MAPPING AT GRENSDALUR-REYKJADALUR AREA HVERAGERDI, SW-ICELAND

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ABSTRACT

The need to train the author in field mapping in a geothermal area prompted this study of the Grensdalur-Reykjadalur area. The area of study lies east of Hengill central volcanic complex in a high temperature geothermal field just N of the small town of Hveragerði.

From the stratigraphic sequence three alternating intervals of glacial-interglacial are deduced. Glacial erosion has exposed extensive alteration of hyaloclastite and basaltic rocks. XRD analysis and borehole study show chlorite zone occuring at the surface. Since this zone is observed at deeper levels within volcanic piles in geothermal areas, a fossil hydrothermal system has been inferred.

Structural features trending NE-SW and NW-SE have been associated with the geothermal activity. Water percolates through these permeable structures into the ground where it is heated by intrusions at shallow depths within the lava pile. A central volcanic complex is suggested by exhumed high topography, intensive dyke intrusion and the high temperature geothermal system.

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1. INTRODUCTION

1.1. Aim of study

In the exploration of a new geothermal prospect a study of the geology of the area is usually important as a first step towards understanding the future performance of the prospect. Geological study also offers a guide to other geoscientific methods for example geochemical sampling and the siting of the first exploration well in the area.
The aim of this study was therefore to offer the author practical training in field mapping in such a prospect area. Emphasis was put on the relationship of geothermal activity to structural features since it has been observed that geothermal activity is closely related to such structures. The study was carried out as part of the six month training programme organized by Orkustofnun (National Energy Authority of Iceland).

1.2. Location of study area

The study area is located east of the Hengill central volcano and fissure swarm and is regarded as one of the high temperature areas in SW Iceland (Fig 1). This area has been considered a central volcanic complex whose activity is on the decline and crustal spreading has been cited as the explanation for its having been displaced eastwards (Saemundsson, 1979).

2. GENERAL GEOLOGY OF SW ICELAND

The geology of SW Iceland is characterized by a zone of active volcanism and tectonics. It is the landward continuation of the Mid-Atlantic Ridge. The volcanic zone assumes ENE trend and is represented by NE trending fissure swarms arranged en echelon (Jakobsson et al., 1977).

Hyaloclastite ridges and table mountains (tuyas) are prominent geological features formed by volcanic activity during glaciation. During Holocene most of the lowlands within the volcanic zone have been covered by lava flows. Large volume lava production, high temperature geothermal fields and the high topography are factors suggestive of intrusive complexes near the centers of the fissure swarms. (Saemundsson, 1979). SW Iceland is also an active seismic zone whose seismicity has been attributed to an EW transform fault (Einarsson and Bjornsson, 1979).
The regional structure of the lava pile show dips towards the axis of the volcanic zone (Saemundsson and Einarsson, 1980). Steep dips just east of Hengill and the deep rooted lava piles shown on the section, Fig 2 (from Saemundsson and Einarsson, 1980) suggest a central volcanic complex.

3. PREVIUOS WORK

3.1. Geology

In his study of the Hengill area Saemundsson (1967) mapped the Dalir series as the oldest rocks in the SW part of the study area. According to him the Dalir series consists of both hyaloclastites and basalt lavas of olivine basalt and tholeiitic composition. However subdivision is missing. Dalir series are normally magnetized and evidently belong to the Bruhnes geomagnetic epoch (Saemundsson and Arnorsson, 1971). Saemundsson (1967) indicated a number of dykes and intrusions on his map. The idea of a central volcanic succesion was first presented by Saemundsson and Arnorsson (1971). See also Saemundsson (1979) and Saemundsson and Fridleifsson (1979). The study area lies mainly within the Dalir series.

3.2. Borehole geology

In the period 1958-61 a total of 8 holes were drilled in the area with the intention of building a power station at the southern margin. The idea has since been abandoned and only a few of the wells are now used for district heating and greenhouses by the local population.

