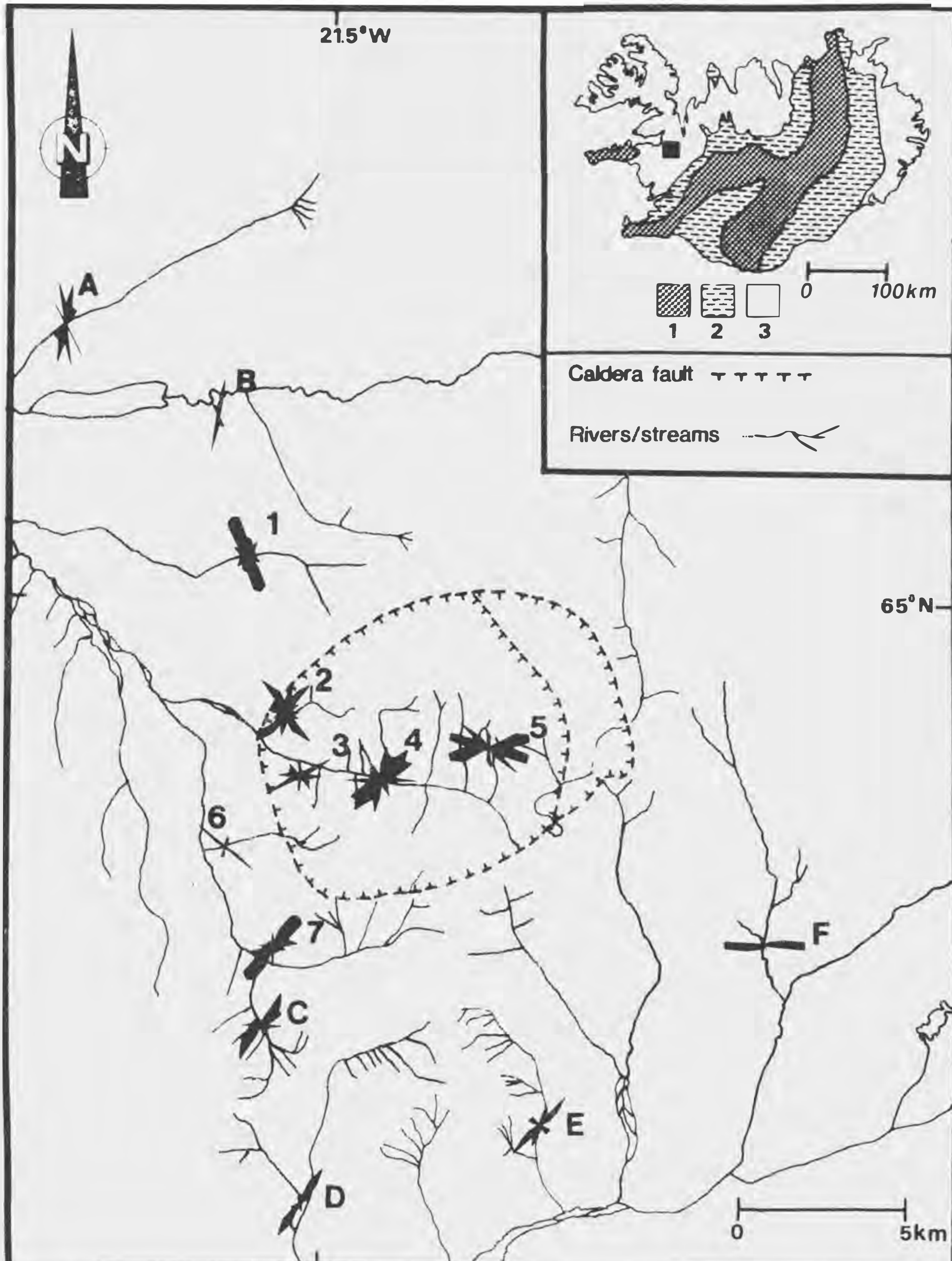
These faults are the only ones found north of the Reykjadalur volcano, but on the southern side of the volcano the faults can be followed as far as to Thverarhlid. These faults cut the Reykjadalur central volcano.

3. NW-SE faults

Faults of this trend occur in small number in the southernmost part of the area.

Fig.1

Fig. 1 Simplified map of the investigated area. A to F are localities of regional dykes. 1 to 7 are localities of inclined sheets. Inset: 1 Neovolcanic zone, 2 Plio- Pleistocene rocks, 3 Tertiary rocks.



METHODS

Terminology

Here the term inclined sheet is used for sheets associated with the central volcano. The term regional dyke or dyke is used for sheets occurring outside the central volcano i.e., more than ten kilometres from the caldera margin. The term sheet is used when no distinction is made between inclined sheets and regional dykes.

Field measurements

The sheet intrusions were studied systematically and the following parameters were recorded for each sheet (where possible):

1. Strike and dip
2. Thickness
3. Lithology
4. Type of host rock
5. Vesicles and amygdales in the sheet
6. Vesicles and amygdales in the host rock
7. Alteration of the sheet and the host rock
8. Number and form of columnar rows in the host rock
9. Form of sheet (e.g. matching features on the sheet walls)
10. Lithology and abundance of xenoliths
11. Crosscutting relationships

12. Other features (e.g. flow-lines, chilled margin and other internal sheet structures)

It was not possible to measure all these parameters in each locality, but the first four were always recorded.

Analytical methods

A representative selection of sheets from different localities and with different lithologies was collected for chemical analysis. The samples were rushed to -150 mesh in a tungsten-carbide ballmill. 9.0 g rock powder was mixed with 9.0 ml moviol glue. This mixture was pressed to tablets with 10 tons pressure in 30 s. Then the tablets were dried at 60^{o} C for 2 hours. These tablets weres analysed with the analytical facilities at the department of geology of the University of Bergen, Norway, on an automatic Phillips 1450 XRF with full mass-absorption correction for all elements. Seventen international standards were used for calibration. International standards were also analysed as unknown for instrument stability check. This analytical procedure took much less time than would have been needed for similar work using the present analytical facilities at N.V.I. The chemical analyses are listen in Table 3.

DESCRIPTION

Field observation

The sheets were studied in the river and stream traverses shown in Fig. 1. A distinction was made between inclined sheets associated with the volcano (station 1 to 7 in Fig. 1), and regional dykes (stations A to F in Fig. 1) far outside the volcano.

Lithological variation

Broadly the sheets can be grouped into porphyritic and aphyric basalts. Most sheets are fine grained to very fine-grained. The porphyritic sheets contain mainly lath-shaped plagioclase phenocrysts, but in addition phenocrysts of clinopyroxene occur in some sheets. The plagioclase phenocrysts are up to 3 cm long and comprise almost 50% of the volume of the rock. They are mainly confined to the caldera and decrease in abundance with distance from the caldera. The porphyritic sheets comprise slightly above 30% of the total number of sheets but are mainly confined to the caldera.

Within the caldera the sheet swarm contains an enormous number of crosscutting sheets (Fig. 2), but it has not been possible to distinguish between subsets of dominant trends and relative age. The dominating directions are shown in Fig. 1.

The regional dykes, which occur outside the caldera are normally aphyric, relatively thick, steeply dipping, and intrude perpendicular to the dip of the lavas. The regional dykes show well developed columnar rows, often in several sets, developed perpendicular to the dyke walls (Fig. 3).

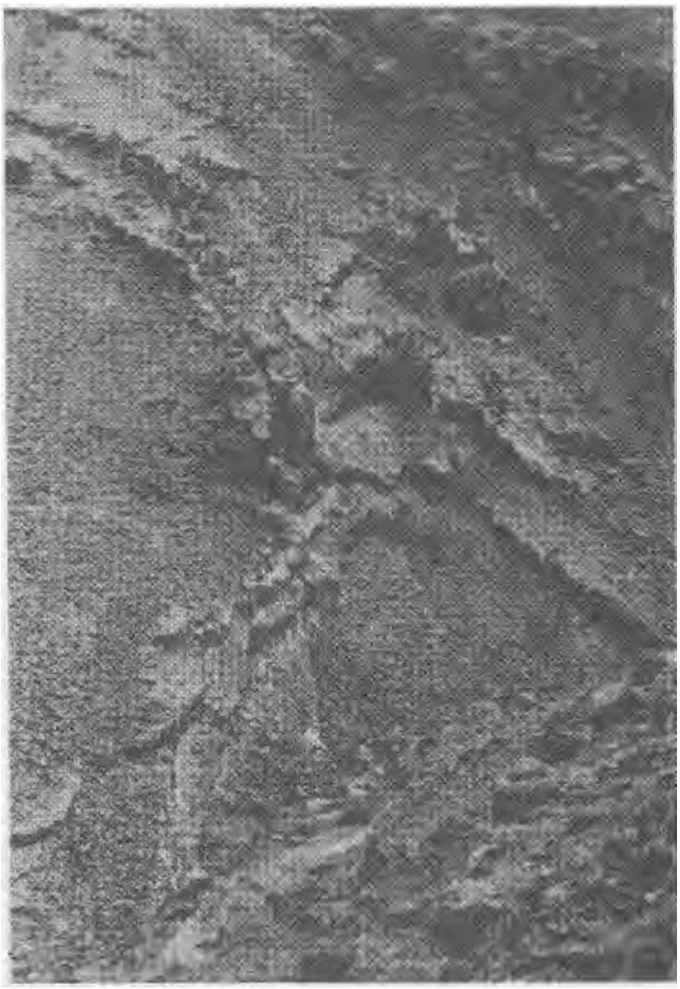


Fig. 2 Crosscutting inclined sheets at locality 2 in Fig. 1. The sheets occur in complex crosscutting relationships with no age dependent preferred strike.

Petrography

Many thinsections were made for general classification and alteration studies of the sheets. The typical ophitic (dolerite) texture is most common with intergrowths of plagioclase and clinopyroxene, and clinopyroxene as the dominant chadacryst. The plagioclase is usually lath- or needle-shaped and sometimes arranged in glomerophyritic aggregates together with clinopyroxene. The plagioclase commonly shows undulatory zoning. The plagioclase phenocrysts in the porphyritic sheets are commonly poikilitic with inclusions of earlier formed plagioclase, clinopyroxene and opaques. The opaque minerals often occurs in particular zones in the plagioclase oikocrysts.

The degree of alteration is high for many of the sheets, is seen by desintegration of the plagioclase to epidote, calsite and zeolites and the alteration of clinopyroxene to chlorite and opaques. Very high degree of alteration is characterized by complete obliteration of the primary textures and appearance of considerable amount of secondary pyrite.

Most regional dykes are less altered than the inclined sheets at the caldera centre, but many dykes contain small cavities filled with secondary amygdale minerals.

Fig. 3 Typical regional dyke with several columnar rows perpendicular to the dyke wall.

