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The simultaneous production of basalts, enriched and depleted in large lithophilic trace ions (LIL), within the same fissure swarms in Iceland

by G. E. SIGVALDASON *, S. STEINTHORSSON **, N. OSKARSSON * and P. IMSLAND *

Abstract. — The active tholeiitic volcanic zones of Iceland are composed of parallel or en echelon arranged fissure swarms. The volcanic productivity of the fissure swarms increases inland. Within each fissure swarm basalts are produced which range from low potassium, abyssal type tholeiites, strongly depleted in light rare earths and large lithophilic trace elements to basalts enriched in these components. The width of the chemical spectrum within each fissure swarm increases inland. All basalt types have been produced within postglacial times (10 000 years).

The close relationship in space and time between LIL « depleted » and LIL « enriched » basalts is difficult to explain on the basis of current models assuming two laterally distinct mantle sources.

Éruption simultanée à partir des mêmes essaims de fissures en Islande de basaltes enrichis et appauvris en ions traces lithophiles de grande taille (LIL)

Résumé. — Les zones d'activité volcanique tholéitique en Islande comprennent des essaims de fissures parallèles ou en échelon. La productivité volcanique des essaims de fissures augmente vers l'intérieur de l'île. Dans chaque essaim de fissures, les éruptions produisent des basaltes allant de tholéites de type abyssal à faible teneur en potassium, fortement appauvries en terres rares légères et en éléments traces lithophiles de grande taille à des basaltes enrichis en ces mêmes éléments. La largeur du spectre chimique dans chaque essaim de fissures augmente vers l'intérieur de l'île. Tous les types de basaltes ont été produits durant les temps postglaciaires (10 000 ans). La relation spatio-temporelle étroite entre les basaltes enrichis et appauvris en LIL est difficile à expliquer sur la base des modèles existant qui supposent l'existence de deux sources mantéliques distinctes.

Introduction.

The active tholeiitic volcanic zones in Iceland (fig. 1) are composed of fissure swarms arranged parallel or en echelon with an aggregate width of 50 to 70 km. To the south the volcanic zone is a direct continuation to the submarine Reykjanes Ridge, but to the north the volcanic zone and the submarine Kolbeinsey Ridge are offset by the Tjörnes Fracture Zone. By definition the borders of the volcanic zone are placed at the first appearance of lavas older than the last magnetic reserval (700 000 years).

Subglacial eruptions along fissure swarms have produced marked ridge like structures. Volcanic production, expressed both in frequent eruptions and occasional large volume eruptions, increases inland along the volcanic zones [Jakobsson, 1972]. In central and north Iceland Sigvaldason [1974 *a*] has reported a systematic relation between chemistry and volume of lava. Occasionally highly productive fissure swarms may develop into volcanic centers producing basalts, icelandites and dacites or rhyodacites. The characteristic lava type produced is tholeiitic basalt. Silicic products are minor or absent at either end of the tholeiitic volcanic zones correlating with smaller volcanic productivity in these areas. The silicic rocks have been interpreted as a result of fractional crystallization from a basaltic parent [Carmichael, 1964], but remelting of the basaltic substratum due to high geothermal gradient in zones of intense dyke intrusions is an alternative possibility [Sigvaldason, 1974 *b*; Gronvold, this volume].

Systematic variations in the chemistry of tholeiitic basalts along the volcanic zones have been

