NORDIC VOLCANOLOGICAL INSTITUTE 78 03
UNIVERSITY OF ICELAND

EFFECT OF MAGMATIC ACTIVITY ON FUMAROLE GAS COMPOSITION IN THE NÁMAFJALL-KRAFLA VOLCANIC CENTER, N-ICELAND

by

Níels Óskarsson

February 1978

ABSTRACT

The Námafjall-Krafla volcanic center N-Iceland is a volcanically active north-south trending fissure swarm bisecting a caldera structure. Two geothermal fields are active in the area, the Krafla field inside the caldera and the Námafjall field immediately south of it.

During a current volcanic and seismic period fumarole activity increased in both fields. The chemical composition of fumarole gases at the Krafla field changed at the onset of magmatic activity. Monitoring of fumarole gas at the Leirhnjúkur eruptive fissure inside the caldera show hydrogen to be released prior to and during volcanic eruption. The change of chemical composition of the fumarole gases from the Krafla field is believed to result from injection of a magmatic gas phase into the hydrothermal system.

INTRODUCTION

Outlines of geology

One of the most active volcanic areas in N-Iceland since late Pleistocene time is the Námafjall-Krafla volcanic center, close to the western margin of the neovolcanic zone (Saemundsson, 1971). The center has developed a caldera structure extensively fractured and faulted along a zone N´15°E, commonly referred to as the Námafjall-Krafla fissure swarm.

The eroded rim of the caldera is roughly indicated by outcrops of acid and intermediate rocks (Fig. 1) as the rhyolitic dome Hlídarfjall to the southwest and the rhyolite ridge Hrafntinnuhryggur within the eastern rim of the caldera. Subglacial fissure eruptions have built up hyaloclastite ridges running through the caldera, the most outstanding of these being the Námafjall-Dalfjall--Leirhnjúkur ridge, running through its faulted and eroded south rim. Postglacial lavas of tholeiitic basalt have issued from numerous vents along the fissure swarm and on fissures running along the north-eastern caldera rim.

In postglacial time (last 10.000 years) eruptive periods were initiated by explosive eruptions, in Lúdent and Hverfjall respectively (Thorarinsson, 1960), the first of these lasting until 6000 B.P. Intermediate lavas at Hvannstód and south of Námafjall were formed at this stage.

The present activity period started 3000 yrs B.P. Numerous basaltic lavas were produced along the fissure swarm inside as well as south of the caldera.

The most recent eruption before 1975 was the "Mývatnseldar" eruption 1724-1729 (Thorarinsson, 1960), starting in March 1724 with intense seismic activity along the fissure swarm and the formation of the explosion crater Víti inside the caldera. New hydrothermal activity was observed at Leirhnjúkur inside the caldera and at Bjarnarflag to the south, followed by basaltic eruptions at both places.

The geothermal fields at Námafjall and Krafla

Two major geothermal fields exist in the Námafjall--Krafla volcanic center, i.e. around Námafjall and on the fissure swarm west of Krafla (Fig. 1). The Námafjall field is divided into two areas by the hyaloclastite mountain ridge Námafjall. East of Námafjall is the Hverarönd-Námafjall area, and the Bjarnarflag area northwest of Námafjall.

In this paper the two thermal areas around Námafjall will be treated as one geothermal field since the chemical composition of their fumarole gasis is indistinguishable. Groundwater flow beneath Námafjall is probably controlled by the tectonics of the fissure swarm and the upflow of thermal fluid on both sides of Námafjall is caused by the same thermal anomaly in the crust.

The geothermal field within the Krafla caldera covers a wide area. Activity is most intense on the faulted western slopw of Mt. Krafla, south of the explosion crater Víti, and at the northern end of Leirhnjúkur.

It will be noted that these centers of fumarole activity are identical with the eruptive vents from

1724-1729. Other less active geothermal fields as well as many extinct fumarole grounds within the caldera are in the vicinity of eruptive vents of fissures (Fig. 1), indicating a connection between geothermal activity at the surface and the extrusion of volcanic material (Saemundsson, 1971).

Current activity

During the summer 1975 increased seismic activity was noted at the Námafjall-Krafla fissure swarm. On December 20th that year a minor basaltic fissure eruption occurred at Leirhnjúkur followed by a tectonic event at the fissure swarm north of the caldera and enormous increase of geothermal activity at Leirhnjúkur (Björnsson, et al., 1977).

Towards the end of September 1976 a sudden subsidence of the caldera floor resulted in seismic activity and the initiation of minor hydrothermal activity along the fissure swarm north of Leirhnjúkur. A similar event occurred in October that year and again in January 1977. A second minor eruption occurred in April 1977 followed this time by seismic activity and faulting to the south of Leirhnjúkur towards Bjarnarflag. The third eruption north of Leirhnjúkur somewhat larger than the previous ones occurred in September 1977. Seismic activity and faulting along the swarm was followed by increased surface activity of the hydrothermal area at Bjarnarflag.

An unusual but informative aspect of the September eruption was the extrusion of a small amount (few m^3) of fresh pyroclastite through a deep (1.3 km) geothermal well at Bjarnarflag (Larsen, 1978). In January 1978 the caldera floor subsided again this time followed by seismic activity towards the north (Fig. 5). Precision measurements of ground movements (Tryggvason, 1978) during and after the three last events indicate an extensive dilatation of the crust (1-2 m) across the fissure swarm following the seismic periods.

The current opinion is that the magmatic and tectonic activity at Námafjall-Krafla is caused by injection of magma from depth into a permanent shallow magma reservoir beneath Leirhnjúkur. The energy stored by the uplift of the caldera floor is released periodically by intrusion of magma along the vertical fracture system of the fissure swarm at shallow depth (1-3 km) and occasional extrusion of small lavas above the uplift center.

The aim of this preliminary report is to evaluate the effects of seismic and magmatic activity on the composition of hydrothermal gases evolved from the two geothermal fields. Monitoring of fumarole gas after the 1975 eruption at Leirhnjúkur shows the two fields to respond differently to the activity in respect to gas chemistry. The composition of fumarole gas changed at the onset of volcanism in the Krafla field but remained unchanged at the Námafjall field, although both fields showed variations in fumarole activity. In the following the chemical changes will be outlined and their possible origin discussed.

COMPOSITION OF FUMAROLE GAS BEFORE AND AFTER THE 1975 ERUPTION

Composition before the 1975 eruption

Before discussing the chemical change at the Námafjall-Krafla fumaroles in detail, the compositional range previously occupied by the fumarole gases will be reviewed.

Gases from the Námafjall field were analysed in 1950 and again in 1970 (Arnórsson, 1971) in connection with the exploitation of the area. Fumarole gases from the Krafla field are among the best documented hydrothermal gases in Iceland, analysed in 1890, 1906, 1950 and finally in 1970 prior to the exploitation of the field (Arnórsson, 1971).