RESULTS

Structural data

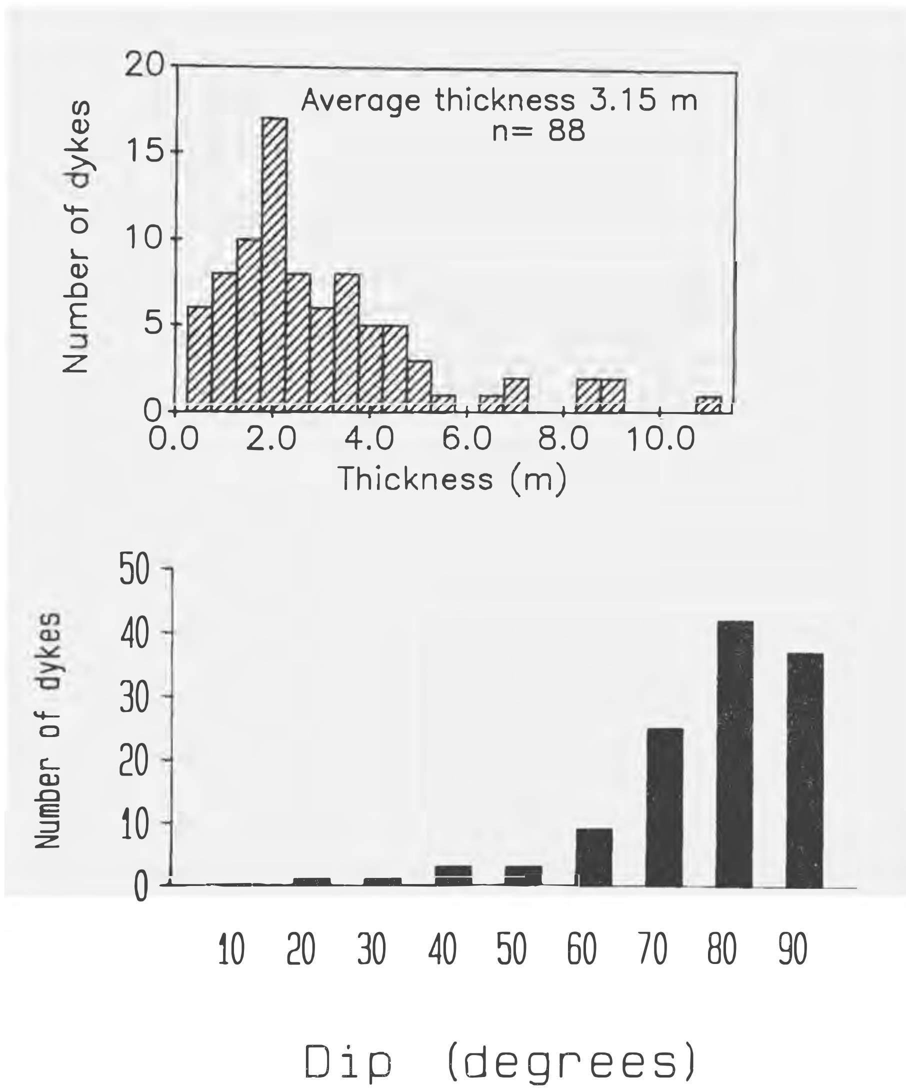
Regional dykes

A total 88 regional dykes were measured. The average dip and thickness for the different stations is as follows (Table 1). The average dip of the regional dykes is 81^{o} and the average thickness is 3.2 m. The dip and thickness distributions are shown in Fig 4. The lowest average dip and thickness were observed at station C, which is partly due to occurrence of several inclined sheets at this locality.

Table 1 Statistical results for the regional dykes.

Station	A	B	C	D	E	F
	10	24	21	23	15	16
Dip (avg)	75	84	65	79	81	81
Dip (std)	13	6	18	11	90	
Thickness (avg)	4.3	3.7	1.5	2.1	3.6	2.5
Thickness (std)	3.1	2.1	1.1	1.0	2.7	1.4
Max thickness	11.6	8.9	5.0	5.0	9	6.5
Min thickness	0.9	0.7	0.3	0.5	0.4	0.6
Traverse length	3250	10500	2500	4500	3000	2750
Dilation %	1.33	0.83	1.32	1.07	1.84	1.48

Fig. 4 Thickness and dip distribution of regional dykes. Note that the distributions are very different from those of the inclined sheets (Fig. 5).



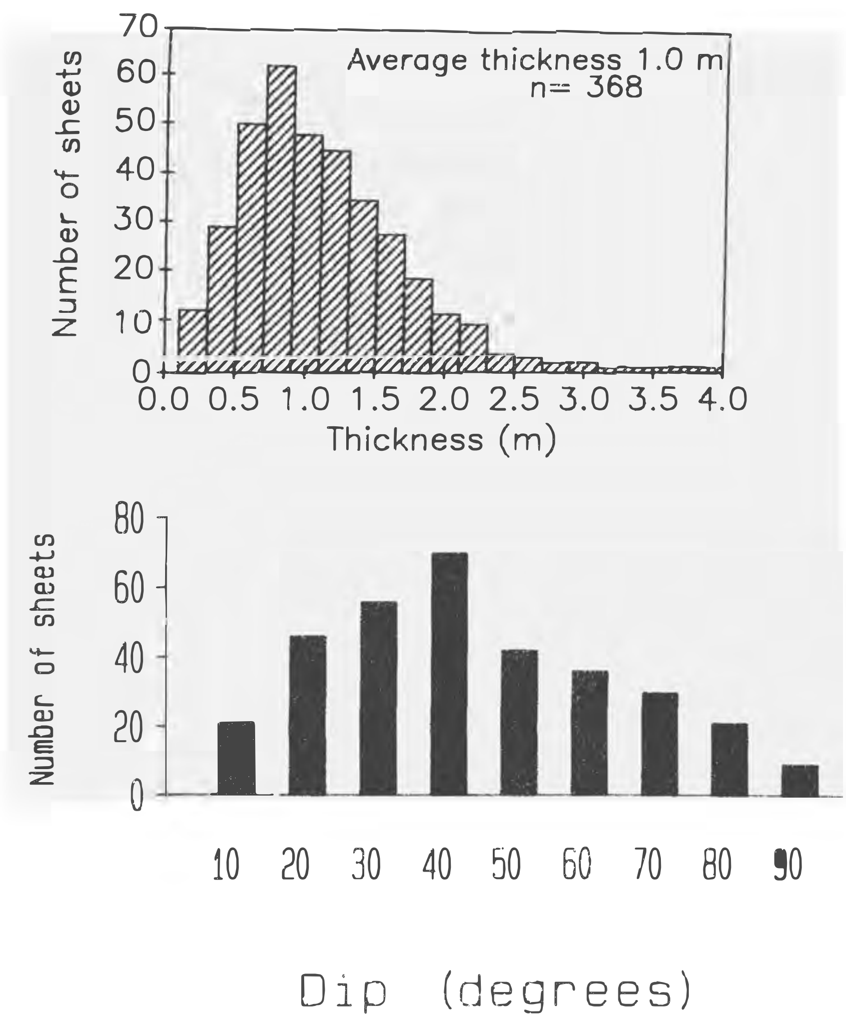
Inclined sheets

A total of 368 inclined sheets gave following dip and thickness variations at the seven stations. The average value for all cone sheets is 45^{o} for dip and 1.0 m for thickness. Histograms of dip and thickness are shown in Fig. 5

Table 2. Statistical results for the inclined sheets.

Station	1	2	3	4	5	6	7
N	49	74	49	102	43	10	47
Dip (avg)	55	38	46	45	56	41	31
Dip (std)	19	18	20	20	20	23	19
Thickness (avg)	1.1	0.8	0.9	1.1	1.1	0.6	0.9
Thickness (std)	0.6	0.6	0.4	1.2	0.6	0.5	0.4
Max thickness	2.9	3.2	1.9	4.0	3.5	1.8	1.6
Min thickness	0.1	0.1	0.2	0.1	0.2	0.1	0.3

Fig. 5 Thickness and dip distribution of inclined sheets. The average dip is about 45°.



Discussion of dip, strike and thickness variations

The variation in dip, strike and thickness of the inclined sheets and regional dykes is discussed in detail by Gautneb[1]. For the sake of completeness the most important results are summarized here.

The regional dykes are steeply dipping. The deviation from the vertical can often be attributed to subsequent tilting of the associated lavas. The strike follows the orientation parallel to the extinct volcanic zones. The average thickness of the dykes exceeds that of the inclined sheets by about 2 m.

The inclined sheets show large variation in dip and thickness. The dip variation reflects changes in the stress field during growth of the shallow magma chamber and variation in dimensions of the magma chamber with time (Gautneb et al.[2]). The average dip decreases with distance from the caldera centre.

Chemical data

Regional dykes

The regional dykes consists mainly of qz-tholeiites (Fig. 5). One sample classifies as Fe-Ti basalt and two samples as intermediate basaltic-andesites. The regional dykes have a fairly

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[1] Gautneb H. 1989. Structure of the Reykjadalur sheet swarm. MS submitted to Tectonophysics

[2] Gautneb H., Gudmundsson A., Oskarsson N. 1989. Structure, petrochemistry and evolution of a sheet swarm in an Icelandic central volcano. Geological Magazine (in press).

uniform composition. Most regional dykes are qz-normative, only two samples contain 2-4% normative olivine, other samples contain 1-9% normative quartz (Table 4).

The trends show a some scatter (Fig. 7) particularly the alkalis (Na_2O and K_2O) which show large scatter. There is an increase in CaO, V, Cr, Ni, and Cu with increasing MgO/Fe_2O_3t and decrease in Na_2O, K_2O, P_2O_5, Sr, Y, Zr, Nb, Ba, Ce, Nd, and La. Other elements show a random distribution. These trends show increase in incompatible and decrease in compatible elements with evolution. Plagioclase and clinopyroxene fractionation seems to be responsible for most of the variation, with some frationation of magnetite and ilmenite in the most highly evolved samples.

The most primitive regional dyke (sample D11, Table 3) is 4.90 m thick, stands vertically and consists of little altered aphyric basalt at station A. The most evolved dyke basalt (sample D27a, Table 3) is a 0.90 m thick and consists of aphyric (station B). There is no indication of any close chemical resemblance between nearby dykes. For instance, dykes D27a and D 27b are separated by not more than five metres of host basalts but have a difference in MgO of 4 wt%, and very distinct differences in all other elements as well. This indicates that these dykes were formed by very different magmas, probably widely separated in time. If these compositional differences of samples D27a and D27b are representative for other regional dykes they would suggest that individual dykes in a cluster were generated under similar stress conditions but by different source magmas.

Fig. 6 MgO/(MgO+FeOt)*100 versus TiO_2 for the regional dykes. Most dykes have composition similar to qz-tholeiite.