* Nordic Volcanological Institute, Reykjavik, Iceland.
** Science Institute, Univ. of Iceland, Reykjavik, Iceland
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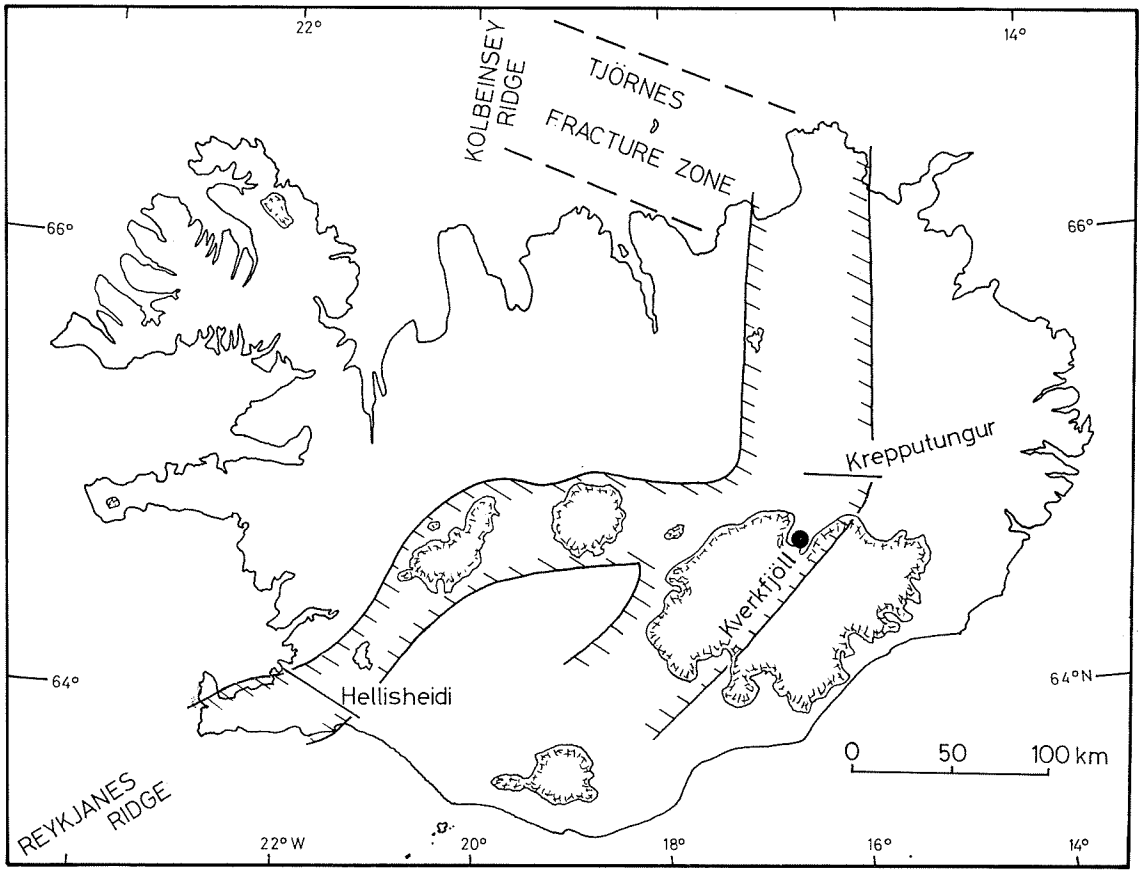

FIG. 1. — Map of Iceland showing the position of the zone of Recent tholeiitic volcanism. Profiles of figures 3 and 4 are indicated.

reported by Sigvaldason *et al.* [1974] and Sigvaldason and Steinthorsson [1974]. In the present communication we describe variations observed within individual fissure swarms.

VOLCANIC HISTORY.

The postglacial (10,000 years) volcanic history of Iceland is relatively well known [see for example Björnsson, 1967]. During this period volcanic eruptions have produced all significant types of rocks which are observed in the entire exposed stratigraphic pile of Iceland (13-16 m.y.). Thus the last eruptions producing abyssal type tholeiite basalts occurred some 1,000 years ago, rhyodacitic lavas and tephras have been produced in abundance in the last 1,000 years and tholeiites high in potassium and other large lithophilic trace ions are common products of eruptions in this century [e.g. Askja, 1961 ; Leirhnukur, 1975]. Such high potassium tholeiites are the products of frequent eruptions which generally last for a short period (few weeks or months) and are small in volume (less than 1 km³). Large volume (1-10 km³) eruptions of abyssal type tholeiites are less frequent and few have been witnessed in historic times.

The time interval required to produce all significant volcanic rock types in Iceland is so short that the sources for the different magmas appear to be continuously available.

SECULAR AND SPATIAL RELATIONS WITHIN INDIVIDUAL FISSURE SWARMS.

What has been said about the volcanic zones as a whole applies with some restriction to individual fissure swarms.

A feature common to all fissure swarms along the tholeiitic volcanic zones is the production of abyssal type tholeiites. These low potassium tholeiites have REE distribution pattern, isotope ratios and concentrations of large lithophilic ions identical to characteristic ocean rift basalts dredged from abyssal depths (Tabl. I). The source for such basalts is present all

	NAL 16	NAL 18	KAL 10
SiO_2	49.43	47.86	50.25
Al_2O_3	16.64	15.36	13.10
TiO_2	0.72	1.68	2.79
Fe_2O_3	1.33	2.27	3.26
FeO	7.90	9.27	11.01
MnO	0.14	0.17	0.30
MgO	8.46	8.15	4.88
CaO	14.30	11.48	9.14
Na_2O	1.98	2.20	2.84
K_2O	0.06	0.36	0.64
P_2O_5	0.04	0.12	0.30
H_2O	0.18	0.36	0.88
Sr	105	210	205
Rb	4	4	14.5
Zr	59	103	205
Y	16	19	21.5
Zn	50	83	n. d.
Cu	59	49	—
V	253	250	—
Ni	133	185	—
Cr	'585	565	—
Ce_{N/Yb_N}	0.66	2.24	3.51