Outlines of the chemical character of the fumarole gases are shown in Fig. 2 in terms of the components H_2S-CO_2-H_2 plotted on a triangular diagram. The CO_2/H_2 ratio and the CO_2/H_2S ratio are commonly believed to indicate the temperature and degree of boiling of a degassing hydrothermal fluid. Dissolved hydrogen in the thermal fluid is assumed to be controlled by the temperature dependant reaction:

$$HS^{-}_{(aq)} + 4H_2O_{(1)} \rightleftarrows SO^{2+}_{4(aq)} + H^{+}_{(aq)} + 4H_{2(g)}$$

Higher temperature drives the reaction towards right. As hydrogen is assumed to be transferred quantitatively to the gas phase of the first formed boiling fraction the CO_2/H_2 ratio in the H_2S-CO_2-H_2 triangular diagram will be an indication of the relative equilibrium temperature of the thermal fluid prior to boiling. The CO_2/H_2S ratio on the other hand will reflect the degree of boiling since H_2S becomes enriched in the later steam fractions due to higher solubility in the fluid (Arnórsson, 1974).

The chemical trend of the Námafjall field can be described qualitatively in terms of the two parameters mentioned above (Fig. 2). The samples form a continuum over a wide compositional range. Those with the highest hydrogen content, indicating the highest temperature of last equilibrium with fluid, also show the highest fraction of boiling by low CO_2/H_2S ratios. This is in agreement with the above assumptions, as well as the evidence provided by gas samples from the geothermal wells at Bjarnarflag, which indicate higher boiling fraction than the fumarole gases. The scatter of points towards right in Fig. 2 is explained by oxygen contamination lowering the H_2S content by oxidation, without affecting the CO_2/H_2 ratio.

The presence of oxygen in the samples might be explained by air contamination during sampling but is more likely to result from release of dissolved oxygen from cold surface water in contact with the fumarole vent.

It is evident from Fig. 2 that the compositional range of samples from the Krafla field points towards somewhat more restricted temperature conditions of degassing than observed in the Námafjall field.

With one exception the older gas analysis from the Krafla field are confined to a narrow region on the H_2S-CO_2-H_2 plot (Fig. 2). No significant differences can be seen between samples from the eastern part of the field (Víti, Fig. 1) and its western margin, although the hottest fluid seems to have prevailed at Víti (point marked V, Fig. 2).

An exception is the point marked H on Fig. 2. This sample, representing the southeast border of the thermal field, (Fig. 1) is believed (Arnórsson, 1971) to have equilibrated at low temperature or even to have degassed from a previously boiled fluid.

Composition after the 1975 eruption

Collection of fumarole gases started in mid-January 1976. Since then samples have been collected on average every other month and analysed for the components CO_2, CO, CH_4, H_2S, H_2, O_2 and (N + inert gases). Sampling sites are marked on Fig. 1. Site A is a small fumarole formed in Jan. 1976. It was sampled from Jan. 1976 until October that year, when activity had decreased beyond practical sampling conditions. Site H is a fumarole with no visible change in surface activity throughout the magmatic episode, sampled since Jan. 1976. Site L has been sampled since its reactivation in July 1976. Finally the site V has been sampled since July 1976, when gas release increased enormously.

Chemical analysis of samples from the Krafla field are reported in Tables I-IV. It is evident that samples from all sampling sites are with few exceptions of the same bulk composition

The chemistry of thermal gases from the Námafjall area collected after Dec. 1975 (Table V) show no signs of different origin or abrupt change of degassing conditions following the magmatic event. Thus the thermal fluid seems to be unaffected even by magma intrusion on Sept. 8, 1977.

The compositional change of the fumarole gases at the Krafla field following the eruption 1975 is shown on Fig. 2. In short the change can be described as a removal of hydrogen and hydrogen sulphide from the gases along with increase of carbon dioxide swamping out all the chemical trends previously existing. Practically all the data points are clustered into the CO_2 corner.

The quality of samples can be evaluated by estimation of their air contamination.

Fig. 3 shows carbon dioxide plotted against nitrogene. Samples collected after the 1975 eruption cluster around a line representing the mixing of air and 97% carbon dioxide leading to the conclusion that the samples are in reality of monotonous composition, but suffering from somewhat varying air contamination. For comparison the older analysis are plotted on the same diagram, where they occupy an entirely different field, with the exception of sample marked H previously stated to be of slightly different origin. The samples L_1 and L_2 from Leirhnjúkur plot towards the older samples on Fig. 3 although of different composition.

Compositional difference between samples from the various sampling sites is shown on Fig. 4, which is the expanded CO_2 corner of Fig. 2.

An informative feature is the separation of samples from site H. The sample from 1970 is shown in the lower left region in alignment with four of the new samples. It is thought that at this marginal site the gas samples lower in carbon dioxide are derived from variously boiled thermal fluid but samples from the same locality plotting at the CO_2 corner of Fig. 4 are of the new gas composition observed regionally.

The shift of data points from site H on Fig. 4 indicate periodic removal of hydrogen and hydrogen sulphide from a system not overwhelmingly affected by the magmatic event, since the fumarole is able to restore its previous gas composition intermittently. This indicates that fumarole H is on the margin of the area influenced by the magmatic events.

An important feature to be noted and discussed later is the exceptionally high hydrogen content of three samples from site L marked L_1, L_2 and L_3 in Figs. 2, 3 and 4.

Although very similar in composition samples from sites L, V and H have a slightly different CO_2/H_2S ratio. The samples from Víti (V) are somewhat higher in H_2S than samples from Leirhnjúkur (L) and four samples from site H are still higher than those from Víti. Other samples from H are more dispersed, roughly occupying the same field as those from L and V.

This compositional difference correlates with distance from Leirhnjúkur, H_2S increasing away from the eruptive fissure (Fig. 1).

CORRELATION OF HYDROTHERMAL ACTIVITY, GAS COMPOSITION AND MAGMATIC EVENTS

During the months preceeding the eruption at Leirhnjúkur on December 20th 1975, the discharge of one geothermal well in the Krafla field (well no. 3) was analysed regularly. Although left unnoticed at that time, a slight but significant increase of hydrogene in the thermal fluid was reported (Fig. 5) (ref.).

During the eruption a large steam crater opened up south of Leirhnjúkur boiling off large amount of water. This increase in fumarole activity was followed by drying up of the previously active thermal ground north of Leirhnjúkur (marked L, Fig. 1). In mid-January a new fumarole was observed in the floor of the valley east of Leirhnjúkur (A on Fig. 1). In June and July 1976 the steam vent south of Leirhnjúkur became less active and the thermal ground north of Leirhnjúkur resumed vigorous boiling and gas release. At the same time increased gas release was observed on the thermal grounds south of Víti (V on Fig. 1) continuing towards the end of the year. At the south margin of the thermal field (H on Fig. 1) no change in surface activity was noted. Subsequent eruptions on fissures north of Leirhnjúkur were followed by steam explosions in vicinity of the craters without visible effects on the thermal grounds except the ground north of Leirhnjúkur (L on Fig. 1), where gas release increased markedly for some days following the eruption of September 8th 1977.