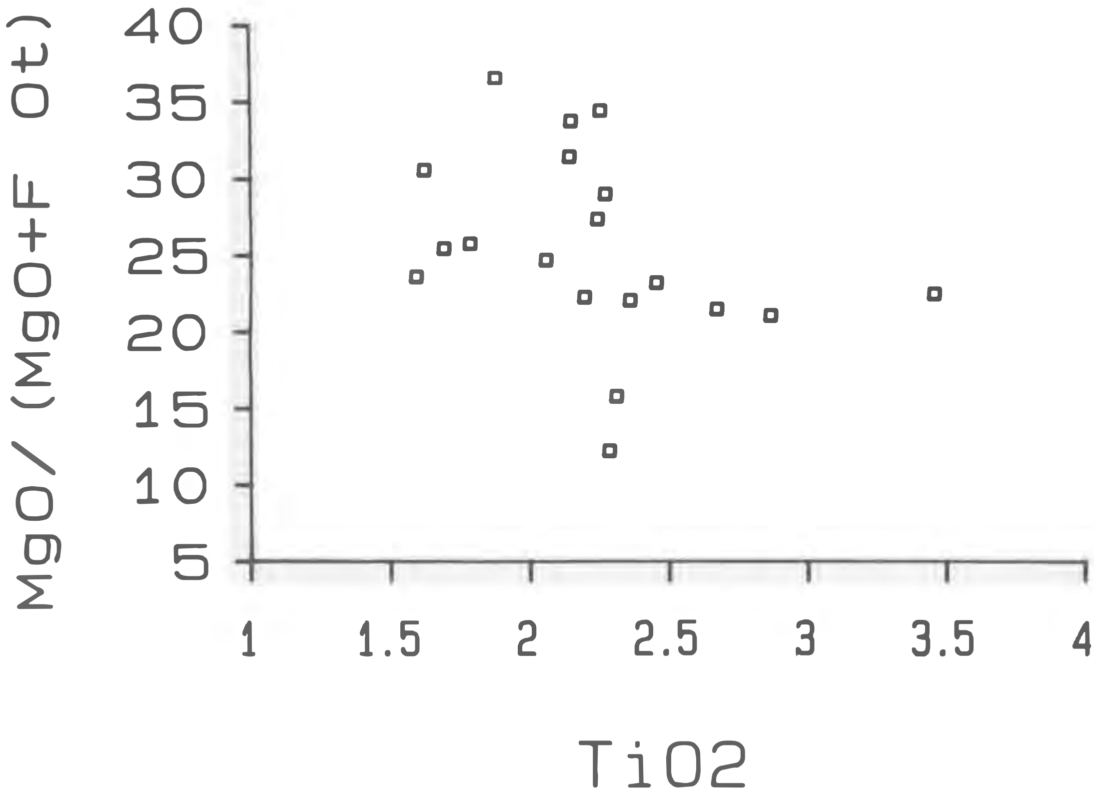


Fig. 7 Composition of regional dykes. MgO/Fe2O3t*100 versus most other elements.

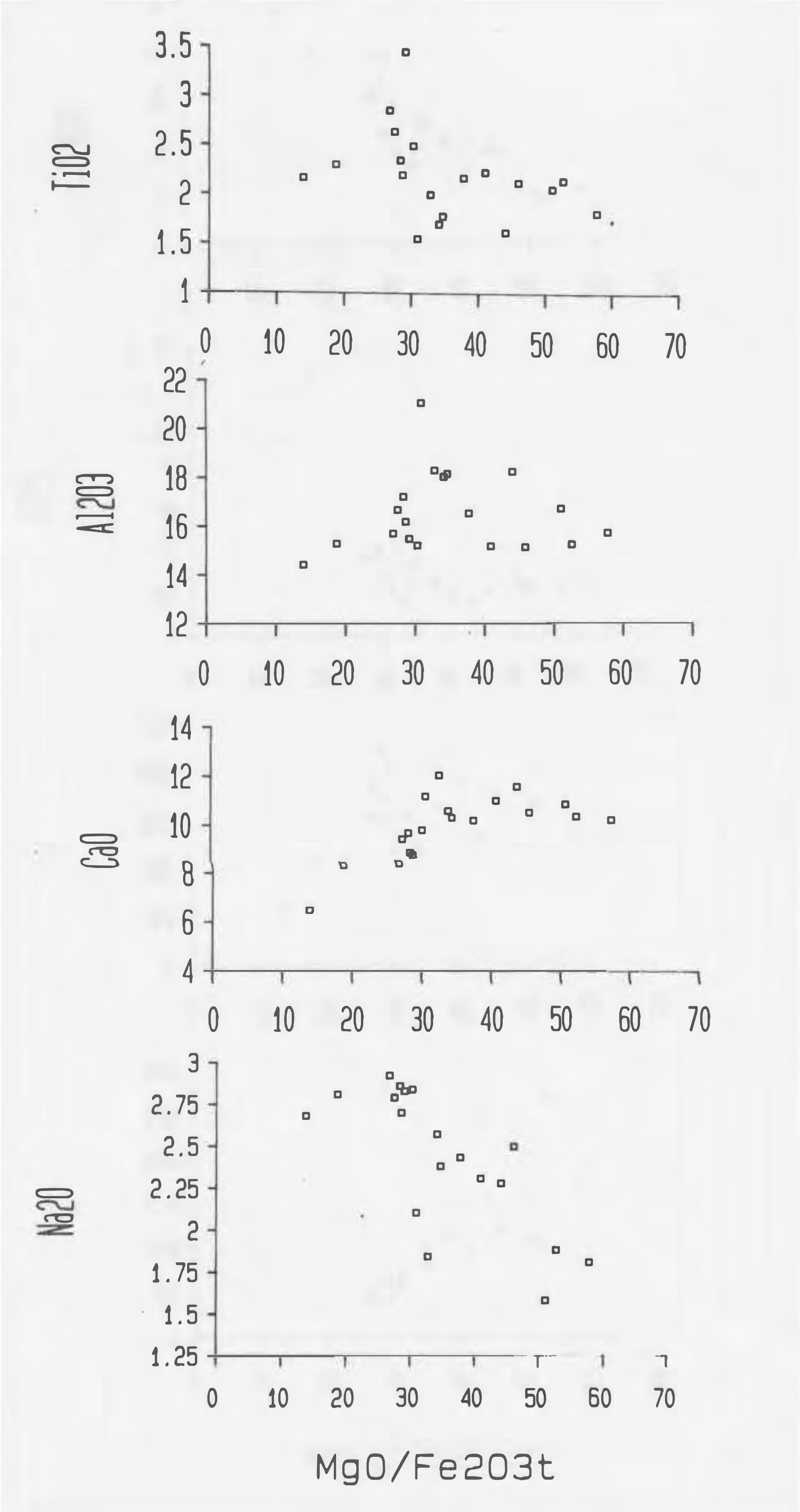
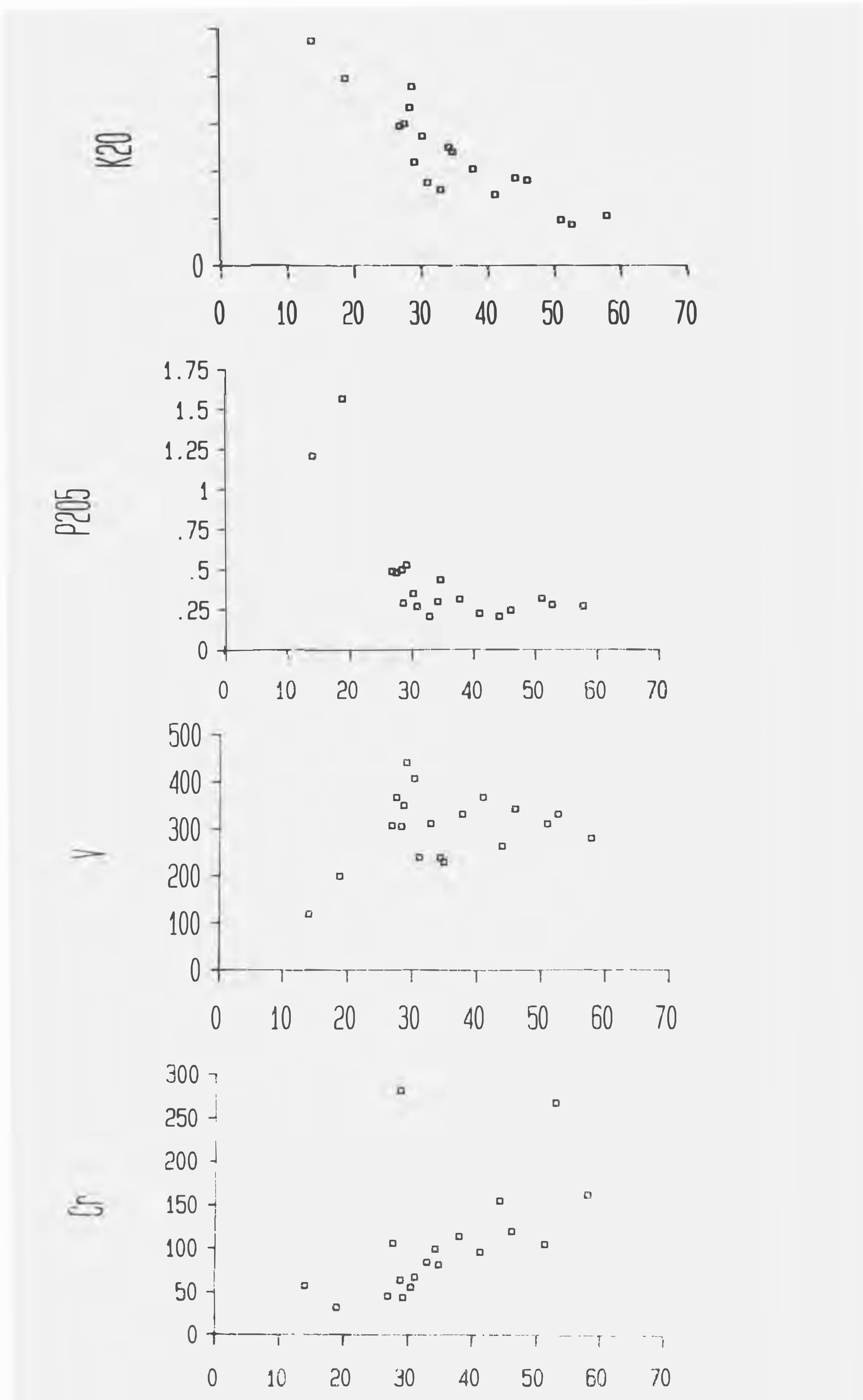
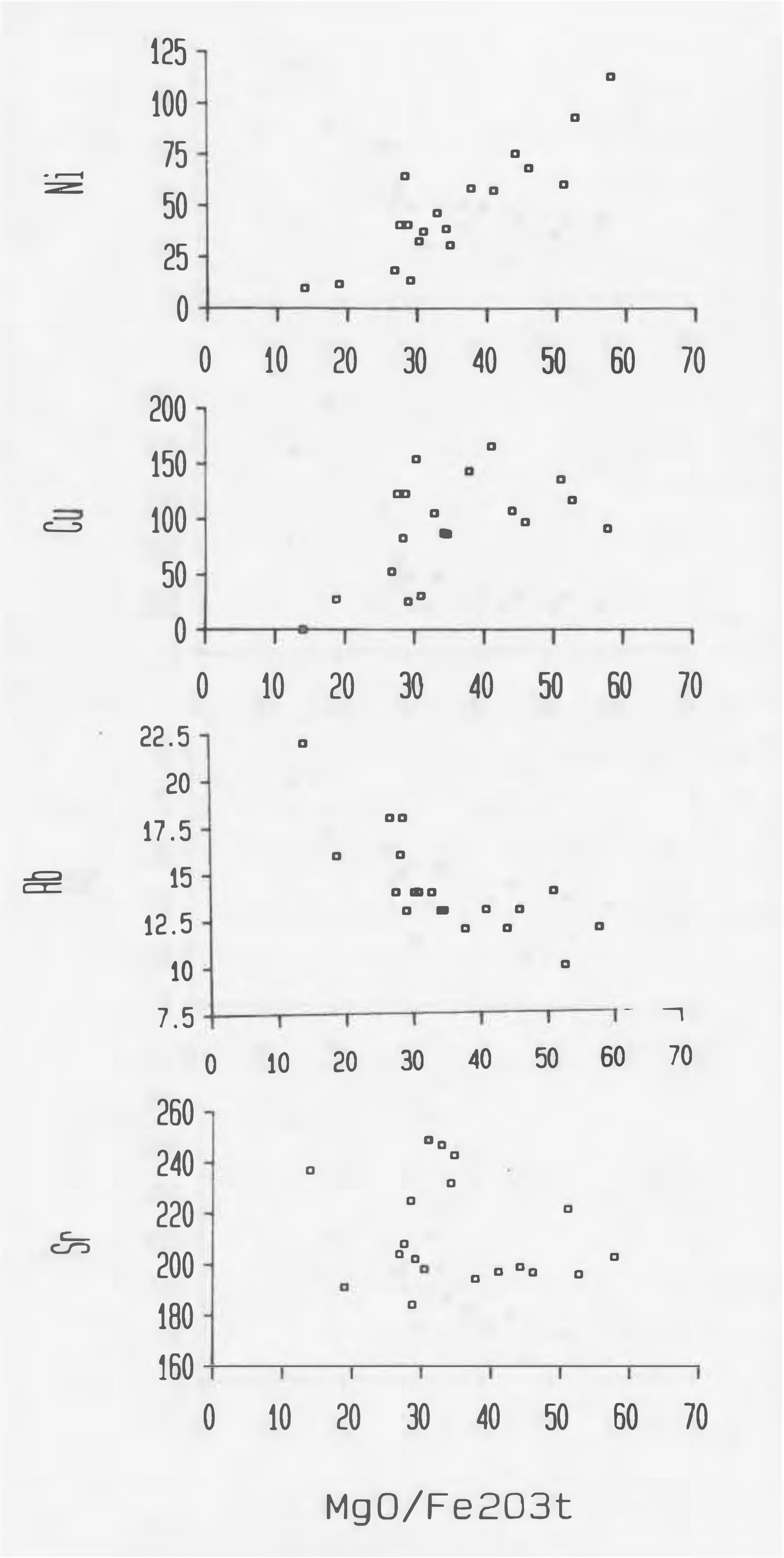


