

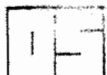
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REYKIR - REYKJAVÍK

Investigation of three low-temperature geothermal
areas in Reykjavík and its neighbourhood.

Jens Tómasson and Hrefna Kristmannsdóttir

Prepared for the International Symposium on
Water-Rock Interaction
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ABSTRACT

Results from investigations of three low temperature areas are presented and compared. Two of the areas are subareas of the Reykjavík (capital) geothermal area and the third, Reykir, is about 20 km from Reykjavík.

The temperature ranges from 60 centigrade to 126 centigrades. There are three main rock types: basalts, hyaloclastics, and dolerite intrusions. The mineral paragenese in those areas strongly indicate cooling in the systems.

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Introduction.

The Reykir and the Elliðaár area and Seltjarnarnes peninsula are situated in South Western Iceland (see fig. 1). Those areas are all utilized for the house heating of Reykjavík, the capital city, and the neighbourhood. The Elliðaár and Seltjarnarnes are subareas of the big geothermal system usually named the Reykjavík (the capital city) geothermal area. One of the other subareas in the Reykjavík area, Laugarnes, has been described before by Sigvaldason (1963). The division between the subareas is reflected by different chemical and isotopic composition of the water (Árnason and Tómasson 1971).

The Reykir area has been exploited since 1944, but in 1969 more intensive exploration started. There are now drilled yearly about ten deep (up to 2000 m deep) drillholes. The water composition is similar in the whole area and very like that of the Elliðaár area.

Table 1 shows the significant chemical analysis of the water from each area.

All these geothermal areas are situated on the flanks of the volcanic zone in rocks of Quaternary age (see fig. 1).

The areas are low-temperature geothermal areas (Bödvarsson 1961). Maximum temperatures and thermal gradients are different between the areas and also within the individual areas. In fig. 2 are shown some typical temperature curves from each area. These curves will be further discussed in a later section.

The subsurface geology of the areas.

In fig. 3-5 are shown geological sections through each area.

The Elliðaáir and Seltjarnarnes areas are covered by olivine tholeiite basalts of late interglacial age. The lavas are underlain by sediment and beneath there is a major discordance. The underlying rocks are a succession of lavas and hyaloclastites of Quaternary age. These rocks are tilted in towards the present volcanic zone (see fig. 1). The regularity of the succession is however disturbed by two central volcanoes (Friðleifsson, 1973). The Elliðaáir and Laugarnes area are on the outskirts of the Kjalarnes central volcano, but the Seltjarnarnes area some distance away from it. The Reykir area is situated between the Kjalarnes and Stardalur central volcanoes.

In the Elliðaáir area interglacial basalts with sedimentary interlayers are found in the uppermost 200-400 m depth. Beneath that depth to about 1000 m depth are three main horizons of breccia and tuff divided by basalt layers and dolerite intrusions. Beneath 1000 m basalts are dominant.

In Seltjarnarnes the uppermost 300-400 m depth (beneath the top layers) are basalts interbedded with hyaloclastites in about equal amounts. Series of basalts interbedded by thick sedimentary layers are found from 600-800 m depth. From 900 m to 1000 m hyaloclastic rocks predominate. From 1000 m to the deepest part reached by drilling basalts are the dominant rocks.

In the Reykir area the hyaloclastic formation reaches to the surface and is dominant to 1000-1200 m depth. Beneath that depth are basalts with some hyaloclastites dominant down to 2000 m. Dolerite dykes are intruded into those lower formations in increasing amount with depth. In all these areas we have similar geological features with hyaloclastic formations common to at least 1000 m depth, but their magnitude is much less in the Seltjarnarnes area than in the others.

Alteration of the rocks.

The magnitude of alteration is dependent on the rock type, temperature, permeability of the rocks and water composition.

The geothermal system reaches to the surface in Reykir area and so does the alteration. But in the other two areas there is negligible hydrothermal activity on the surface. The geothermal alteration is slight down to 200 m depth in the Elliðaáir area. In fig. 6 are shown sections for typical drillholes from each of the areas. In the sections are shown simplified stratigraphic sections, distribution of secondary minerals and the estimated rock temperature.

Silica minerals.

Opal is found in the top layers and is there often the only secondary mineral together with iddingsite. Opal is also found in zones from about 500 m down to 1000 m depth. Quartz is found in the Elliðaáir area below 1000 m.

In the Seltjarnarnes area quartz is found at a greater depth and there seems to be a connection between the present temperature and the occurrence of quartz. Only at temperatures above approximately 120°C a continuous occurrence of quartz is found. In the Reykir area quartz is found much higher up in the section and cannot be correlated with the prevailing temperature conditions.

Zeolites.

The zeolite zone covers nearly the range of the deepest holes. Chabazite is the first to appear in Elliðaáir and Seltjarnarnes areas and forms a zone down to 300-400 m depth. In Reykir the chabazite zone is mostly lacking, but it is found with levyn in some holes above 100 m.