From the study of downhole alteration Sigvaldasson (1963) observed that montimorillonite is the dominant clay at shallow depths after which chlorite dominates. Abundant calcite and zeolites are found throughout the drilled section below the acid zone. Laumontite is the commonest zeolite. Epidote occurs at greater depths and two possibilities have been advanced to interpret it's occurence. First that it is a relict mineral existing in a metastable state preserved from a fossil hydrothermal system and secondly it's formation under present conditions (Sigvaldasson, 1963). Temperature profiles show negative gradients at shallow depths of drilled section (Stefansson and Steingrimsson, 1981) indicating the upflow zone north of the drilled area i.e. within or north of

the study area.
In the present study XRD analyses of hyaloclastite samples show chlorite occuring at the surface.

4. GEOLOGY OF GRENSDALUR-REYKJADALUR AREA

4.1. Stratigraphy

The basis of stratigraphic classification is on whether the particular series or formation was formed during a glacial or an interglacial period. Postglacial lavas to the S of the mapping area are the youngest.
Three hyaloclastite formations and a similar number of lava series comprise the stratigraphic sequence corresponding to a minimum of 300 000 y since their time of emplacement.

4.1.1. Grensdalur hyaloclastite

Surface geology of the area (Figuress 3 a,b) identifies the Grensdalur hyaloclastite as the oldest rock. This formation covers most of the central part of the mapping area and also outcrops at the NW part where glacial erosion has exposed about 250 m of the pile. The total thickness is not known since the lower limit was not found. The hyaloclastite is interspersed with tholeiite basaltic intrusions of similar composition. These are believed to have been intruded in the later phase of the eruptive sequence while the hyaloclastite was still in a semi-solid state and can therefore be considered syngenetic.
This surmise is supported by a gradation from coarse grained intrusive basalts through a pillow breccia intermediate into hyaloclastite.

This formation has also been intruded by dykes and sheets of various thicknesses and orientations implying greater intrusive activity at depth. These may have acted as temporary heat source driving the hydrothermal system. Strong dissection by structurally controlled erosion has occured particularly in the northern part exhuming high degree alteration.

4.1.2. Djupagil lavas

Djupagil lavas outcrop on the SE part of the mapping area and consist of at least two flow units. The younger olivine tholeiite unit is about 10-15 m thick and bears striae marks of a past glacial period. The lower unit is a porphyritic tholeiite whose lower contact is buried beneath scree material.

4.1.3. Dalafjall hyaloclastite

Dalafjall hyaloclastite outcrops in the middle part of the mapping area between two portions of the Grensdalur hyaloclastite. High elevation areas within this series are capped by basaltic flows of similar composition which mark the emergence of the volcanic pile from subglacial enviroment (Jones, 1970).

Within this series steep dips have been observed which may be attributed to tectonic tilting. Faults with downthrows 20-30 m have been traced by comparing relative displacement of basaltic flows. At it's base the Dalafjall hyaloclastite has about a meter thick tillite layer. This indicates that between the eruption of Djupagil lavas and Dalafjall hyaloclastite a time of relative quisence occured. Some plagiophyric and non-porphyritic units are observed within it. The total thickness of this series fades out to the SW under Kviar lavas.

4.1.4. Kviar lavas

Kviar lavas are a series of tholeiitic basalts. They outcrop in the Western portion of the mapping area and are overlain by later hyaloclastites and lava flows. They consist of about ten flow units. These have been divided into 2 subseries: (a) consists of 7-8 flow units 2-3 m thick which represent successive pulses in the eruptive cycle without a marked time lapse between them, (b) 2-3 later flows about 10-15 m thick.

Between these two subseries is a 1/2 meter thick layer of fluviatile deposit. The grains are poorly sorted but cross-bedding structures are clearly seen within it.

4.1.5. Astaðafjall hyaloclastite

Astaðafjall and Reykjafjall hyaloclastites outcrop on the margins of the mapping area on the W and E respectively. These were not studied. However from the section both Reykjafjall and Dalafjall conform to the regional dip of the lava pile to the W. Since the Dalafjall is seen to thin out under Kviar series it is a fair approximation that both hyaloclastites were formed during the same glacial period.

4.1.6. Lateglacial lava

The Lateglacial Bitra lava covers the Western portion of the mapping area and a few other places where it lies on top of the Dalafjall hyaloclastite, Djupagill lavas and Kviar lavas. It consists of several flow units porphyritic in plagioclase.

4.1.7. Postglacial lavas

Postglacial lavas to the W and S of the mapping area were taken from Saemundsson's (1967) map.