Fig. 7 continued



MgO/Fe2O3t

Fig. 7 continued



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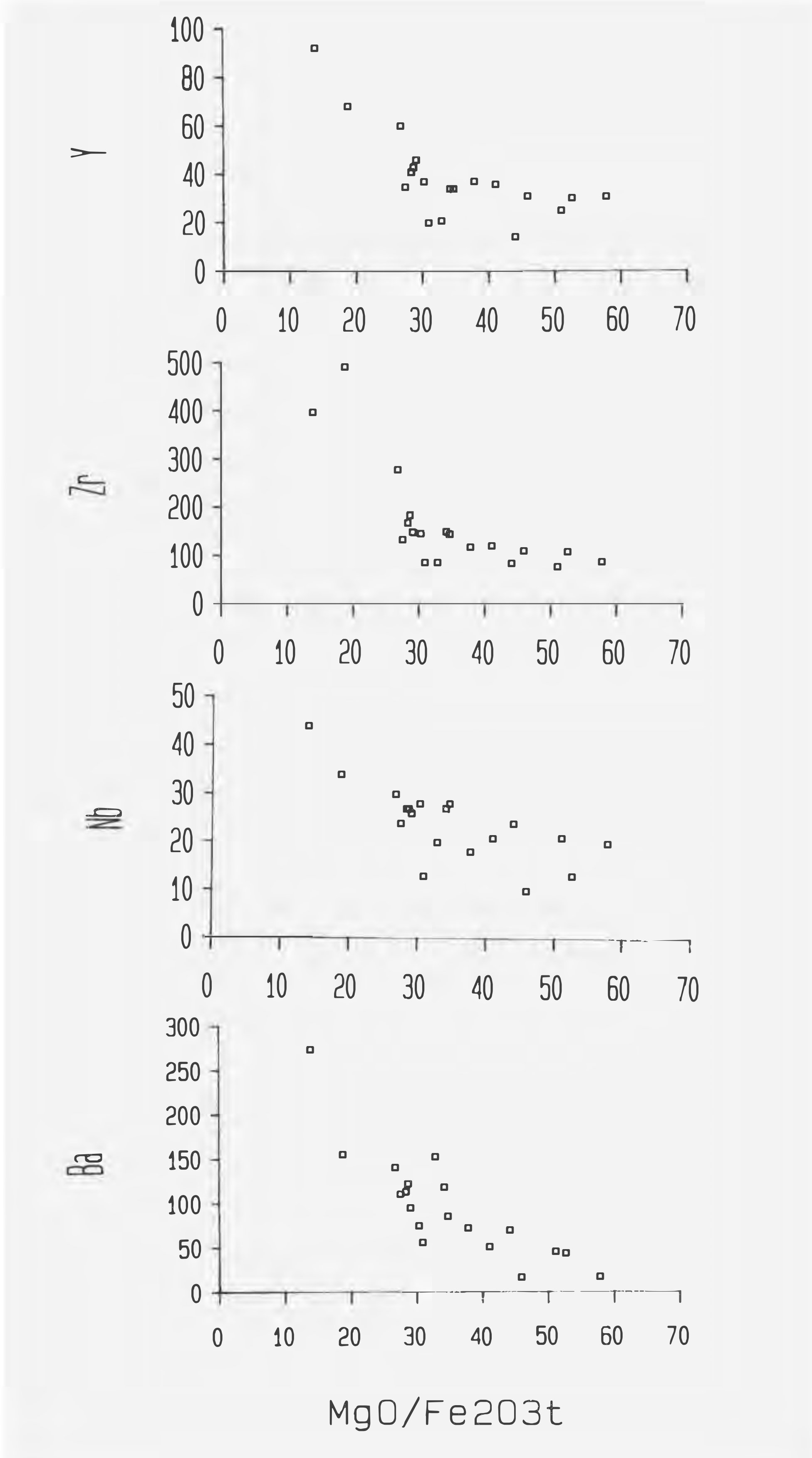

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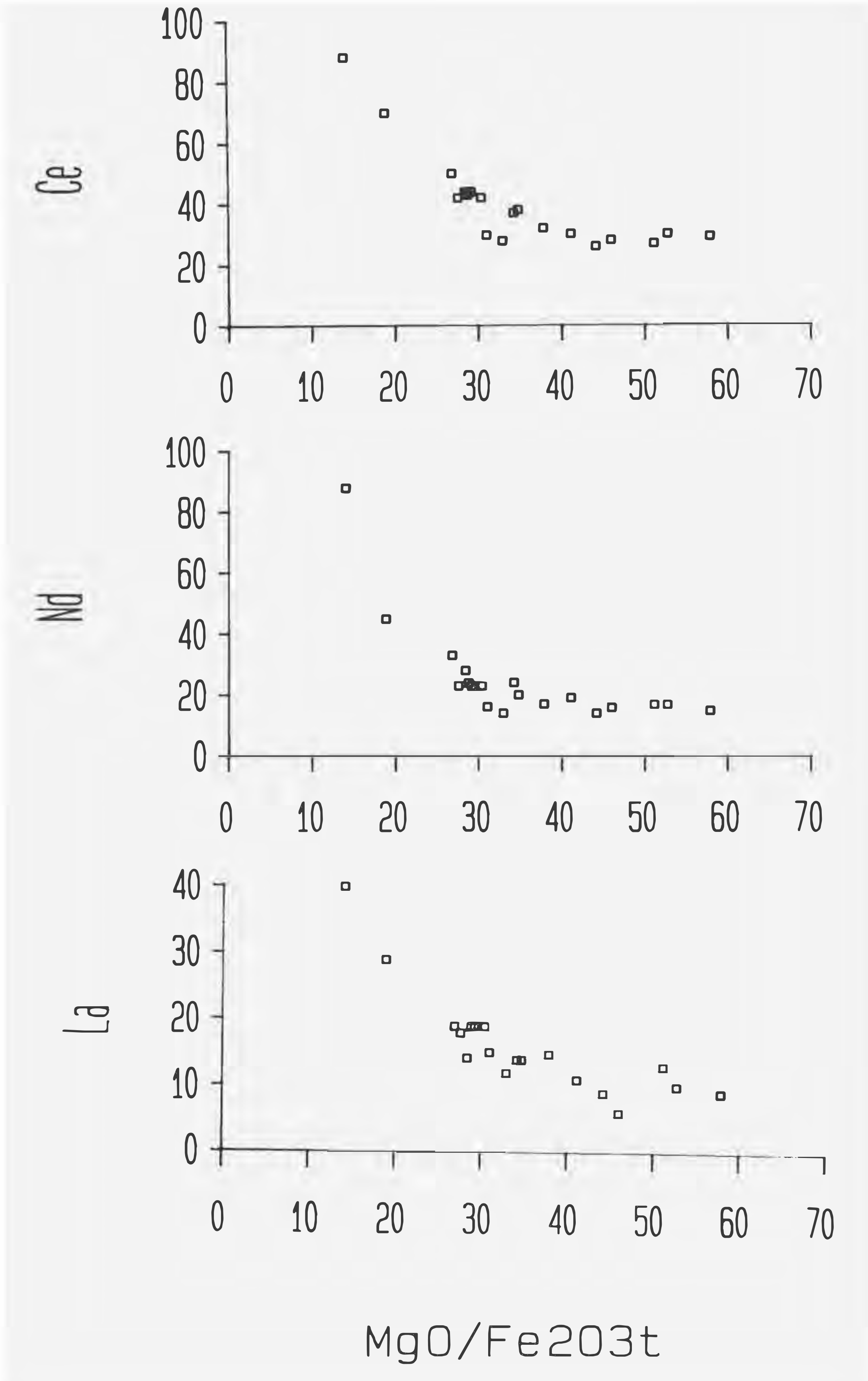


Inclined sheets

The inclined sheets show a greater compositional spread than the regional dykes. The sheets consist mainly of qz-tholeiites, but in Fig. 8 one individual sheet classifies as ol-tholeiite, one as rhyolite and four sheet as Fe-Ti basalts. Of the 45 analysed sheets, 20 are olivine normative, and of these 5 have more than 10% normative olivine. The trends show generally a large scatter, in particular the porphyritic sheets which have a considerably higher Al_2O_3 content than the aphyric sheets. The large scatter indicates that there was a great variation in the composition of the source magma, which by all probability was followed by a very inhomogeneous alteration. There is an increase in CaO, Ni, and V, with increasing MgO/Fe_2O_3t (Fig. 9) and decrease in TiO_2, Na_2O, K_2O, P_2O_5, Rb, Y, Zr, Ce, Ba, Nd, and La. Other elements vary randomly. The inclined sheets show the same increase in incompatible elements and decrease in compatible elements, with evolution as the regional dykes. The most primitive inclined sheets (samples 407, 409, 401, sp413, Table 3) occur at stations 2 and 3 in the eastern part of the caldera. Conversely, the most evolved sheets (samples d41, 416, 417, 128) occur in the central part of caldera. Other sheets show no relationship between composition and location. It is not possible to distinguish chemically between other subgroups of sheets.