Mesolite - scolesite forms the next zone but reaches the surface in most of the Reykir area. Thomsonite is mainly found in this zone. The mesolite-scolesite zone, where clearly defined, reaches down to about 500 m. Stilbite is usually found at a little greater depth than mesolite-scolesite and sometimes forms a zone beneath. These two zones are not clearly separated and the formation of either mineral is considered to be dependent on the rock type.

Seltjarnarnes. Prehnite is first recognized at about 1700 m at the same level as epidote is found. Prehnite and epidote are restricted to the olivine tholeiite basalt series below 1700 m. The epidote in Seltjarnarnes has different optical properties and is probably nearer to clinozoisite in composition than the epidote from the two other areas.

Other Minerals.

Pyrite is found locally concentrated, not dependent on depth. Haematite is found sporadically in some sediments and hyaloclastic rocks.

Traces of gyrolite and reyerite are found in the upper part of some of the drillholes in the Reykir area.

Clay Minerals.

Reykir. Smectite minerals are found up to the top of the section and are dominant down to about 400 m depth. Chlorite is dominant from 600-700 m. In between, smectite minerals and various kinds of mixed-layer minerals of chlorite and smectite are found alternatively or together.

Elliðaár. The first occurrence of smectite minerals is in the basalt at about 200 m depth. They are not dominant secondary minerals until at 400-500 m. Chlorite occurs first at 700-900 m depth and is found together with smectite down to 1400 m. Beneath 1400 m chlorite and "swelling chlorite" are found together.

Seltjarnarnes. Smectite is the dominant clay mineral from 100 m to 500 m. Chlorite is found from 1100 m and is dominant below 1500-1700 m. In the zone between, randomly mixed-layer minerals and smectites occur together.

Celadonite is found in Seltjarnarnes in a zone from 100-150 m depth. Celadonite is also found in one drillhole in the Elliðaáir area at 800-900 m. It is not known in the Reykir area.

The clay minerals were identified by x-ray diffraction. Partial chemical analysis and DTA analysis have been performed on some of the samples. The smectites are, as in most basaltic rocks so far investigated, from deep drilling in geothermal areas in Iceland, tri-octahedric and iron-rich. There is supposed to be a gradual change from the smectite minerals through smectite interlayered with chloritic layers to chlorite. By x-ray diffraction the interlayered minerals and chloritic minerals with poorly developed brucite layers are identified as various types of mixed-layer minerals and swelling chlorites. Detailed investigation of similar minerals from other areas (Kristmannsdóttir, in prep. and Kristmannsdóttir and Tómasson, 1974) has shown close similarity in structure and composition of all those minerals.

Discussion.

Summing up the results from all areas shows that the main zeolite zones are the same in all areas from the top to the bottom:

- 1) chabazite zone
- 2) mesolite/scolesite zone
- 3) stilbite zone
- 4) laumontite zone.

In Reykir the uppermost zone is almost lacking.

The clay minerals form three main zones:

The uppermost with dominant smectite and its first occurrence is dependent on the rocktype (see section 3, p. 6).

The lowest zone with chlorite as the dominant "clay" mineral and an intermediate zone with interstratified minerals of smectite and chlorite, together with one or the other or both of them. Those zones are the same as found in the few investigated high-temperature geothermal areas (Tómasson and Kristmannsdóttir, 1972). The clay mineral zones are however not so clearly defined as in the high temperature areas.

Very complex processes have created the final alteration scheme found in those low temperature geothermal areas. Remnants of former high-temperature alteration partly in connection with the central volcanoes, the results of slight retrograd alteration and alteration in progress due to the prevailing heat conditions all occur together in a confusing picture. To interpret this picture experimental data for the alteration minerals are needed. They exist for some of the simpler zeolites but for the more complex minerals data are scarce. Comparison with alteration in other geothermal areas, especially high-temperature areas, where similar minerals are formed, can often give some information. Of the minerals not found to be in connection with the measured temperature are epidote and prehnite. The formation of quartz, and perhaps chlorite too, would not be expected at so low temperature as those minerals are found at in Reykir. To some extent this is also valid for the Elliðaáir area, but in the Seltjarnarnes area those minerals seem to be nearer to equilibrium conditions.

The alteration in the Reykir area is much greater both in amount and degree than in the two other areas even though the temperature is about 20-30°C lower. As mentioned in the case of prehnite there are at Reykir signs of retrograde alteration between epidote-prehnite and this is also observed in the case of the clay minerals.

The zeolites also show in some cases irregularities in the zones which could indicate retrograde formation but this is less obvious than for the others.

As stated before the mineralogy in Seltjarnarnes appears to be in closer equilibrium with the thermal condition than in the other areas. Signs of retrograde metamorphic processes are not found. This is because the area lies outside the zone affected by the central volcano.

References.

Árnason, B. and Tómasson, J. (1970). Deuterium and Chloride in Geothermal Studies in Iceland. Geothermics, special issue, vol. 2, part 2, 1405-1415.