All of these rock formations are normally magnetized and evidently belong to the present geomagnetic epoch, Brunhes. Through this stratigraphic column (Fig 3 c) three alternating intervals of glacial and interglacial are discerned. If a 100 000 y interval is assumed for each glacial-interglacial cycle, this suggests an age of about 0.3 my.

4.2. Structural formations

Basaltic dykes and sheets about 1-2 m wide and striking NNE-SSW (Fig 6) are observed within the Dalafjall and Grensdalur hyaloclastites. One rhyolitic dyke trending N45E was seen cutting through Grensdalur hyaloclastite. A great number of them have dips of 10-15 degrees W especially those within Grensdalur hyaloclastite. Most of these dykes have been formed by lateral magma flow during rifting episode(s) if the concept of a central volcano holds in the area. Dyke density is about 0.2% within Grensdalur hyaloclastite.

A great number of fissures were observed to have cut both Grensdalur and Dalafjall hyaloclastites. While it is easier to classify some of the fissures within Dalafjall hyaloclastite as faults due to displacement of basaltic flows, it is not possible to do the same within the Grensdalur hyaloclastite: it is a monogenetic formation.

These fissures have been divided into two; first those that were actually observed and/or inferred in the field (Fig 4) and those that were deduced from examination of aerial photographs (Fig 5). A plot of rose diagrams (Fig 6) show two dominant stuctural orientations, NE-SW and NW-SE for those structures obtained from aerial photographs. The NE-SW trending fissures cut through the young lavas on the West and are therefore the younger. Another N-S trending set also cuts the young lavas. Exact time relationship was not determined. While geothermal manifestations are related to fissures and faults none seem to have any direct relationship with dykes as would be expected.

Several landslides have been mapped. The one on Reykjafjall makes it possible to trace Grensdalur hyaloclastite as an underlying exposure. These may have been prompted by tectonic activity or they are due to gravitational slumping owing to the high precipitation in this area or a combination of the two which is the more likely. In spite of the great number of structural features, surface drainage is not signicantly affected by structural trends except the middle course of Djupagil. The predominant southerly direction of the tributaries of Varma appear to be controlled more by topography rather than by stuctural trends.

4.3. Thin sections

Microscope analyses of thin sections from the area show that except for the rhyolitic dyke found within Grensdalur hyaloclastite the rocks are tholeiitic to olivine tholeiitic with possible gradations between the two. The rocks are highly altered where olivine has been replaced by clay minerals in most of the sections. Olivine occurs only as a relict. Many vesicles are filled with secondary minerals, calcite, smectite and probably zeolites. In some vesicles secondary mineral infilling is sequential with calcite forming the core and smectite forming a rim around it. Crystalline occurence of calcite, quartz and pyrite is suggestive of stable hydrothermal conditions during their time of formation. In addition to relict olivine the other primary minerals observed are plagioclase, whose laths intergrow with pyroxene (ophitic texture). In other samples the laths grow side by side with pyroxene (interstitial texture). Magnetite is abundant in most of the samples with slight alteration (oxidation?) to haematite.

The rhyolitic sample (14743) was taken from a dyke which had chilled margins against the host rock, Grensdalur hyaloclastite. Under the microscope it exhibits flow bands (low viscosity magma) and strong haematite staining.
For such strong oxidation to have taken place there must have been infusion of oxygen into the system. This means that the geothermal fluid had either cooled down significantly to allow oxygen to dissolve or there was sufficient mixing with meteoric water. Geothermal waters in high temperature areas are devoid of oxygen. The large number of vesicles seen indicate presence of magmatic gases most likely hydrogen sulphide and carbon dioxide which exsolved as a result of changing conditions of temperature and/or pressure. A few rhyolitic dykes have been mapped in the vicinity of this area (Saemundsson, personal communication, 1987).

4.4. Geothermal activity / alteration

Geothermal activity may be divided into two broad groups: the extinct (regional) and the recently and presently active areas. The extinct activity is evidenced by greenish altered hyaloclastite and basaltic rocks occuring within the oldest rock unit, Grensdalur hyaloclastite. Alteration of the rocks have resulted in replacement by kaolinite, smectite and probably zeolites. In some vesicles calcite and smectite infillings are observed while in other cases calcite, pyrite and quartz in crystalline form were observed occuring together. The latter suggests stabilized rock-fluid equilibrium; a mature hydrothermal system.