Fig. 8 MgO/(MgO+FeOt)* 100 versus TiO_2 for the inclined sheets. Most sheets are qz-tholeiites, but Fe-Ti basalts and rhyolite are also present.

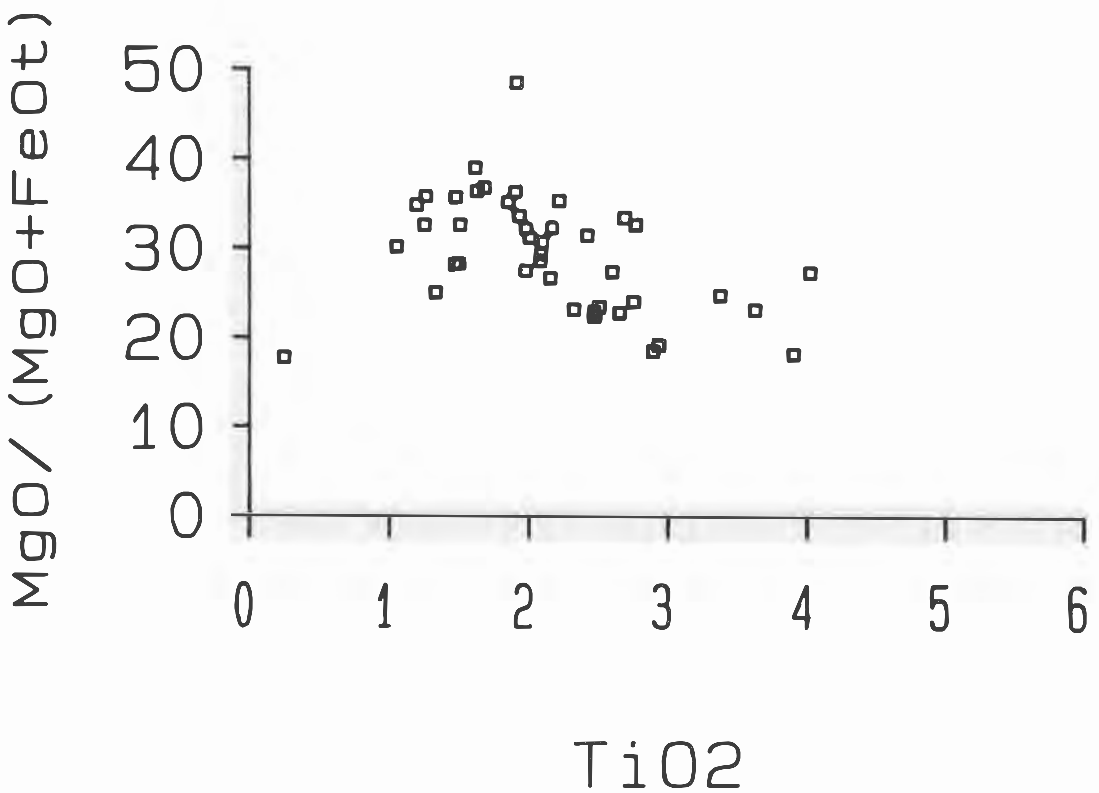
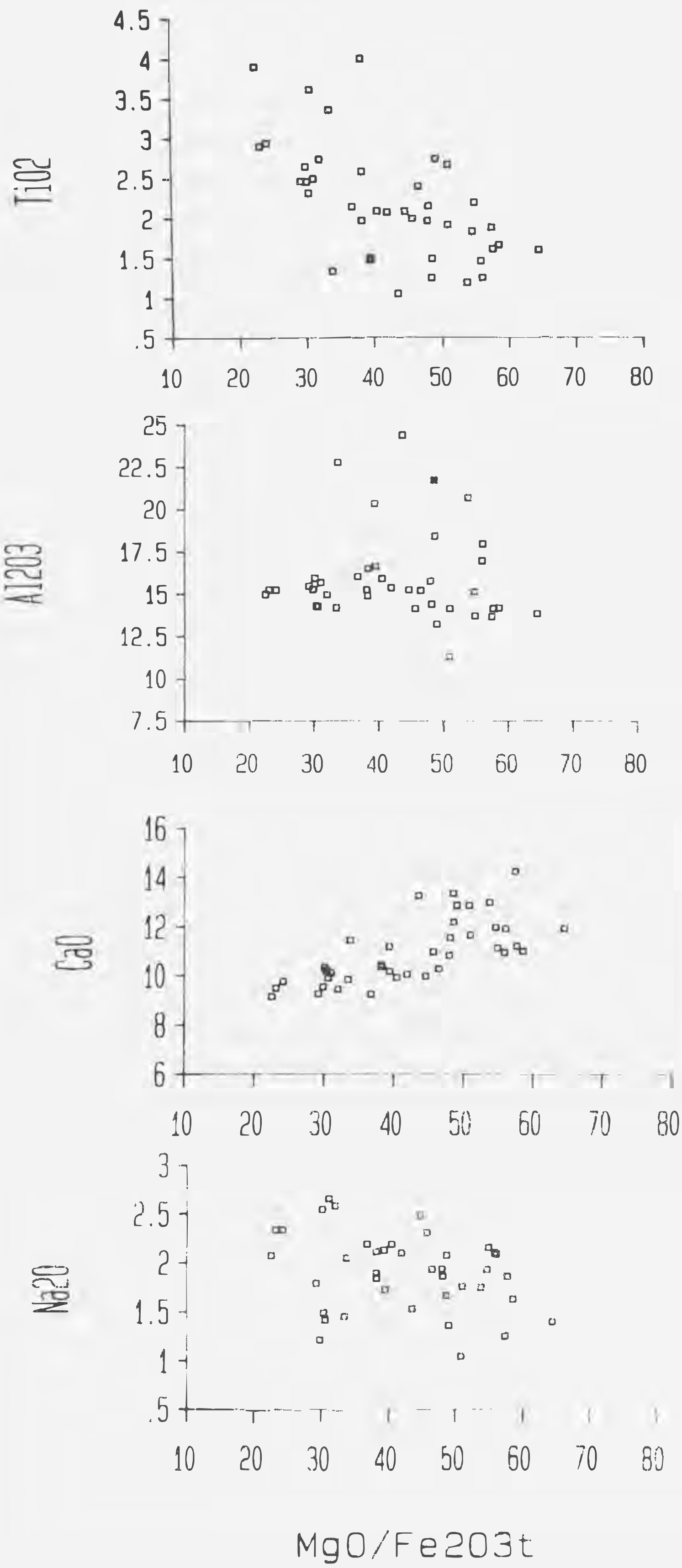


Fig. 9 Composition of the inclined sheets.



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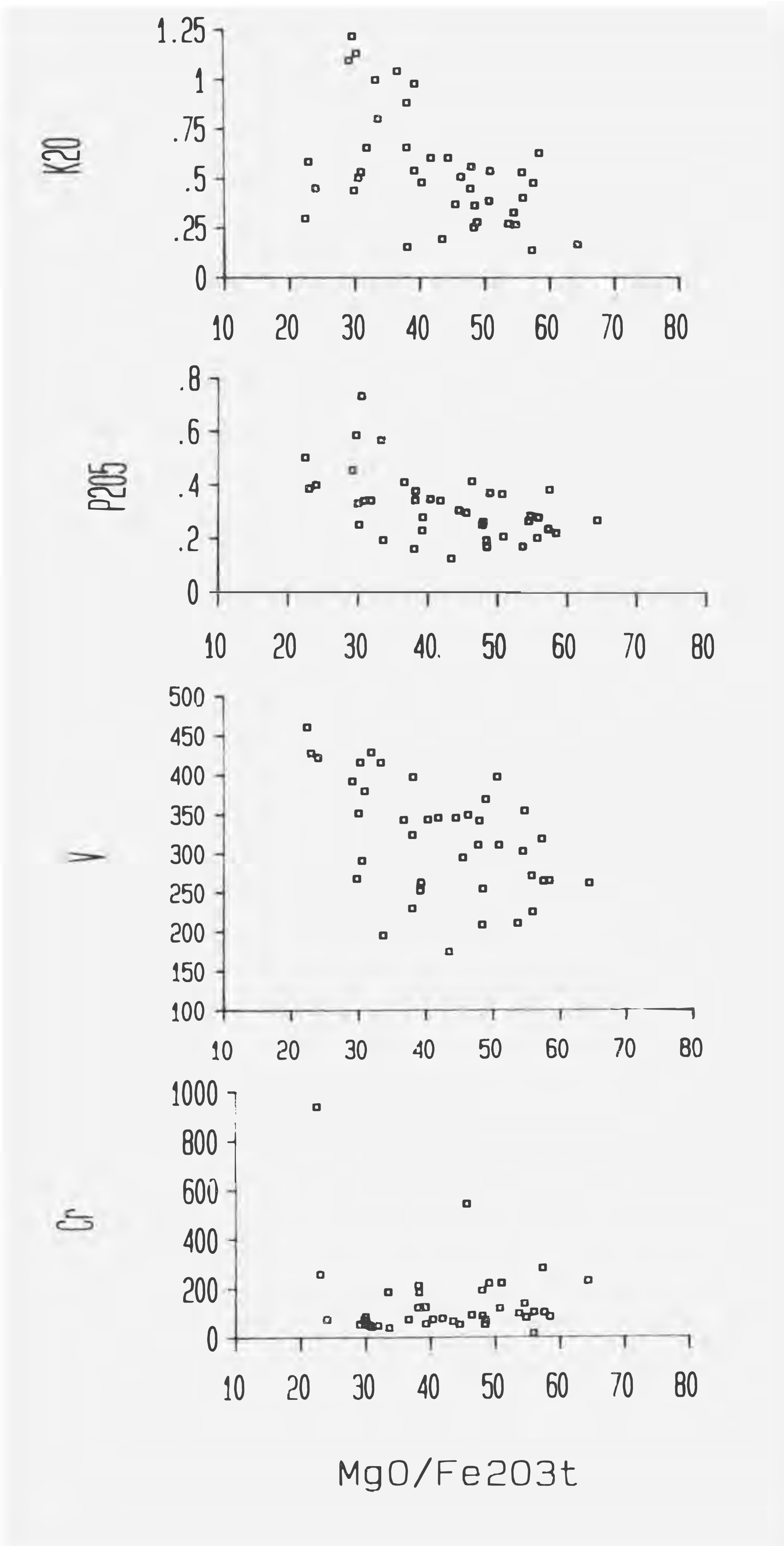