TABL. I. — Basalts from the fissure swarm at Krepputungur. Sample locations are indicated in figure 1 and figure 4. Analyses NAL 16 and NAL 18 from Sigvaldason [1974 *a*], KAL 10 is an unpublished analyses by Albertson and Oskarsson. The analyses of Ce and Yb were provided by P. Potts, Open University. N. d. not determined.

along the Icelandic tholeiite zones. In addition each fissure swarm produces basalts higher in potassium and other large lithophilic ions and with increasing relative concentration of light rare earth elements. In any single fissure swarm the compositional spectrum from low potassium abyssal type tholeiite to tholeiites relatively enriched in large lighophilic elements is continuous. The width of the compositional spectrum is fixed for an individual fissure swarm and depends on the location of the swarm. The compositional sprectrum is narrow at either end of the volcanic zones but widens towards the center of Iceland (fig. 2).

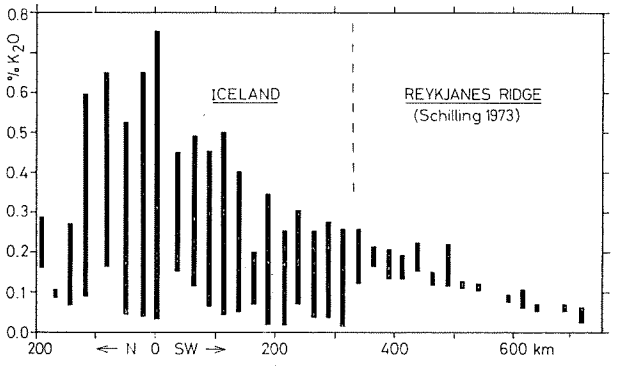

FIG. 2. — Range of K_2O values in tholeiitic basalts plotted against distance from Central Iceland (Kverkfjöll).

In figures 3 and 4 we have plotted potassium values against location of eruptive vent across

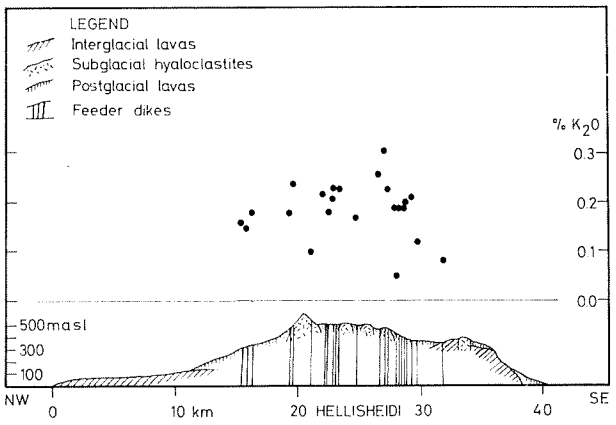

FIG. 3. — A schematic profile across a fissure swarm in SW-Iceland, showing height above sea level and K_2O content of individual lavas.

two fissure swarms, one at the southern end of the volcanic zones, and the other in the center of Iceland. In table I are listed relevant chemical data for those basalts marked with crosses in figure 4. In both cases it is evident that abyssal-type tholeiites are produced side by side with high-potassium tholeiites. The basalts represented in figures 3 and 4 form a small part of a large data bank including samples from all fissure swarms exposed in the tholeiitic volcanic zones. The major part of the basalts is younger than 100,000 years. Throughout this period basalts of any composition within the compositional spectrum have been produced in close proximity in space and time.

CONCLUSIONS.

Volcanic history and field geology clearly show that low potassium abyssal type tholeiites are produced all over the volcanic zones of Iceland in close proximity with, and at the same time as tholeiites showing different degrees of enrichment in large lithophilic ions.

The characteristics that we find the most striking in the Icelandic tholeiites are (*a*) the fine scale distribution pattern of petrochemical types observed within each fissure swarm, and Iceland as a whole, (*b*) the pervasive covariation of all elements, including isotopes and RE-elements, and (*c*) the tendency of some of the dike swarms to evolve into silicic volcanic centres with time. These observations, taken together, seem to indicate well defined evolutionary processes (to produce the covariation) operating at rather shallow depths (to allow the fine-scale distribution pattern).