Most of the presently active and recently active areas are hot springs, steam vents, steaming ground and boiling mud pools belonging to the former and altered ground of the latter. Although they are distributed throughout most of the mapping area majority of the manifestations are found in the central part some evidently lying linearly (Fig 7). It is appropriate to note here that these could be one and the same activity which has shifted probably due to tectonic deflection and/or self sealing. Around the presently active areas reddish-brown iron compounds dominate over green, whitish and yellow deposits corresponding to smectite, kaolinite (zeolites?) and sulphur.
No chemical analysis was however carried out to confirm them. A first XRD analysis of surface samples shows smectite and chlorite as the dominant clay minerals. Both chlorite and pyrite are high temperature minerals formed at depth within volcanic piles in geothermal systems. Their occurence at the surface in this area is therefore strong indication that erosion has exhumed a fossil hydrothermal area. This in effect means that the area may be having an imprint of hydrothermal systems. This observation compares well with borehole data in the S margin which show chlorite occuring at depths of about 100 m (Sigvaldasson, 1963). Cross-cutting mineral veins were observed but not studied. Since it is

believed that at least two hydrothermal systems have been in existance their (mineral veins) study may reveal this history (Fridleifsson, 1983).

Geothermal manifestations are arranged in such manner that their alignment conforms with the structural trends, at least some of them. Other manifestations and particularly those in the central area have been affected by rock slumping so that the linear arrangement is obscured. Worth noting is that very few manifestations are found within the Dalafjall hyaloclastite and also that the manifestations are concentrated in areas of low topography.

5. DISCUSSION

The idea of a central volcano is strongly evident and a number of observations tend to confirm it: the high temperature geothermal system and extensive alteration suggesting presence of intrusions at shallow depths as the source of heat; the great number of thin dykes and sheets; the occurrence of rhyolitic dykes and the high topography of the exhumed lava pile that may have been a result of high volume volcanic eruption, an observation associated with central volcanoes.

In addition it has been observed that the rocks underlying the Grensdalur-Reykjadalur rock pile and to the E of this area are reversely magnetized (Saemundsson and Arnorsson, 1971).This implies that the life span of this volcano is younger than 0.7 my which is consistent with the minimum three glacial-interglacial intervals deduced from stati-graphy.

Precipitation in this area is high. Water percolates through the permeable faults and fractures where it is heated by shallow intrusions in the volcanic pile. A convection gradient is then created resulting in a hydrothermal system (the target of geothermal exploration). This area lies within the EW transcurrent fault zone whose strike-slip movement keeps them open.

The classical subglacial eruptive sequence was not very manifest. Some pillow fragments and breccia were observed embedded in the hyaloclastite masses. In case of Dalafjall rock formation it's subaerial products are observed while the picture is unclear for Grensdalur hyaloclastite.

Temperature profiles from the 8 drillholes located in the area show negative gradients at shallow depths. A profile across them show declining temperature from N to S. This indicates that at these depths the wells encounter horizontal outflow zones. For the purpose for which these wells were intended their siting was poor: the upflow zone is to the N i.e. within or north of the study area where thermal activity is greatest.

6. CONCLUSIONS

The stratigraphy of this area shows that this is a central volcanic complex that is slowly being displaced eastwards away from the axial rift zone by crustal spreading.

Structural features, faults, fissures (and dykes) control geothermal activity which are kept open by active tectonics.

Glacial erosion has exhumed a fossil hydrothermal system on which the present system is imprinted.

Intensive alteration of hyaloclastites and basaltic rocks has led to replacement of primary minerals with clay minerals.

Before siting of drillholes in a new geothermal prospect a thorough study is called for as the mere presence of altered ground is not sufficient data. Shifting and/or deflection of activity may be the cause of the alteration.