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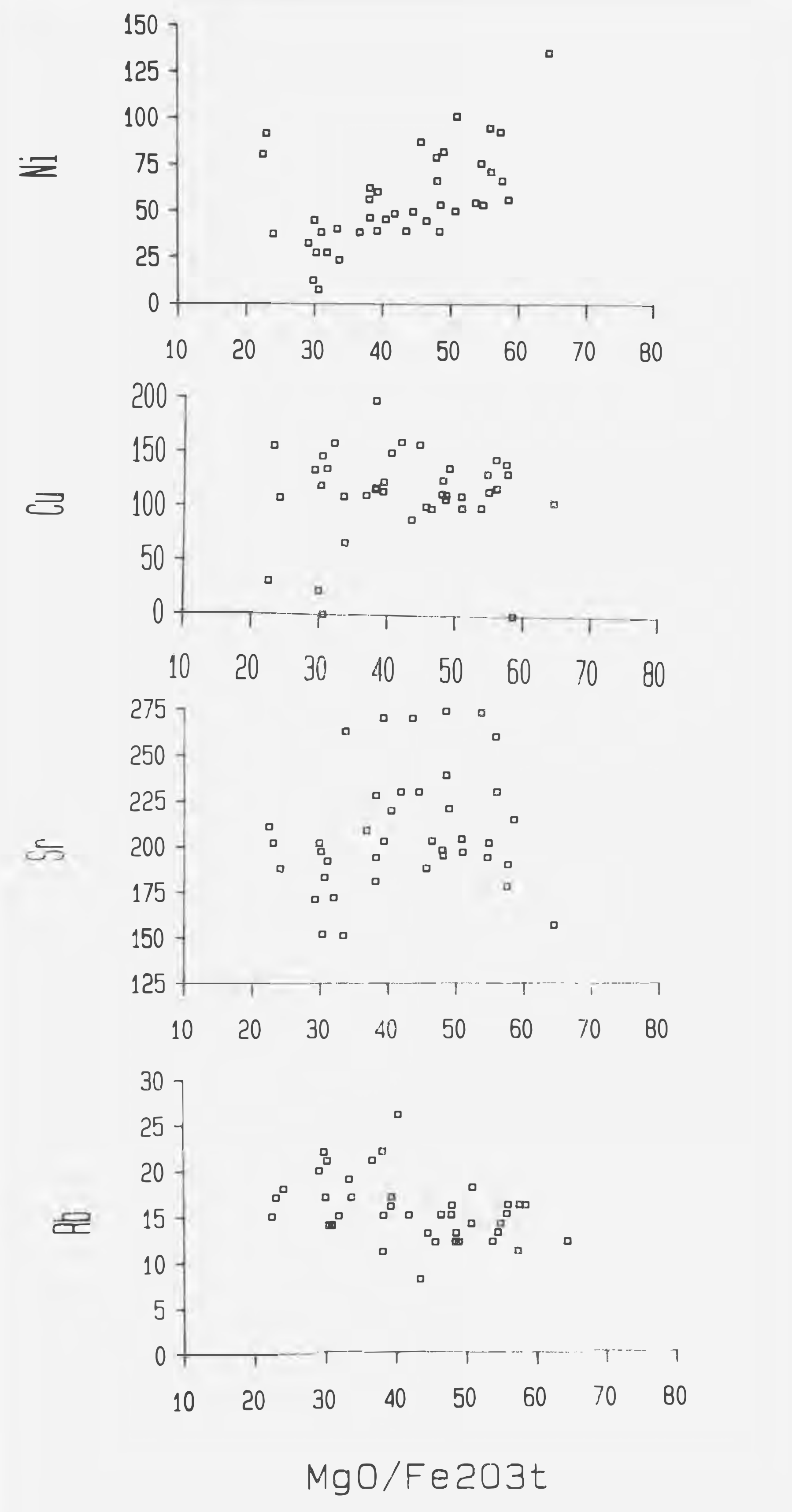

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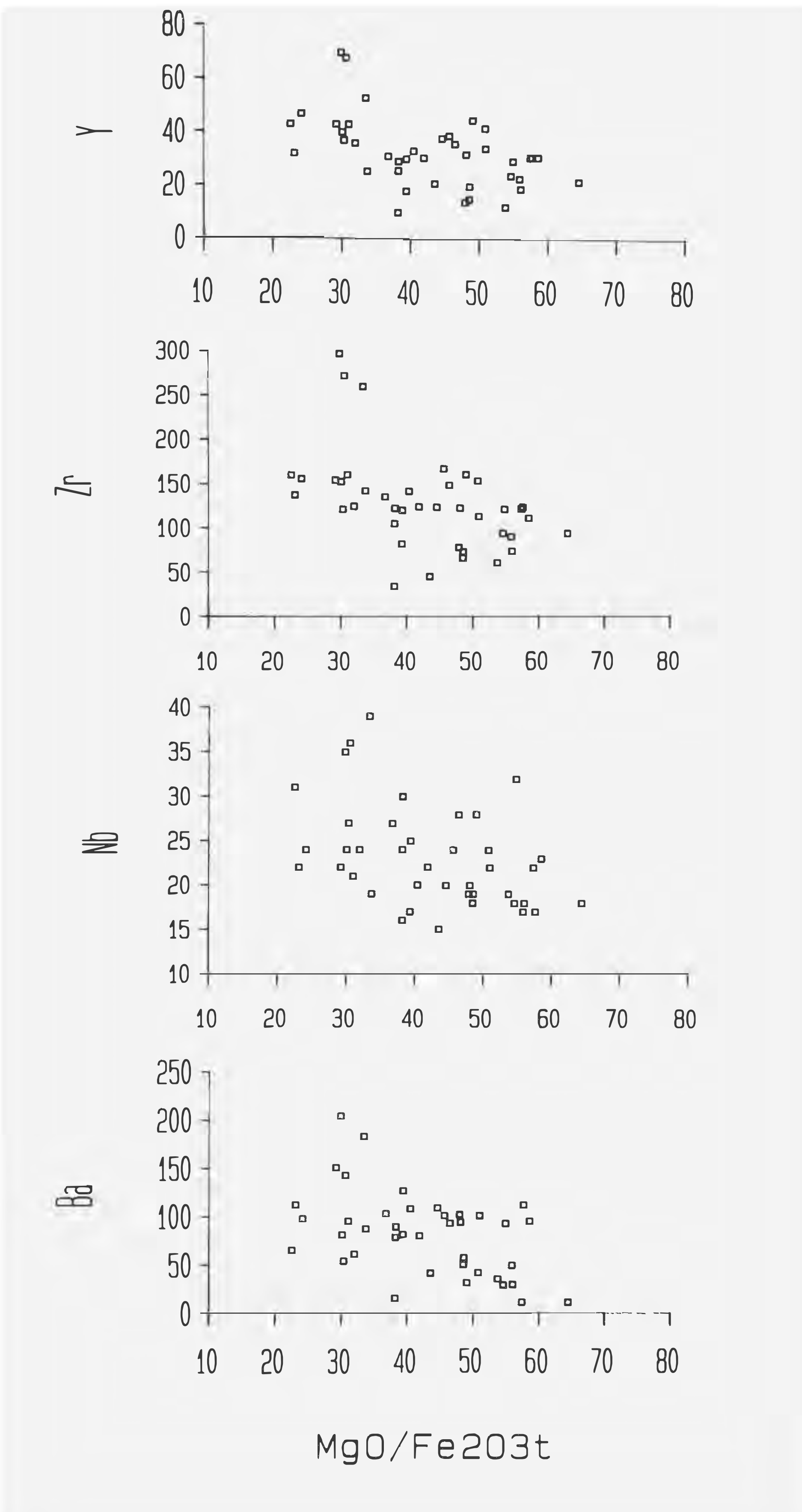

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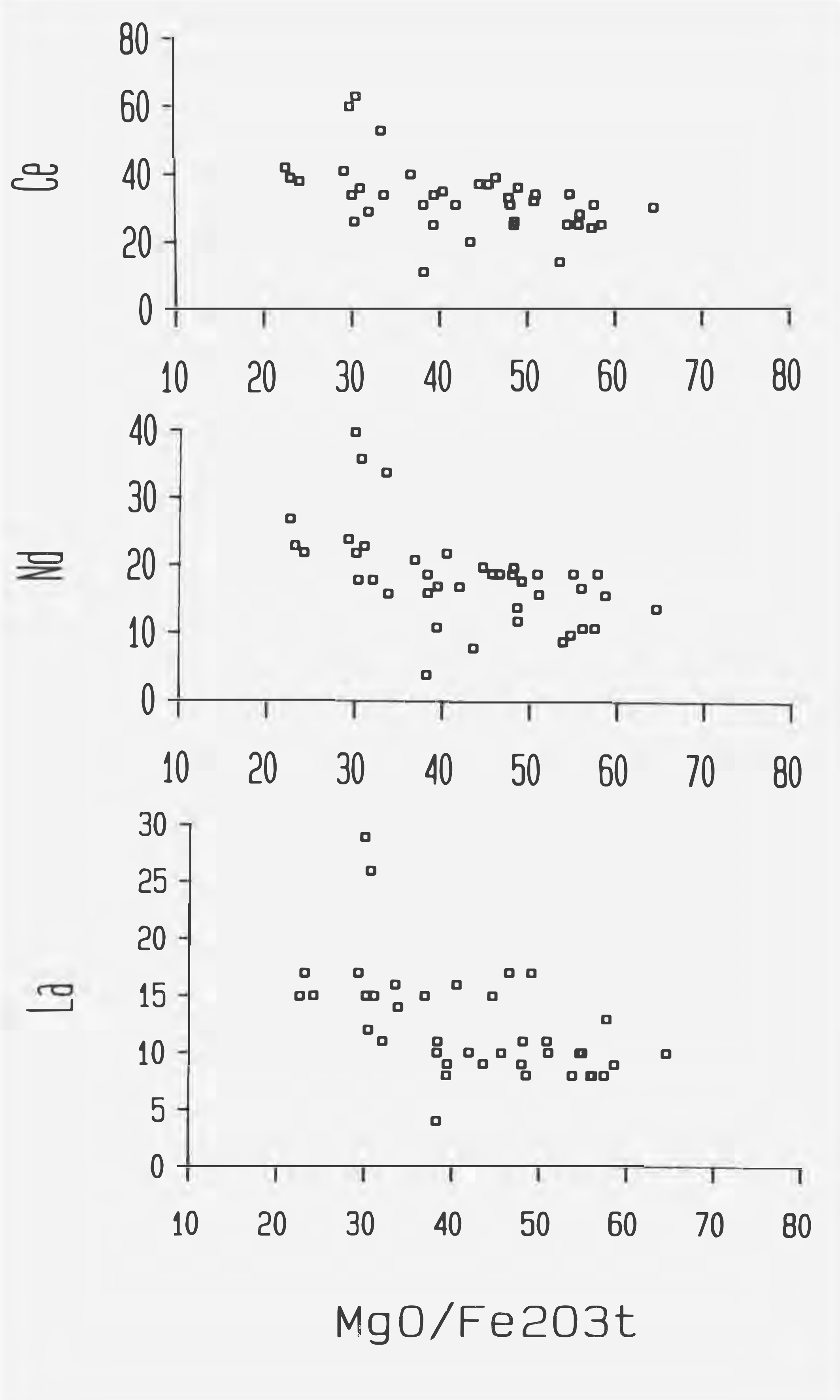

Chemical comparison of regional dykes and inclined sheets.

Inclined sheets and regional dykes show the same chemical trends. The scatter, however, is considerably larger for the inclined sheets, which may partly be related to greater alteration and a larger variation in the sheet source magma. There is no significant chemical difference between the inclined sheets and the regional dykes.