No changes in fumarole activity were noted around Námafjall until during the event in Sept. 1977, when boiling of fumaroles in Bjarnarflag increased markedly as a result of magma intrusion into the aquifers (see above).

In January 1976 when sampling and analysis of thermal gases from the Námafjall and Krafla thermal fields were started, a major compositional change had occurred in the Krafla fumaroles, as compared to the last available (1970) analysis of fumarole gases prior to the eruption. By that time the major element composition of the discharge form well no. 3 showed no signs of change (Gíslason, 1976). When analysed in March 1976 the discharge had an entirely different composition with dissolved carbon dioxide two orders of magnitude higher than before. Another observation informative in this connection is the chemical behaviour of a discharge from well no. 4 at Krafla. This 2 km deep well was drilled in August 1975, but went out of control in early September that year. The water discharge from the well was analysed in September and November 1975. The sulfate content was about 200 ppm and pH about 9. In March 1976 this water contained 1500 ppm sulfate at pH 1.8. The acidity and sulfate content of the water then reached its previous state in half a year along with decreasing discharge from the well (Gíslason, 1976).

This might indicate that the effects of magmatism can be dated to the period Jan.-March 1976 in well no. 3. Unfortunately no data are available on the composition of the discharge from the ruined well no. 4 for the period Dec. 1975 - March 1976. Since then, however, the discharges from both wells trend slightly towards their previous composition indicating that the changes had occurred before March 1976.

Well nc. 3 in Krafla released hydrogen above average before the eruption 1975 (Fig. 5). This observation warrants a closer look at the behaviour of hydrogen in the fumarole gas, since exceptionally high CO_2/H_2 ratio is one of the most outstanding characteristics of the gas composition after Jan. 1976 (Fig. 1).

On Fig. 5 the CO_2/H_2 ratio at sampling sites V and L is plotted as a function of time. Magmatic and tectonic events in the Krafla area are also indicated on the time scale. Samples from sites V and L have high CO_2/H_2 ratios. Exceptions are the samples collected in the autumn 1977 at Leirhnjúkur. The hydrogen content of these samples are much higher than average.

Three weeks before the eruption on September 8th 1977 the hydrogen increased significantly and reached a maximum of 20.3% on the day following the eruption and then decreased again.

The data are dispersed in time, but clear evidence shows that hydrogen is released from the fumarole in high amount prior to and during volcanic eruption within the caldera. The broken line in Fig. 5 shows a possible connection between the dispersed data points. The origin of the increased hydrogen content is probably the early distillation of hydrogen from an ascending magma. Hydrogen would diffuse rapidly to the surface via aquifers of the thermal field (Sato, 1976).

This observation suggests that hydrogen might be the long looked for chemical component of a fumarolic gas, which can serve as a monitor in volcanic prediction.

DISCUSSION

Factors that are not likely to be changed as a result of magmatic events are regional hydrostatic pressure and the stable mineral assemblage of the aquifers. The mineral assemblage is the solid part of the enormous buffer system controlling the chemical composition of the thermal fluid. It has been shown that hydrothermal alteration has little effect on bulk chemical compositions of drill cores in the Krafla field. Calcite and quartz are the principal secondary minerals along with pyrite and smectite in the upper sections and epidote, chlorite and phrenite at depth (below 1 km). The most obvious chemical change shown by the core material is the FeO/Fe_2O_3 ratio trending towards unity, when at maximum close to the aquifers (Kristmannsdóttir, 1976). This indicates that magnetite might be expected among the metamorphic minerals although not looked for.

The regional variations in gas chemistry in the Krafla fumaroles after the 1975 eruption could result from: a) changing degassing behaviour of the preexisting thermal fluid or b) addition of a magmatic gas phase to the system.

a) Changing degassing behaviour

Tectonic movements affecting the upflow zone of a thermal fluid, might change aquifers and cause mixing of fluids equilibrated at different conditions.

If the previously degassing aquifer at Krafla was assumed to flow down to a warmer aquifer, increased boiling would be expected. This is incompatible with the higher CO_2/H_2S ratio observed. If on the other hand an upper, cold aquifer flowed down to the degassing aquifer, less boiling activity would be expected and the nitrogen content of the emanating gas might be expected to increase markedly as this is generally enriched in cold water (Arnórsson, 1974). This can hardly be the case at Krafla since boiling activity and gas release increase markedly.

The upflow of a deep aquifer to the surface and its degassing to swamp out the previous fumarole gas, is difficult to evaluate. The assumption can be made that a deeper and thus warmer aquifer, where boiling is initiated by upflow, would give off the bulk of its hydrogen at the onset of degassing. This again conforms badly to the observed changes as hydrogen is lower in the new composition.

A temperature change of the degassing aquifers can result in change of gas composition due to different boiling behaviour of the fluid. This can hardly be the case at Krafla as the trends shown by the CO_2/H_2S and CO_2/H_2 ratios of the fumarole gases point towards opposite directions of temperature change, CO_2/H_2S towards lower but CO_2/H_2 towards higher fractions of boiling.

b) Addition of magmatic gas

Possible effects of a magmatic gas mixing with the somewhat variously boiled thermal fluid of the Krafla fumaroles, can be evaluated qualitatively by considering the interaction of the stable mineral assemblage, hydrothermal fluid and the acid magmatic gases CO_2 and SO_2 considered to be the dominating sulphur compound of magmatic gases at near surface conditions (Nordlie, 1971).