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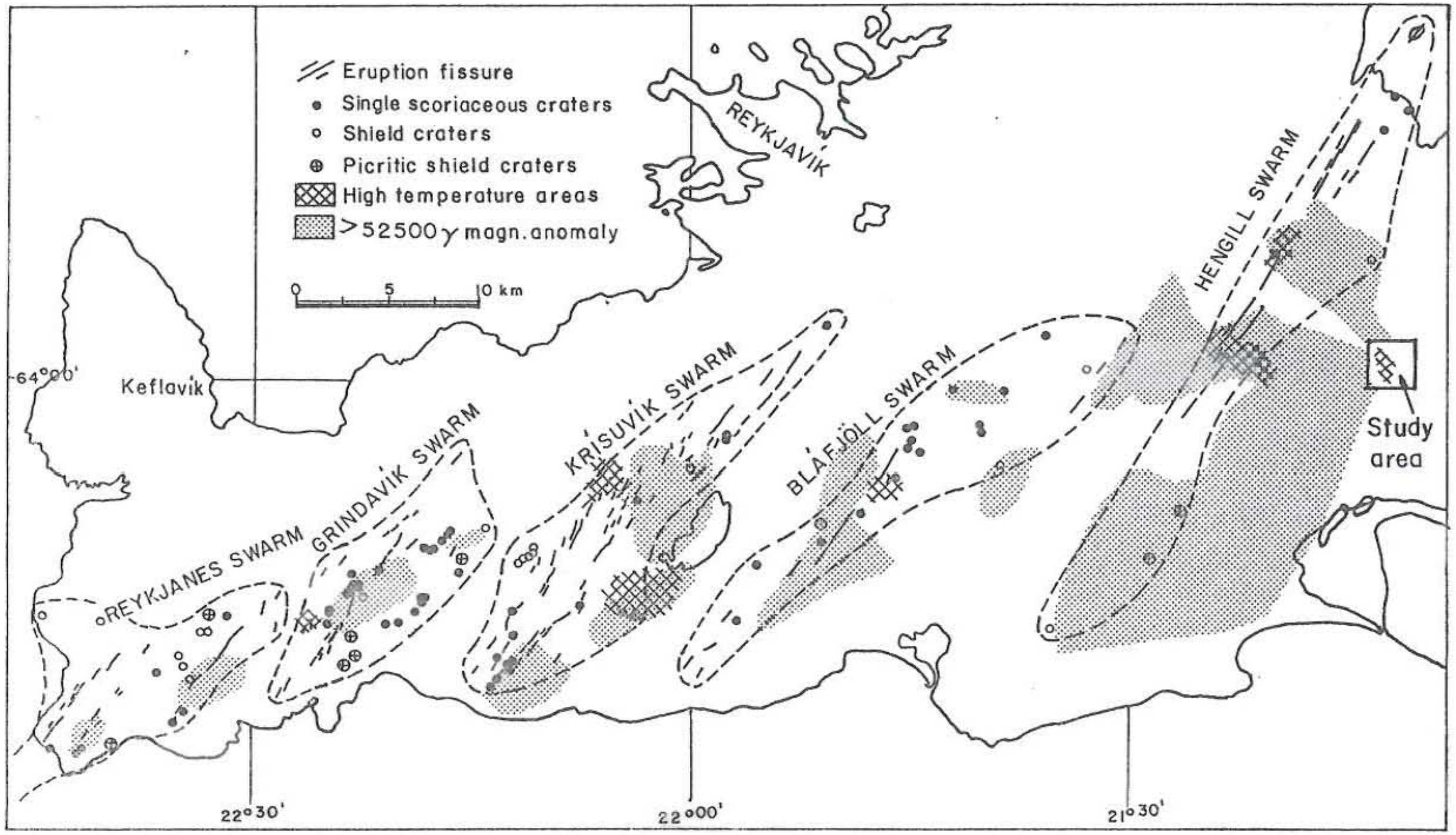