The regional dykes were probably derived from a deep-seated magma reservoir beneath the volcanic system of which the Reykjadalur central volcano was a part. Intuitively one might expect the regional dykes to be more primitive than the inclined sheets, because the latter were mainly derived from a shallow magma chamber which may be expected to contain more evolved magmas. One would thus also expect a greater variability in the chemistry of the inclined sheets because of replenishment in the shallow magma chamber.

There are several possible explanations for the observed lack of chemical difference between dykes and inclined sheets.

1. Some regional dykes may have been laterally injected from the shallow magma chamber.

2. The magma in the deep-seated magma reservoir undergoes fractionation and crustal contamination that may be on the same scale as in the shallow magma chamber so that the composition of magmas in the deepseated reservoir was similar to that of magmas in the shallow magma chamber.

3. The composition of the shallow chamber magmas might also be more diverse due to multiple injections of primary magmas, accompanied by fractionation and crustal contamination. Thus the overall chemical composition of inclined sheets may become indistinguishable from that of the regional dykes.

Isotope and REE analysis are probaly necessary to find any distinct difference between source magmas of the regional dykes and inclined sheets.

SUMMARY AND CONCLUSIONS

This report describes the structure, lithology and chemistry of sheet intrusions of the Reykjadalur central volcano and surrounding areas. Based on lithology and structural differences, the intrusions are divided into regional dykes and inclined sheets. The main results can be summarised as follows: The regional dykes occur as steeply-dipping, relatively thick (3.5 m average) intrusions. They are on average about 1‰ of the total rock. The inclined sheets show larger variation in dip and are, on average, about 1.0 m thick. They occur in two contrasting lithological types, aphyric and porphyritic, respectively. The porphyritic sheets comprise about 30 % of the sheets.

Chemical analyses show that the regional dykes are mainly qz-tholeiities, with some Fe-Ti basalts and basaltic andesites. The compositional variation of the inclined sheets is greater than of the regional dykes. Most are qz-tholeiites but ol-tholeiites and rhyolites are also present.

Comparison of inclined sheets and regional dykes shows that there is no statistically significant difference in the chemistry of inclined sheets and regional dykes.

ACKNOWLEDGEMENTS

The author thanks Haukur Johannesson, Museum of Natural History for introduction to the field area, Magne Tysseland, Department of Geology, University of Bergen, Norway for providing access to XRF facilities and Agust Gudmundsson for helpful comments on the manuscript.

ROCK	LOK	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	V	CR	CO	NI	CU	ZN	RB	SR	Y
D6	B	50.67	1.69	18.01	11.59	.20	3.97	10.53	2.54	.49	.30	239	101	40	39	88	99	13	232	34
D30	B	50.67	2.31	15.29	15.03	.34	2.84	8.35	2.81	.79	1.57	200	32	50	12	28	129	16	191	68
D22	B	48.78	2.67	16.67	14.27	.23	3.94	9.54	2.81	.60	.48	369	107	49	41	124	102	14	108	35
D9	B	49.34	2.36	17.22	13.34	.21	3.80	9.71	2.86	.67	.50	307	283	45	65	83	106	16	225	41
D3	B	50.76	2.19	16.17	14.02	.21	4.04	8.88	2.69	.76	.29	353	63	50	41	124	111	18	184	43
D25	B	48.70	1.62	18.24	11.69	.17	5.17	11.56	2.27	.37	.21	265	156	42	76	108	82	12	199	14
D19	B	48.73	2.24	16.52	13.44	.21	5.09	10.53	2.49	.42	.33	334	115	46	59	144	95	12	194	37
D27a	B	52.42	2.28	14.42	16.22	.42	2.27	6.85	2.82	1.00	1.27	120	57	49	10	0	191	22	237	92
D21	B	50.04	1.78	18.14	12.03	.20	4.19	10.33	2.37	.48	.44	230	83	42	31	87	104	13	243	34
D27b	B	48.17	2.14	15.13	14.11	.20	6.49	10.64	2.51	.36	.25	345	121	51	69	98	91	13	197	31
D29	B	47.75	2.27	15.18	14.50	.23	5.96	11.22	2.34	.30	.23	370	97	51	58	167	102	13	197	36
D14	A	47.60	3.45	15.48	15.97	.28	4.66	8.77	2.82	.44	.53	443	43	55	14	26	128	13	202	46
D11	A	47.62	2.25	15.26	13.99	.20	7.38	10.88	1.96	.18	.29	335	270	49	94	118	95	10	196	30
12a	A	47.86	2.14	16.71	12.94	.23	6.62	11.34	1.64	.20	.33	314	106	44	61	137	88	14	222	25
355	C	47.09	1.87	15.73	14.06	.20	8.14	10.55	1.85	.22	.28	283	164	52	114	92	98	12	203	31
D334	D	47.42	2.05	18.26	12.99	.21	4.28	12.36	1.88	.33	.21	314	85	45	47	106	89	14	247	21
320	D	50.26	2.86	15.68	14.58	.26	3.91	8.45	2.92	.59	.49	309	45	48	19	53	136	18	204	60
334	D	49.33	2.45	15.21	14.91	.24	4.53	9.66	2.79	.54	.34	409	55	53	33	155	115	14	198	37
351	F	49.05	1.59	21.05	10.60	.15	3.29	11.48	2.15	.36	.28	240	67	36	38	31	63	14	249	20
D33	B	48.66	1.98	15.84	13.39	.20	6.42	10.86	1.94	.45	.26	312	190	47	80	113	88	15	198	14
D41	1	48.34	2.94	15.25	16.31	.26	3.94	9.76	2.34	.45	.40	422	72	54	38	108	123	18	188	47
470	2	47.47	2.32	14.30	17.27	.31	5.24	10.21	1.50	1.13	.25	417	56	58	28	147	107	21	152	37
SP406	2	49.99	1.51	16.68	13.23	.20	5.21	10.19	1.73	.98	.28	263	55	46	61	124	80	17	203	31
469	2	49.32	2.09	15.98	13.84	.20	5.60	9.94	2.19	.48	.35	345	73	50	46	151	81	26	220	34
SP468	2	48.16	1.48	17.05	12.38	.19	6.91	10.99	2.10	.54	.21	272	16	45	96	146	111	15	260	23
SP408	2	48.39	2.01	14.14	14.59	.22	6.66	11.01	2.31	.37	.30	296	543	49	88	102	106	12	188	39
sp404	2	47.37	1.21	20.76	9.94	.14	5.34	13.04	1.75	.28	.17	211	97	34	55	100	58	12	273	12
SP465	2	46.88	1.69	14.33	14.73	.22	8.62	11.04	1.63	.63	.23	266	83	43	57	0	75	16	215	30
SP464	2	47.64	1.26	21.82	9.18	.13	4.45	13.41	1.66	.26	.20	209	51	32	40	108	53	12	274	15
SP407	2	46.19	1.93	14.24	15.36	.24	7.83	11.70	1.76	.54	.21	311	223	50	102	100	131	18	197	34
402	2	47.38	2.69	11.35	15.63	.30	7.94	12.91	1.05	.39	.37	398	119	50	51	111	111	14	204	42
409	2	44.44	1.91	13.75	15.09	.23	8.66	14.29	1.25	.14	.24	319	282	49	94	142	117	11	178	30
SP411	4	47.74	1.06	24.47	7.97	.11	3.47	13.32	1.53	.20	.13	174	66	28	40	89	63	8	270	21
SP417	4	47.57	2.47	15.50	16.69	.27	4.87	9.27	1.80	1.10	.46	392	55	55	33	134	117	20	171	43
416	4	48.84	2.65	15.31	15.66	.29	4.68	9.55	1.22	1.22	.59	268	73	47	13	22	143	22	202	70
SP412	4	48.17	1.63	14.30	13.77	.20	7.94	11.25	1.86	.48	.39	265	101	48	67	133	93	16	190	30
388	4	47.44	1.62	13.92	13.99	.20	9.02	11.98	1.40	.17	.28	263	230	50	137	106	82	12	157	22
418	4	47.93	1.51	18.50	11.47	.16	5.57	12.23	2.08	.37	.17	255	69	39	54	112	85	13	239	20
128	4	47.26	3.91	14.98	17.56	.31	3.96	9.14	2.08	.30	.51	461	939	58	81	31	153	15	211	43
401	4	45.95	2.17	14.46	15.47	.24	7.44	11.58	1.86	.56	.27	342	86	52	67	126	119	16	195	32
414	4	45.00	3.37	14.22	18.16	.30	6.07	9.85	1.46	1.00	.57	416	188	57	41	109	165	19	151	53
420	4	48.35	2.09	15.45	14.63	.22	6.13	10.08	2.10	.61	.35	347	80	52	49	161	103	15	230	31
SP413	4	46.77	2.22	13.80	14.91	.23	8.18	11.17	2.16	.27	.29	355	80	52	54	116	155	14	202	29
42[illegible]	4	48.11	2.10	15.32	14.43	.22	6.43	9.99	2.48	.61	.31	346	53	53	50	159	101	13	230	38
SP458	6	46.71	2.75	14.99	16.86	.26	5.39	9.45	2.59	.66	.34	429	50	60	28	159	159	15	172	36
SP463	6	48.59	1.27	18.05	11.03	.15	6.18	11.96	2.09	.41	.28	226	103	39	72	119	66	16	230	19
461	6	48.19	1.98	16.54	14.14	.19	5.40	10.41	1.90	.89	.35	324	122	50	57	117	92	22	228	26
sp457	6	46.73	2.60	14.96	16.07	.23	6.15	10.38	1.85	.66	.38	398	183	52	63	118	124	15	194	30
sp462	6	48.61	1.48	20.37	10.95	.16	4.31	11.22	2.13	.54	.23	253	125	37	40	115	80	16	270	18
SP460	6	48.62	2.15	16.09	14.63	.23	5.38	9.25	2.20	1.05	.41	344	72	50	39	111	127	21	209	32
SP456	6	48.63	2.42	15.25	13.73	.44	6.38	10.30	1.93	.51	.42	350	91	44	45	100	153	15	203	36
185	6	43.27	4.02	15.31	17.58	.23	6.71	10.45	2.12	.16	.17	230	210	62	47	199	105	11	181	10
249	6	46.59	3.62	14.28	17.35	.27	5.31	9.92	1.42	.51	.74	291	52	52	8	0	176	14	183	68
423	7	48.51	1.85	15.22	12.73	.18	6.95	12.01	1.93	.33	.27	303	137	46	77	132	80	13	194	24
429	7	48.35	2.90	15.27	16.54	.31	3.82	9.49	2.35	.59	.39	428	257	55	92	156	114	17	202	32
SP421	7	49.93	1.34	22.82	8.43	.12	2.84	11.47	2.06	.81	.20	195	38	29	24	67	62	17	263	26
444	7	48.54	2.51	15.71	14.74	.26	4.57	10.13	2.66	.53	.34	380	46	51	39	135	112	14	192	43
445	7	45.99	2.76	13.28	15.30	.23	7.50	12.91	1.36	.28	.38	370	219	49	83	137	135	12	221	45
347	F	49.22	2.47	15.99	14.17	.23	4.26	10.34	2.55	.44	.33	352	86	49	46	119	114	17	197	40
390	3	48.61	1.91	11.83	12.90	.17	12.24	10.20	1.36	.50	.29	242	857	47	316	75	90	11	223	21
RD1		73.39	.25	13.63	3.75	.06	.81	1.24	3.92	2.89	.04	28	23	10	8	29	129	38	55	168

Table 3 Chemical composition of sheets and dykes.