The dissolution of the acid gases in a thermal fluid at intermediate pH can be described by the reactions:

$$CO_{2(g)}+H_2O_{(1)} \rightleftharpoons H^+_{(aq)}+HCO^-_{3(aq)} \qquad (1)$$

and $$SO_{2(g)}+H_2O_{(1)} \rightleftharpoons SO^{2-}_{3(aq)}+2H^+_{(aq)} \qquad (2)$$

In the presence of ferric iron the sulphite is oxidized according to:

$$SO_3^{2-}+2Fe(OH)^{2+} \rightleftharpoons SO_4^{2-}+2Fe^{2+}+2H^+ \qquad (3)$$

Combination of eqs. (2) and (3) gives:

$$SO_{2(g)}+2Fe(OH)^{2+}_{(aq)} \rightleftharpoons SO^{2+}_{4(aq)}+2Fe^{2+}_{(aq)}+2H^+_{(aq)} \qquad (4)$$

The mineral pair epidote/prehnite is the principal secondary mineral assemblage of the Krafla field and epidote being the host of ferric iron in the system is related to prehnite by the chemical equation:

$$\underset{\text{(epidote)}}{Ca_2FeAl_2Si_3O_{12}(OH)_{(s)}}+2H^+_{(aq)} \rightleftharpoons \underset{\text{(prehnite)}}{Ca_2Al_2Si_3O_{10}(OH)_{2(s)}}+Fe(OH)^{2+}_{(aq)}$$

The ferrous iron formed in eq. (4) will remove bisulphide from solution by:

$$Fe^{2+}_{(aq)}+HS^-_{(aq)} \rightleftharpoons FeS_{(s)}+H^+_{(aq)}$$

This and the formation of sulphate eq. (4) affects the balance between the sulphur species and hydrogen in equilibrium with the mineral assemblage according the equation:

$$HS^-_{(aq)}+4H_2O_{(l)} \rightleftarrows SO^{2+}_{4(aq)}+H^+_{(aq)}+4H_{2(g)} \qquad (5)$$

Reaching equilibrium the system consumes both hydrogen and sulphide as ferrous iron is formed in excess of sulphide formed in eq. (5) (Helgeson, 1969).

The above simple reaction might illustrate a process removing sulphide and hydrogen simultaneously from the thermal fluid, along with carbonate enrichment eq. (1). Thus the observed compositional change of the fumarole gases at Krafla might be explained by the action of magmatic gas dissolving in the thermal fluid.

It has to be assumed that the buffer capacity of the mineral assemblage is sufficiently large to consume the acid formed according to the above reactions. A local precipitation of silica may, however, occur in the aquifers as dissociated silicic acid combines:

$$H^+_{(aq)}+H_3SiO_{4(aq)} \rightleftarrows H_4SiO_{4(aq)}$$

to give solid precipitate

$$H_4SiO_{4(aq)} \rightleftarrows SiO_{2(s)}+2H_2O_{(l)}$$

The highly acid discharge of well no. 4 might reflect conditions described by eq. (4), where sulphuric acid is dominating among the dissolved species.

Ferrous iron formed in excess of sulphide in the system would supposedly precipitate locally along with silica. The formation of ferrous iron available to remove sulphide is more favoured if magnetite is assumed to be the host of ferric iron in the oxidation of sulphide.

The monotonous composition regionally observed for the Krafla fumarole gas points towards a buffered system. It is believed that the rock formation containing the thermal fluid degassing at Krafla is impregnated by emanations from magma at shallow depth. The reactions taking place in the deepest aquifers are buffered by the surrounding mineral assemblage changing the proportions of volatiles in the degassing thermal fluid.

SUMMARY

The chemical composition of fumerole gases at the Krafla geothermal field inside the caldera in the Námafjall-Krafla volcanic center changed at the onset of magmatic activity. Fumarole gases of the Námafjall field remain unchanged although surface activity of the fumaroles have increased during magmatic events.

The chemical change in the Krafla fumaroles is believed to result from magmatic gas infiltrating the degassing aquifers and reacting with the thermal fluid and mineral assemblage of the thermal field. The source of magmatic gas is thought to be a magma known to exist at shallow depth below the caldera floor. During ascend of magma to the surface hydrogen is released and degassed through the fumarole vents prior to eruption.

REFERENCES

Arnórsson, S., 1971. Námafjall-Krafla, survey of the geothermal fields. Professional paper, Nat. Energy Authority, Reykjavik, Iceland (in Icelandic) 81 p.

Arnórsson, S., 1974. The composition of thermal fluids in Iceland and geological features related to the thermal activity. Pp. 307-323 in Kristjánsson (ed.) Geodynamics of Iceland and the North Atlantic. Reidel Publ. Co., Dordrecht, Holland.

Björnsson, A. et al., 1977. Current rifting episode in North Iceland. Nature 266, pp. 318-323.

Gíslason, G. & Arnórsson, S., 1976. Changes in discharge and chemistry of wells no. 3 and 4 in the Krafla field. Progress Report, OSJHD 764, Nat. Energy Authority, Reykjavik,Iceland (in Icelandic) 13 p.

Helgeson, H.C., 1969. Thermodynamics of hydrothermal systems at elevated temperatures. Am. Jour. Sci. 267, pp. 729-804.

Kristmannsdóttir, H., 1976. Geothermal wells no. 3, 4 and 5 in the Krafla field. Stratigraphy and petrology. Professional paper OSJHD 7641, Nat. Energy Authority, Reykjavik, Iceland (in Icelandic) 22 p.

Larsen, G., 1978.

Saemundsson, K., 1971. Námafjall-Krafla, survey of the geothermal fields. Professional paper, Nat. Energy Authority, Reykjavik, Iceland (in Icelandic) 81 p.

Sato, M. et al., 1976. Monitoring of fumarolic gas at Sherman crater, Mt. Baker, Washington. Trans. Am. Geophys. Union 57 (abstract).

Thorarinsson, S., 1960. The postglacial history of the Mývatn Area and the Area between Mývatn and Jökulsá á Fjöllum. Pp. 60-69 in Thorarinsson (ed.) On the geology and geophysics of Iceland. Internat. geol. Congr. 21. Session, Norden. Excursion guide no. A2.

Tryggvason, E., 1978.

TABLE I

Chemical analysis of gas samples from sampling site "A", mol. percent

Date	CO_2	CH_4	H_2S	H_2	O_2	N_2
250176	94.8		0.7		0.2	4.4
260176	97.3	0.6	0.7		1.0	0.6
110376	92.6	0.3	0.8	0.6	1.1	4.6
130576	90.0	0.6	0.6	0.4	4.0	4.4
130676	85.0		0.5	0.4	2.6	13.5
170776	89.0		1.5	0.7	3.5	5.3
110876	63.0		0.5	0.4		36.1
160976	92.9		0.5	0.6	0.8	5.2
281076	70.0		1.0	1.7	5.2	22.1

The gases are analysed by chemical methods using ORSAT apparature.

TABLE II

Chemical analysis of gas samples from sampling site "H", mol. percent

Date	CO_2	CH_4	H_2S	H_2	O_2	N_2	H_2O/Gas
250176	85.1		1.9	2.7	2.6	7.7	
260176 (1)	86.8	0.4	1.9	0.4	2.6	7.5	
120376	84.2	0.8	1.3	2.8	3.5	7.4	
130576	95.8		2.0	0.2	1.4	0.6	
130676	82.5		0.9	0.2	1.9	14.5	
170776	91.0		3.0	2.6	1.2	2.2	
110876	91.0		4.0	1.7	1.2	2.1	
170976	95.9		1.7	0.9	0.4	1.1	
281076	96.3	0.3	1.4	0.2	0.5	1.3	
301176	93.7	0.8	2.1	0.8	0.2	2.4	
130177	91.4	0.1	0.2	0.2	1.9	6.2	
270277	95.2	0.1	1.2	0.2	0.8	2.5	
170677	87.6	0.1	0.9	0.1	0.5	10.8	
160877	97.3		0.9	0.1	0.5	1.2	
130977	96.5	0.4	0.9	0.2	1.0	1.0	163.9
080178	97.7		1.1	0.1	0.3	0.9	

1) 0.4 mol. percent CO excluded.