Consistent with this view are the experimental results of Thompson [1975] which indicate that basalts reflect equilibrium at about crustal depth. Largely overlooked hitherto are the data on $^{18}O/^{16}O$

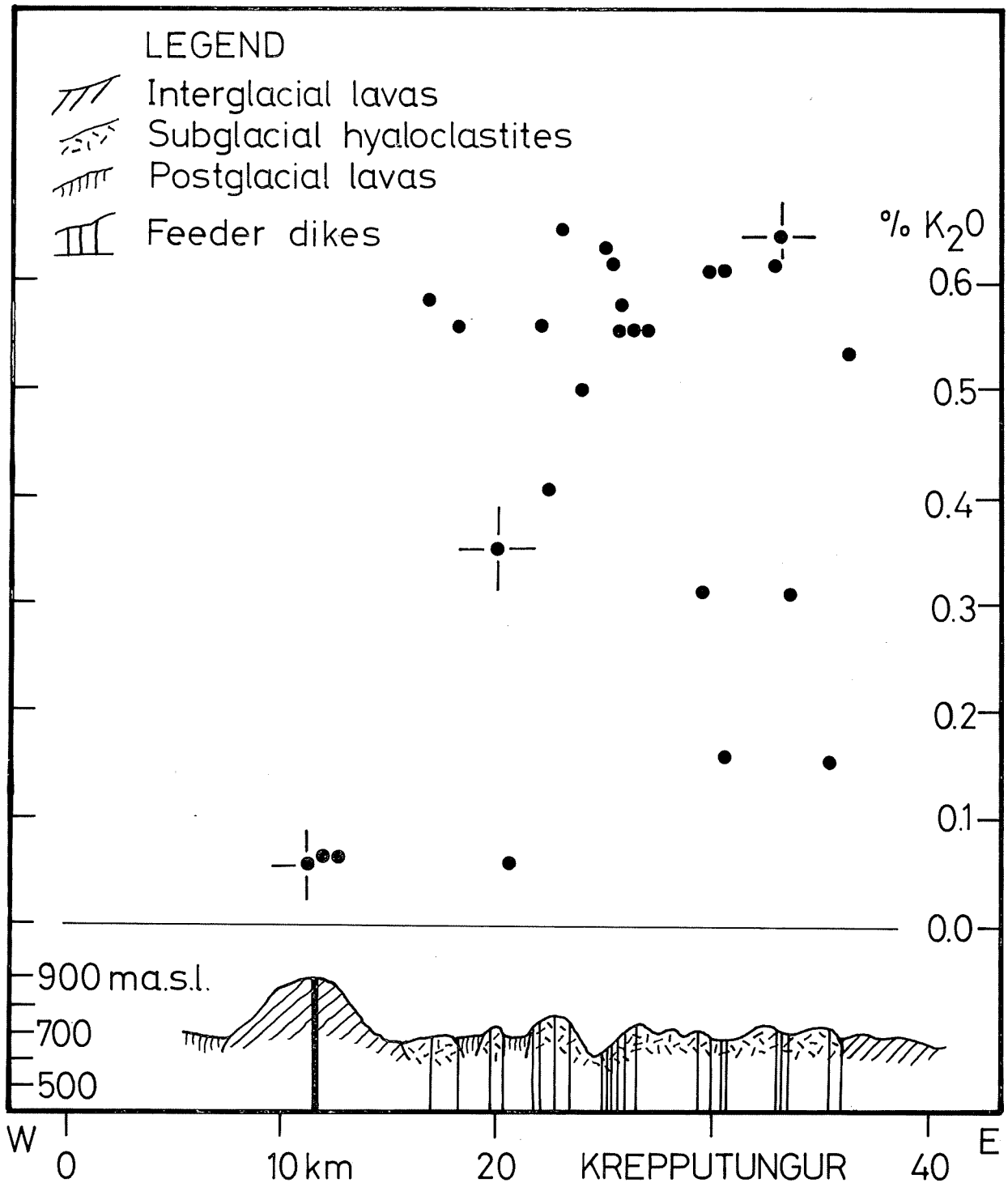

FIG. 4. — A schematic profile across a fissure swarm in Central-Iceland. Full chemical analyses of samples marked with crosses are presented in table I.

ratios of Icelandic basalts by Muehlenbachs *et al.* [1974]. The high-potassium tholeiites turn out to be exceptionally low in ^{18}O. Presently the only process known to produce low ^{18}O values is extensive isotopic exchange with meteoric water. The available evidence therefore indicates that the chemistry of the Icelandic tholeiites is to some extent affected by processes operating at relatively shallow depth. The evidence is still only suggestive, but it puts some constraint on petrogenetic models presently applied to explain the chemistry of Icelandic basalts [e.g. Schilling, 1973].

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