ROCK	ZR	NB	BA	Ce	Nd	La	MgFe
D6	151	27	118	37	24	14	34.24
D30	493	34	155	70	45	29	18.88
D22	134	24	110	42	23	18	27.59
D9	169	27	113	44	28	14	28.44
D3	185	27	122	43	24	19	28.78
D25	84	24	69	26	14	9	44.18
D19	119	18	72	32	17	15	37.86
D27a	397	44	273	88	88	40	14.02
D21	146	28	85	38	20	14	34.80
D27b	112	10	16	28	16	6	46.02
D29	121	21	51	30	19	11	41.10
D14	151	26	94	44	23	19	29.20
D11	109	13	43	30	17	10	52.72
12a	78	21	45	27	17	13	51.12
355	88	20	17	29	15	9	57.90
D334	87	20	152	28	14	12	32.94
320	279	30	140	50	33	19	26.85
334	148	28	74	42	23	19	30.39
351	87	13	55	30	16	15	31.02
D33	78	19	102	33	19	9	47.93
D41	156	24	98	38	22	15	24.15
470	121	27	54	26	18	12	30.34
SP406	120	25	127	34	17	9	39.40
469	141	20	108	35	22	16	40.44
SP468	90	17	49	25	17	8	55.87
SP408	167	24	101	37	19	10	45.63
sp404	61	19	35	14	9	8	53.75
SP465	111	23	95	25	16	9	58.53
SP464	66	18	50	25	14	8	48.50
SP407	113	22	101	34	16	10	50.97
402	153	24	42	32	19	11	5[illegible].81
409	121	22	11	24	11	6	57.40
SP411	45	15	41	20	8	9	43.55
SP417	154	22	151	41	24	17	29.20
416	297	35	204	60	40	29	29.87
SP412	123	17	112	31	19	13	57.64
388	94	18	11	30	14	10	64.45
418	73	19	57	26	12	8	48.58
128	160	31	65	42	27	15	22.55
401	122	20	94	31	20	11	48.07
414	260	39	183	53	34	16	33.41
420	124	22	80	31	17	10	41.92
SP413	120	32	93	34	19	10	54.87
420	123	20	109	37	20	15	44.57
SP458	124	24	61	29	18	11	31.97
SP463	74	18	29	28	11	8	56.03
461	105	24	78	31	19	10	38.19
sp457	122	30	89	31	16	11	38.25
sp462	82	17	81	25	11	8	39.33
SP460	135	27	103	40	21	15	36.76
SP456	148	28	93	39	19	17	46.46
185	34	16	15	11	4	4	38.15
249	272	36	143	63	36	26	30.58
423	94	18	29	25	10	10	54.60
429	137	22	112	39	23	17	23.12
SP421	142	19	87	34	16	14	33.72
444	160	21	95	36	23	15	31.01
445	160	28	31	36	18	17	49.01
347	152	24	81	34	22	15	30.09
390	143	24	68	38	18	17	94.83
RD1	529	68	456	145	78	79	21.74

Table 3 continued

Rock	Q	C	Or	Ab	An	Mg-di	Fe-di	En	Fs	Fo	Fa	Mt	Il	Ap
D6	3.71	0	2.95	21.75	36.65	5.62	6.20	7.38	9.33	0	0	4.67	3.25	.71
D30	7.20	0	4.67	23.78	26.80	1.25	2.50	6.49	14.85	0	0	6.00	4.39	3.72
D22	1.42	0	3.55	23.61	30.86	4.77	6.11	7.52	11.05	0	0	5.65	5.03	1.14
D9	1.63	0	3.96	24.20	32.22	4.71	5.95	7.28	10.53	0	0	5.33	4.48	1.18
D3	3.91	0	4.49	22.85	29.89	4.55	5.85	7.97	11.76	0	0	5.61	4.18	.69
D25	.22	0	2.19	19.29	38.77	7.82	6.73	9.32	9.20	0	0	4.69	3.10	.50
D19	.76	0	2.42	20.56	31.81	7.19	6.92	9.02	9.96	0	0	5.22	4.14	.76
D27a	9.46	0	5.61	22.68	22.55	.42	1.16	5.18	16.39	0	0	6.14	4.12	2.87
D21	3.76	0	2.84	20.14	37.56	4.39	4.74	8.42	10.44	0	0	4.81	3.40	1.04
D27b	0	0	2.13	21.15	28.86	10.08	8.16	8.28	7.68	2.22	2.27	5.61	4.05	.59
D33	1.08	0	2.60	15.99	32.29	8.56	6.70	11.59	10.41	0	0	5.20	3.67	.59
D29	0	0	1.77	19.55	29.67	10.38	9.37	7.86	8.14	1.40	1.59	5.71	4.25	.54
D14	.80	0	2.60	23.94	28.37	4.58	5.29	9.53	12.63	0	0	6.39	6.57	1.26
D11	0	0	1.00	15.91	31.03	9.16	6.38	12.68	10.13	.49	.43	5.35	4.10	.66
12a	1.68	0	1.12	13.37	36.39	7.59	5.44	12.39	10.19	0	0	4.98	3.93	.76
D41	3.11	0	2.60	19.29	28.93	5.30	7.84	7.08	12.00	0	0	6.32	5.43	.92
470	1.08	0	6.32	11.93	27.29	6.99	8.86	9.06	13.18	0	0	6.49	4.16	.57
SP406	3.41	0	5.55	13.96	33.31	5.50	5.51	9.85	11.32	0	0	5.04	2.73	.64
469	2.49	0	2.84	18.36	32.01	6.26	5.78	10.89	11.52	0	0	5.46	3.93	.83
SP468	0	0	3.07	17.26	34.46	8.27	5.79	9.09	7.30	2.65	2.35	4.79	2.73	.47
SP408	0	0	2.07	18.28	25.31	10.76	8.99	8.93	8.56	1.10	1.16	5.43	3.57	.66
sp404	0	0	1.60	14.47	47.00	7.26	5.27	7.76	6.46	1.32	1.21	3.88	2.24	.40
SP465	0	0	3.49	12.86	27.86	10.67	7.19	8.37	6.47	4.68	3.99	5.47	2.98	.50
SP464	.64	0	1.54	14.30	52.11	6.54	5.13	8.22	7.40	0	0	3.72	2.43	.47
SP407	0	0	2.90	13.45	26.56	11.54	8.79	4.82	4.21	5.23	5.04	5.54	3.32	.45
402	1.73	0	2.19	8.38	23.77	16.53	11.84	11.03	9.06	0	0	5.89	4.82	.83
409	0	0	.77	9.73	28.89	17.02	11.50	.94	.72	7.69	6.56	5.52	3.32	.52
SP411	2.03	0	1.18	13.11	59.93	2.64	2.32	7.52	7.59	0	0	3.21	2.03	.31
SP417	1.41	0	6.09	14.30	29.05	4.13	5.31	9.47	13.96	0	0	6.24	4.41	1.02
416	5.80	0	6.74	9.65	30.53	3.81	4.66	9.11	12.77	0	0	5.83	4.71	1.30
SP412	0	0	2.72	15.06	27.90	11.22	7.62	11.29	8.80	1.67	1.43	5.24	2.96	.88
388	0	0	.95	11.17	29.48	12.69	7.74	13.02	9.11	1.62	1.25	5.27	2.91	.62
418	0	0	2.13	17.26	39.33	8.79	6.95	7.38	6.69	1.52	1.52	4.49	2.81	.40
128	4.63	0	1.71	17.09	29.72	3.75	5.54	7.82	13.28	0	0	6.79	7.20	1.16
401	0	0	3.13	14.81	27.66	11.39	9.00	4.40	3.99	5.41	5.41	5.80	3.87	.59
390	0	0	2.78	10.83	23.34	13.13	5.17	18.99	8.59	2.58	1.29	4.86	3.42	.64
414	0	0	5.50	11.42	27.18	5.94	6.30	9.99	12.15	.89	1.20	6.72	5.94	1.26
420	.45	0	3.43	17.01	29.54	7.00	6.31	11.34	11.73	0	0	5.57	3.80	.78
SP413	0	0	1.54	17.60	26.21	12.38	8.46	6.43	5.04	5.24	4.52	5.73	4.06	.66
420	0	0	3.49	20.39	28.01	8.13	6.87	8.38	8.11	2.38	2.54	5.58	3.87	.71
SP458	0	0	3.72	20.98	26.24	6.44	7.38	5.94	7.81	2.77	4.01	6.45	5.01	.78
SP463	0	0	2.36	17.43	38.11	8.95	6.28	9.52	7.66	1.05	.93	4.33	2.37	.66
461	.70	0	5.14	15.74	33.28	6.28	6.23	10.26	11.67	0	0	5.52	3.68	.81
sp457	0	0	3.78	15.15	29.64	7.57	7.25	10.36	11.39	.68	.82	6.21	4.79	.88
sp462	.97	0	3.13	17.68	43.51	4.00	3.89	8.65	9.65	0	0	4.28	2.75	.54
SP460	.65	0	5.97	17.94	29.88	4.86	4.97	10.67	12.51	0	0	5.63	3.95	.95
SP456	2.03	0	2.95	15.99	30.69	7.59	6.05	11.99	10.96	0	0	5.35	4.48	.97
185	0	0	.89	17.35	30.76	8.17	7.00	3.22	3.16	6.42	6.95	6.78	7.39	.38
249	4.27	0	2.84	11.42	29.52	4.99	5.55	10.24	13.07	0	0	6.57	6.53	1.66
355	0	0	1.24	15.31	33.17	7.98	5.28	12.15	9.22	2.77	2.31	5.47	3.48	.64
423	.03	0	1.95	16.33	31.81	12.60	8.67	11.44	9.03	0	0	5.07	3.51	.64
429	2.87	0	3.31	18.95	28.07	4.75	7.44	6.88	12.36	0	0	6.30	5.26	.88
SP421	3.73	0	4.85	17.68	51.50	2.01	2.19	6.26	7.85	0	0	3.42	2.58	.47
444	.52	0	3.13	22.34	29.15	7.13	8.37	8.00	10.77	0	0	5.84	4.73	.81
445	0	0	1.60	11.00	27.97	14.69	10.68	9.26	7.72	1.23	1.13	5.83	5.01	.85
D334	.90	0	1.89	15.57	39.58	7.49	8.42	6.96	8.97	0	0	5.07	3.82	.50
320	4.15	0	3.49	24.71	27.88	3.93	5.11	7.91	11.79	0	0	5.81	5.43	1.16
334	1.45	0	3.25	24.03	27.92	7.08	8.53	8.22	11.36	0	0	6.06	4.75	.83
351	3.07	0	2.07	17.77	45.75	3.13	3.77	6.57	9.07	0	0	4.14	2.96	.64
347	2.40	0	2.60	21.41	30.65	6.88	8.25	7.34	10.09	0	0	5.61	4.65	.78
RD1	33.09	1.86	16.78	32.58	5.79	0	0	1.99	4.44	0	0	1.47	.47	.09

Table 4 Normative composition of sheets and dykes calculated with fixed Fe_2O_3/FeO ratio of 0.15