The gases are analysed by chemical methods using ORSAT apparature.

TABLE III

Chemical analysis of gas samples from sampling site "V", mol.percent

Date	CO_2	CH_4	H_2S	H_2	O_2	N_2	H_2O/Gas
170776	94.0		1.5	1.3	1.9	1.3	
110876	94.0		1.5	1.3	1.9	1.3	
160976	96.5	0.6	1.5	0.5	0.3	0.6	
281076	95.9	0.2	1.3	1.1	0.2	1.3	
011276	96.5	0.2	1.1	1.0	0.3	0.9	
130177	63.7		0.7	0.7	7.7	27.2	
270277	84.6	0.1	0.8	0.5	3.1	10.9	
160677	94.8		0.6	0.2	0.8	3.6	
160877	96.6		1.1	0.1	0.6	1.6	
120977	97.3	0.14	0.7	0.2	0.34	0.62	25.38
281077	97.5		1.5	0.1	0.4	0.5	39.95
080178	97.4	0.4	1.1	0.1	0.4	0.6	

The gases are analysed by chemical methods using ORSAT apparature.

TABLE IV

Chemical analysis of gas samples from sampling site "L", mol.percent

Date	CO_2	CH_4	H_2S	H_2	O_2	N_2	H_2O/Gas
160776	97.0		0.5	0.7	0.7	1.1	
110876	97.0		0.5	1.0	0.6	0.9	
160976	97.4	0.4	1.1	0.1	0.2	0.8	
281076	96.1	0.3	0.4	1.2	0.6	1.4	
011276	96.6	0.6	0.6	0.9	0.5	0.8	
120177	83.7	0.2	0.6	1.0	3.2	11.3	
270277	94.0	0.2	0.6	1.5	0.9	2.8	
160677	81.9		0.5	0.1	3.4	14.1	
160877	93.5	0.2	0.5	1.5	1.2	3.1	
100977 1)	74.2	0.1	1.7	20.3	1.0	2.5	48.52
281077	88.9	0.3	1.5	6.6	1.2	1.5	86.42
161277	83.7	0.1	1.1	3.4	2.6	9.1	
080178	95.5	0.3	0.9	0.4	1.0	1.9	

1) 0.2 mol. percent CO excluded.

The gases are analysed by chamical methods using ORSAT apparature.

TABLE V

Chemical analysis of gas samples from Hveraröndd and Bjarnarflag

	Date	CO_2	CO	CH_4	H_2S	H_2	O_2	N_2	H_2O/Gas
Hv.rönd	270176	67.4	0.8	0.4	4.8	23.1	1.2	2.3	
"	120376	67.2	0.3	1.1	5.8	22.4	0.7	2.5	
"	130576	64.4	0.1	1.2	6.6	12.7	1.8	13.2	
"	130676	56.1	0.4	0.8	5.5	18.2	2.0	17.0	
Bj.flag(1)	270176	43.3	0.2		8.2	5.8	6.9	35.6	
" (2)	271077	41.2		0.9	5.7	46.0	1.4	4.8	247.9

1) Steam vent at well No. 4 Bjarnarflag (ref. sample No. o8700127 in OSNK71 p. 44.

2) Steam vent at Bjarnarflag, formed in October 1977.

The gases are analysed by chemical methods using ORSAT apparature.

TEXT TO FIGURES

Fig. 1. A map of the Námafjall-Krafla area showing the geothermal fields and smapling localities. The map is compiled from Saemundsson (1971).

Fig. 2. H_2S-CO_2-H_2 triangular diagram. The composition of fumarole gases from the Námafjall and Krafla fields before the eruption at Leirhnjúkur Dec. 1975. The new composition of the gas from Krafla is shown in the CO_2-corner. The ratio CO_2/H_2S is indicated by dashed lines to the left of the triangle and the CO_2/H_2 ratio to the right. Samples from the two geothermal fields and geothermal wells in Bjarnarflag are enclosed within dashed lines. Samples to the right within the triangle considered to be contaminated by atmospheric air are connected to apropriate sample groups by dashed lines showing constant CO_2/H_2 ratio.

Fig. 3. CO_2 plotted against N_2 for gas samples from the Krafla field before and after the eruption at Leirhnjúkur Dec. 1975. The symbols are representing sampling sites (ref. Fig. 1). The solid line represents mixing of 97% CO_2 with atmospheric air.

Fig. 4. H_2S-CO_2-H_2 triangular diagram of samples from the Krafla field after the eruption at Leirhnjúkur Dec. 1975. The symbols refer to sampling localities.

Fig. 5. The CO_2/H_2 ratio of fumarole gas from the Krafla field as a function of time. The ratio for samples from well no. 3 at Krafla piror to the eruption at Leirhnjúkur Dec. 1975 is shown to the left (Gíslason, 1976). The tectonic events in the area are marked with dashed lines on the time scale and eruptions at Leirhnjúkur with solid lines. The vertical lines are marked with letters:

Fig. 5
(cont.)

A: Eruption at Leirhnjúkur Dec. 20th 1975, seismic activity to the north.

B: Subsidence of the Krafla caldera floor, seismic activity to the north.

C: October 30th 19 Subsidence of the caldera floor for seismic activity to the north.

D: Subsidence of the caldera, seismic activity to the south.

E: Eruptin at Leirhnjúkur, subsidence of the caldera floor, seismic activity to the south.

F: Eruption at Leirhnjúkur, subsidence of the caldera floor, seismic activity to the south.

Filled circles show samples from Leirhnjúkur and open circles show samples from Víti (Fig. 1). Prior to the eruption at Leirhnjúkur, marked with F the hydrogene of the fumarole gas at L increases. This is clearly shown by the low CO_2/H_2 ratio. A possible similar change for the samples from Víti is indicated by dashed lines as well as possible hydrogene release prior to the eruption in April 1977.