Figure 1 Location of study area

Figure 2 Cross section across SW Iceland showing general dip of the lava pile

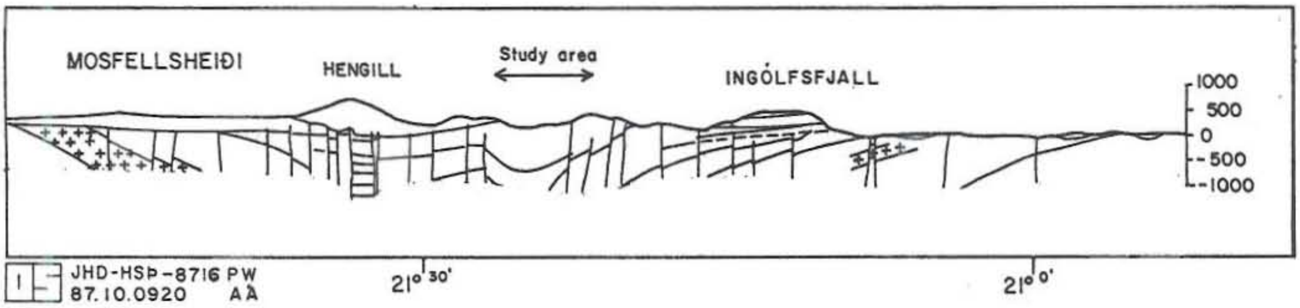

Figure 4 Structural map of Grensdalur-Reykjadalur area

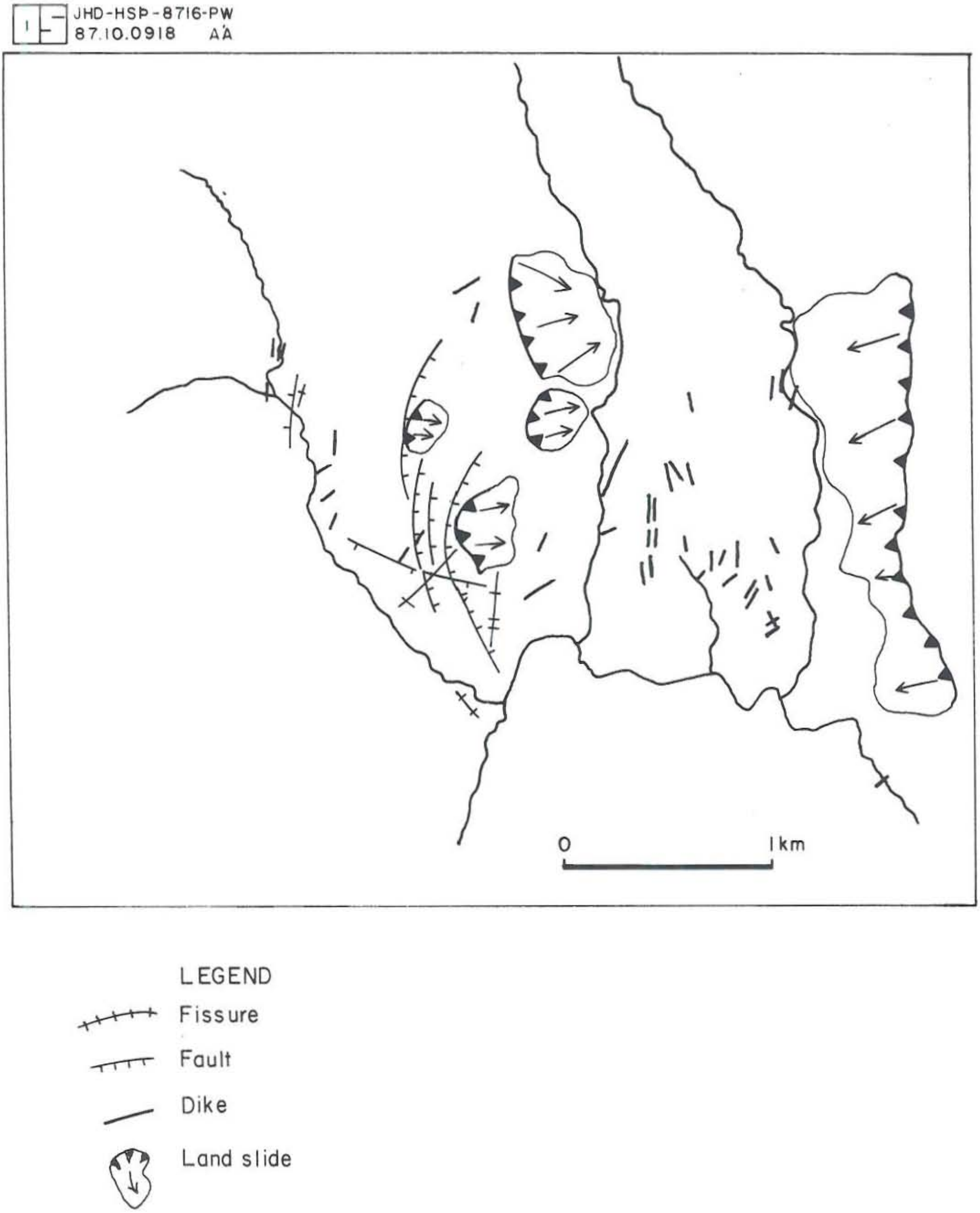