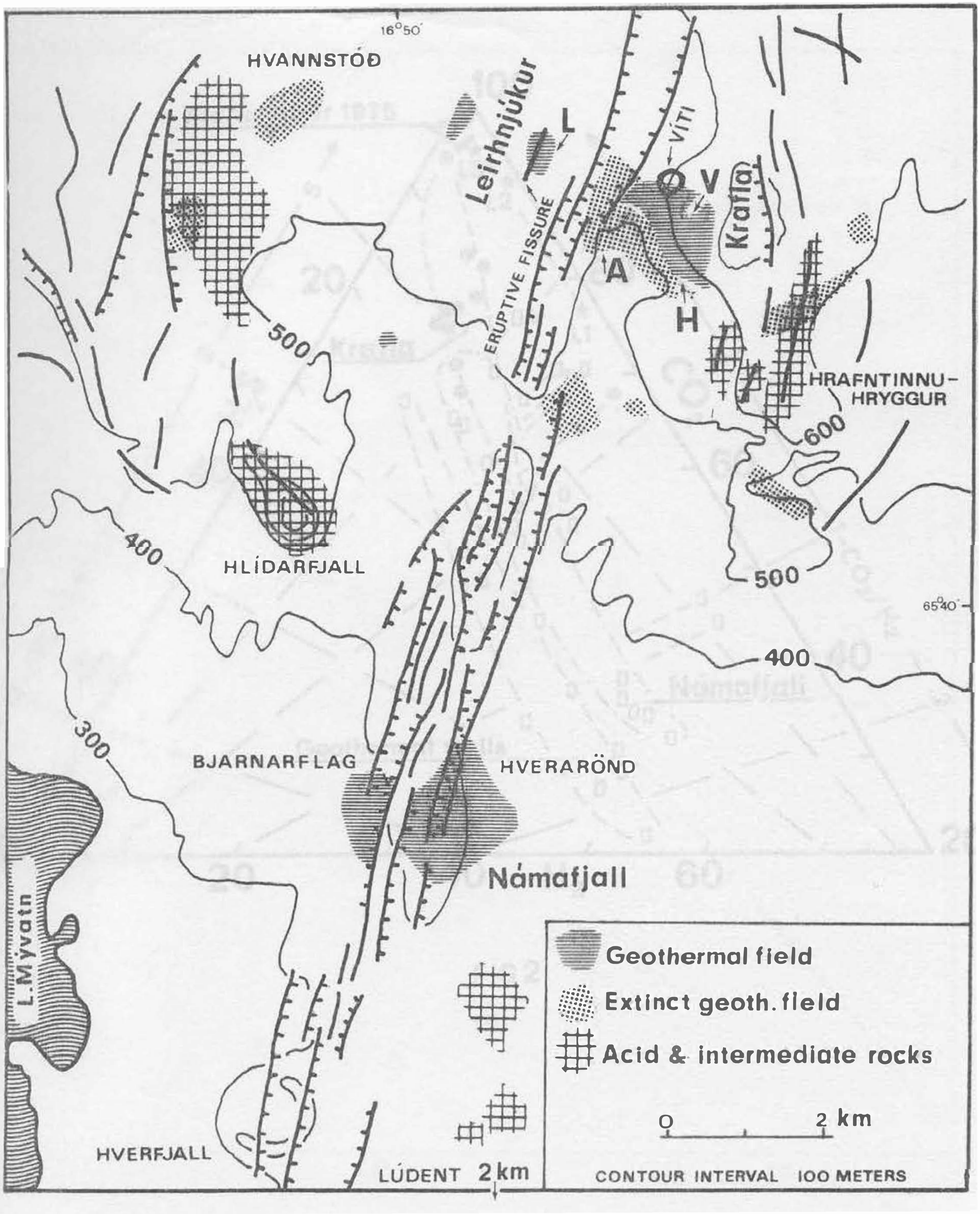
16°50'
HVANNSTÓÐ
Leirhnjúkur
L
VÍTI
V
Krafla
ERUPTIVE FISSURE
A
H
500
HRAFNTINNU-
HRYGGUR
600
400
HLÍDARFJALL
500
65°40'
400
300
BJARNARFLAG
HVERARÖND
Námafjall
L.Mývatn
Geothermal field
Extinct geoth. field
Acid & intermediate rocks
0
2 km
HVERFJALL
LÚDENT
2km
CONTOUR INTERVAL 100 METERS

FIG 1

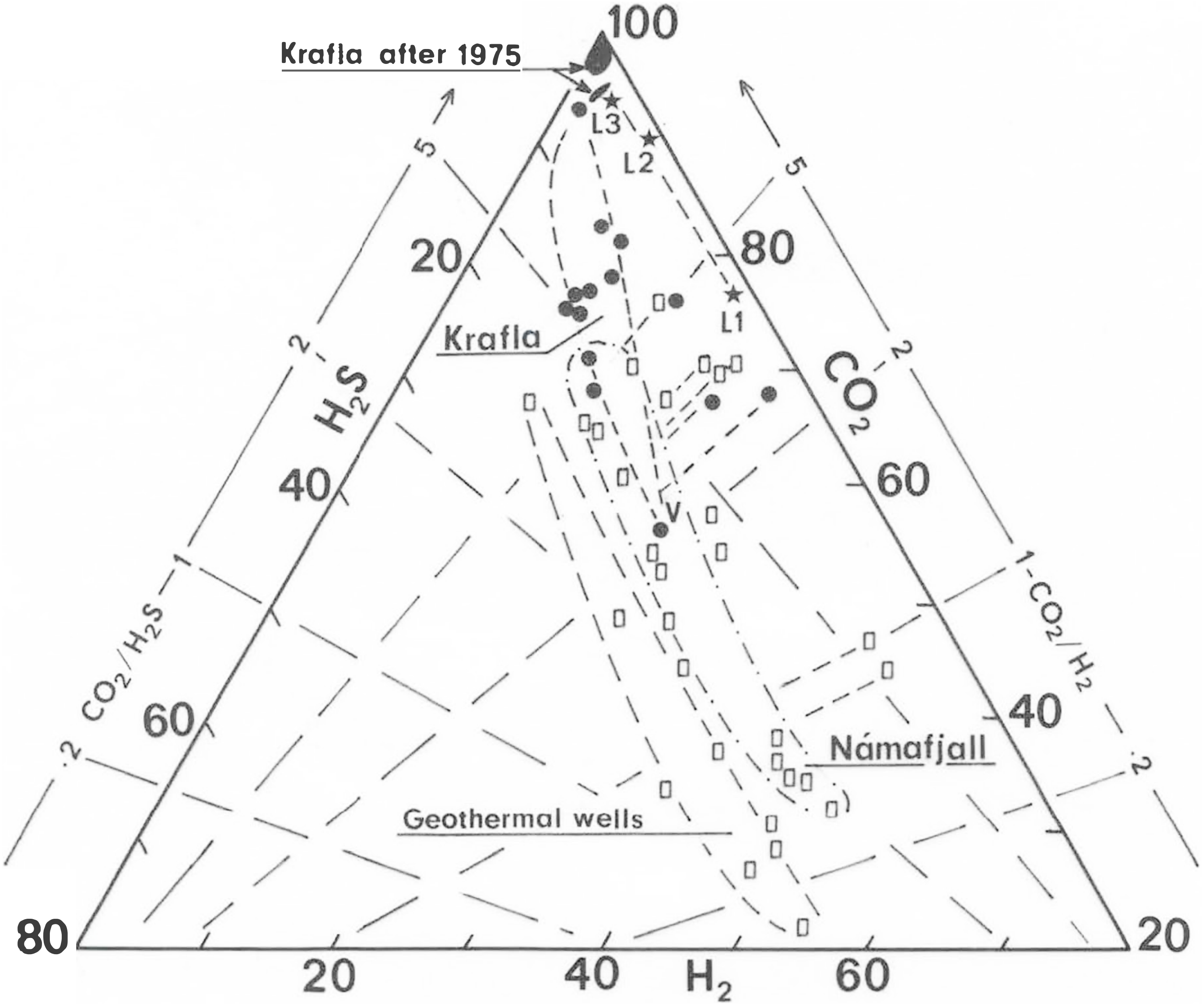
100
Krafla after 1975
5
5
L3
L2
20
80
Krafla
L1
2
2
H2S
CO2
40
60
V
1
1-CO2/H2
CO2/H2S
60
40
Námafjall
.2
.2
Geothermal wells
80
20
20
40
H2
60