Figure 5 Structural map of Grensdalur-Reykjadalur area from aerial photographs

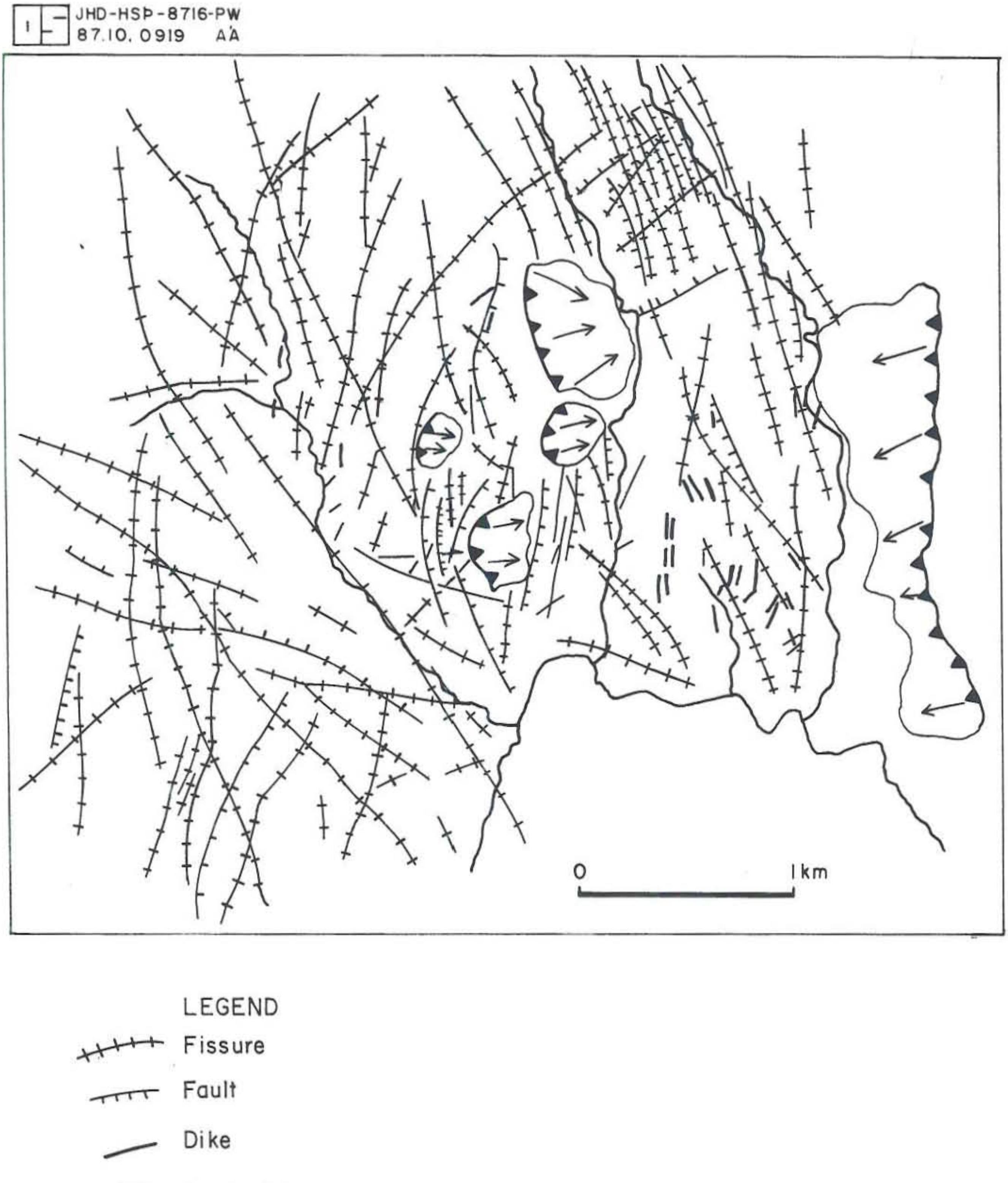

Figure 6 Rose diagrams for structural orientations

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