FIG 2

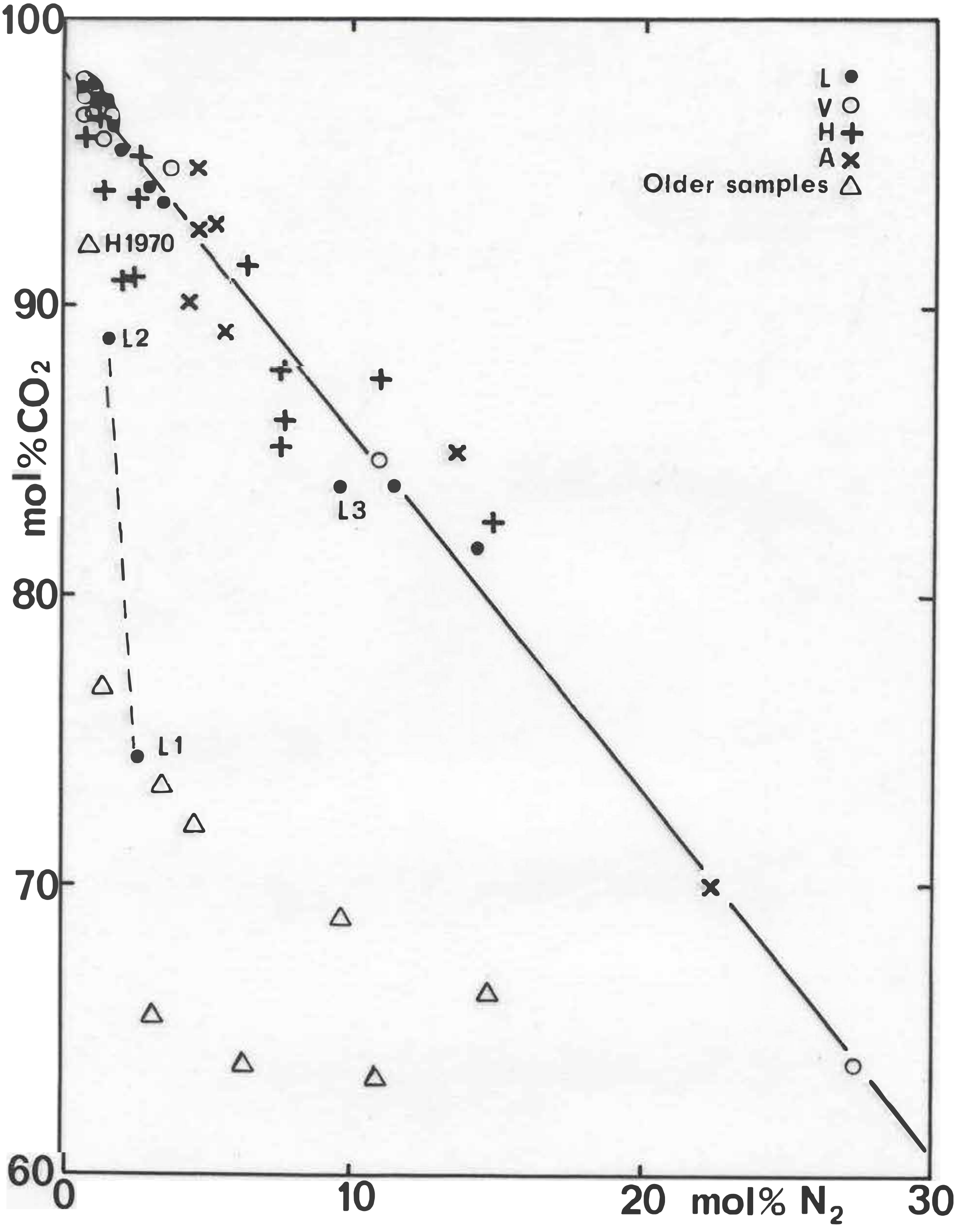
100
90
80
70
60
mol%CO₂
0
10
20
30
mol% N₂
L ●
V ○
H +
A ×
Older samples △
H1970
L2
L1
L3

FIG 3

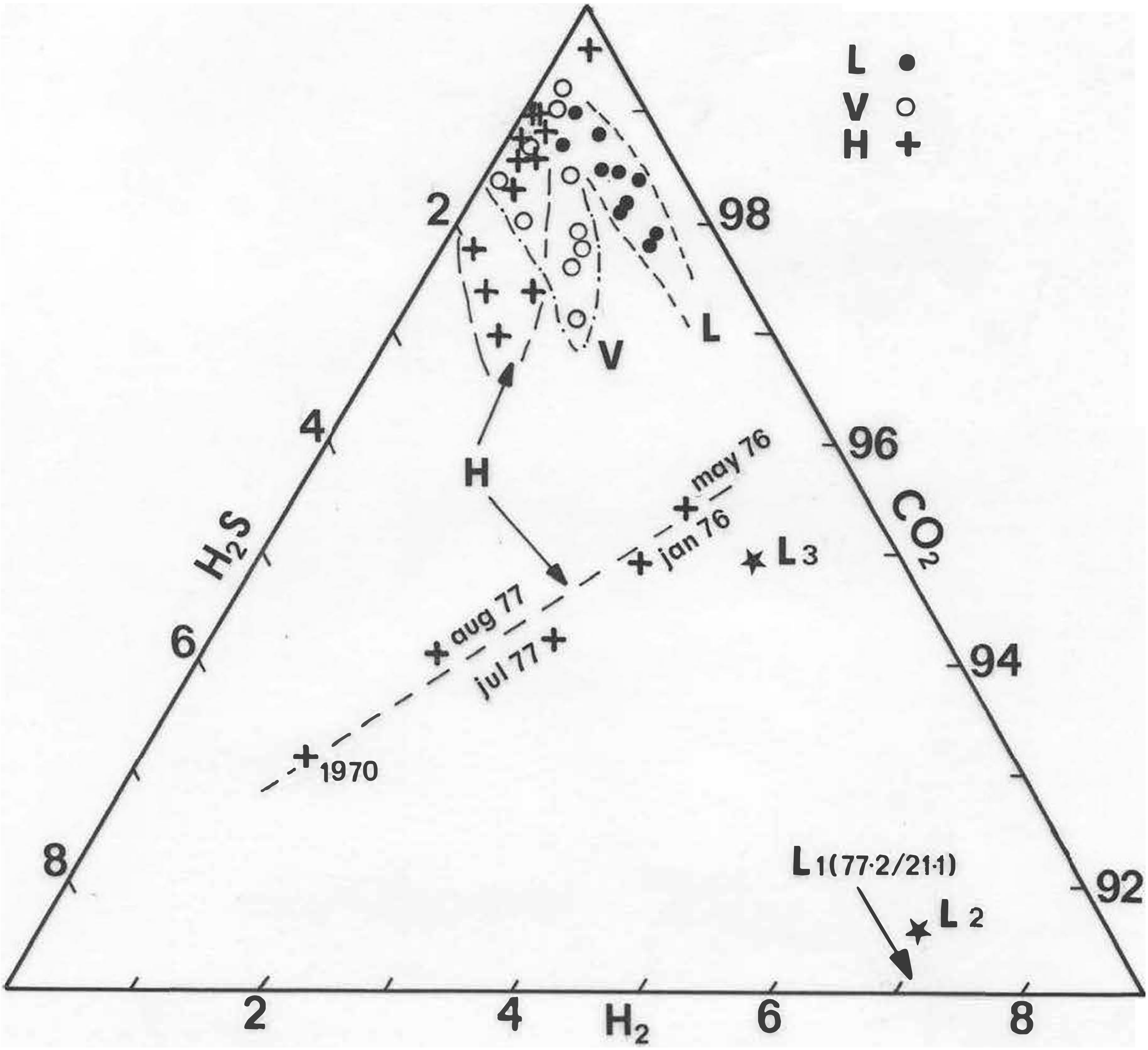
L ●
V ○
H +
2
4
6
8
H$_2$S
98
96
94
92
CO$_2$
2
4
H$_2$
6
8
L
V
H
may 76
jan 76
aug 77
jul 77
1970
L 3
L 1(77·2/21·1)
L 2

FIG 4

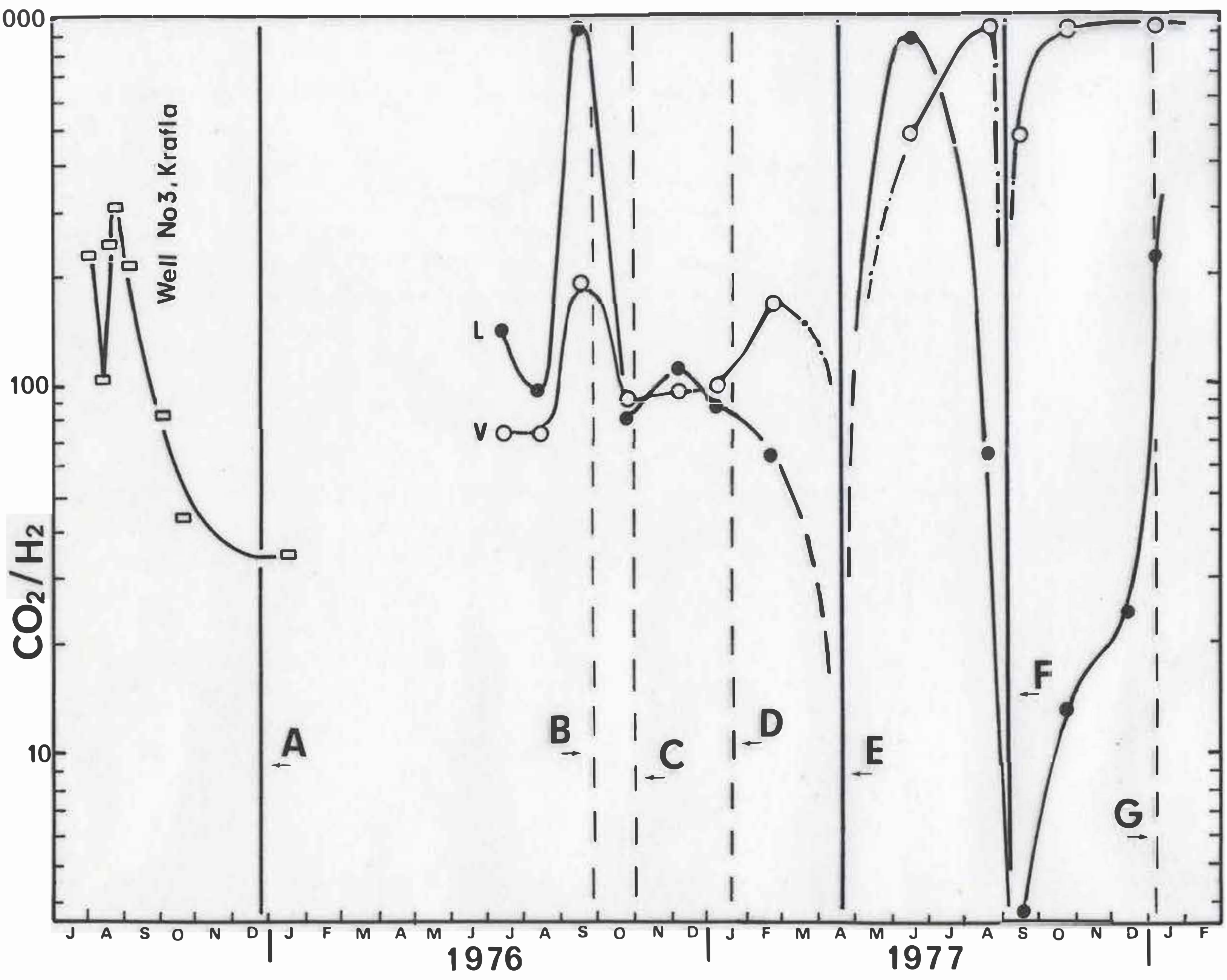
1000
100
10
CO₂/H₂
Well No3, Krafla
L
V
A
B
C
D
E
F
G
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F
1976
1977

FIG 5