Bödvarsson, G. (1961). Physical characteristics of natural heat resources in Iceland U.N. Conference on new sources of energy, vol. 2, Rome.

Friðleifsson, I.B. (1973). Petrology and structure of Esja quaternary volcanic region, southwest Iceland. Unpublished D.Ph.Thesis. Oxford University.

Kristmannsdóttir, H. in prep.

Kristmannsdóttir, H. and Tómasson, J. 1974.
Nesjavellir. Investigation of a high-temperature
geothermal area (this symposium).

Sigvaldason, G. 1963. Epidote and related minerals
in two deep geothermal drillholes, Reykjavík and
Hveragerði, Iceland. U.S.A. Geol. Surv. Profess.
Papers, 450-E, 77-79.

Tómasson, J. and Kristmannsdóttir, H. 1972.
High Temperature Alteration Minerals and Thermal
Brines, Reykjanes, Iceland. Contr. Mineral and
Petrol., 36, 123-134.

Figure captions.

Fig. 1. Geological map of south-west Iceland with index map.

Fig. 2. Four typical temperature curves from the three areas.

Fig. 3. Geological section through the Elliðaár area. Legend for stratigraphical column in figs. 3-5.

1) Fresh basalt, 2) Altered basalt, 3) Tholeiite basalt, 4) Olivine tholeiite basalt, 5) Altered and fresh tholeiite basalt, 6) Dolerite intrusion, 7) Basalts and hyaloclastites, 8) Basalts and sediments, 9) Basalt rich breccia, 10) Breccias and tuffs.

Fig. 4. Geological section through the Seltjarnarnes area.

Fig. 5. Geological section through the Reykir area.

Fig. 6. The distribution of the secondary minerals in a typical drillhole from each area. Legend for the mineral classification.

1) Smectite, 2) Mixed-layer minerals, 3) Chlorite, 4) Chabazite, 5) Thomsenite, 6) Mesolite/Scolecite, 7) Mordenite, 8) Stilbite, 9) Heulandite, 10) Laumontite, 11) Analcite, 12) Calcite, 13) Quartz, 14) Epidote.

TABLE 1.

Major component composition of water from a significant drillhole in each area.

Locality	Temp. °C	SiO ₂	Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	*CO ₂	SO ₄ ⁻⁻	S ⁻⁻	Cl ⁻	F ⁻
Seltjárnarnes											
Drillhole S-4	114	101	362	10	132	0,09	17	209	<0,1	554	0,95
Reykjir											
Drillhole MG-10	78	72	45,6	0,6	2,2	<0,1	35	14,4	<0,1	13,2	0,7
Ellidáár											
Drillhole G-23	100	130	48	1,2	1,5	0,24	48,7	27	-	19,2	0,4

* Total carbonate as CO₂

Fig. 1.

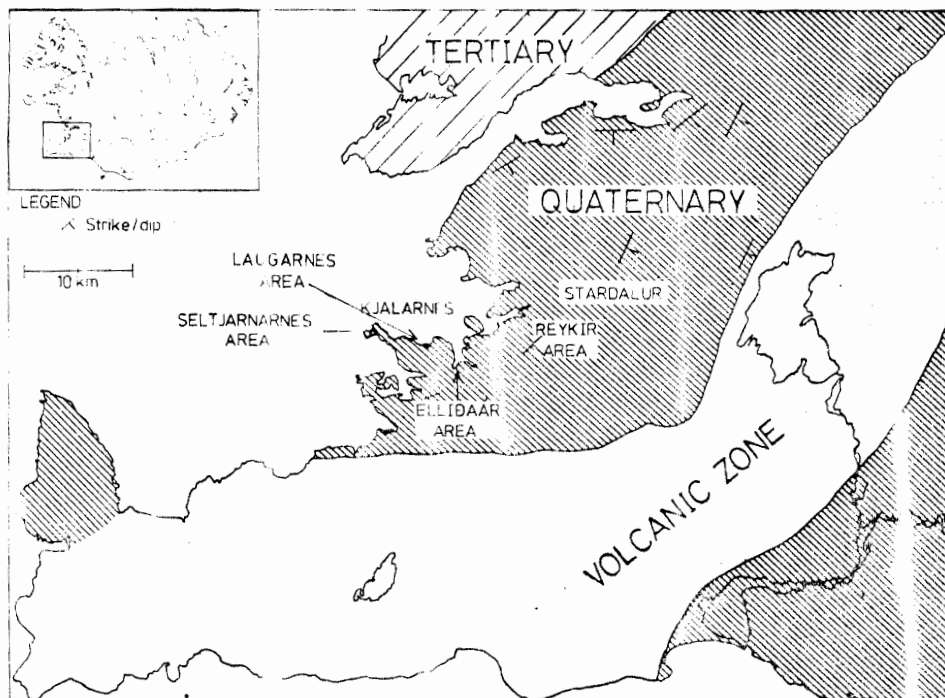


Fig. 2.

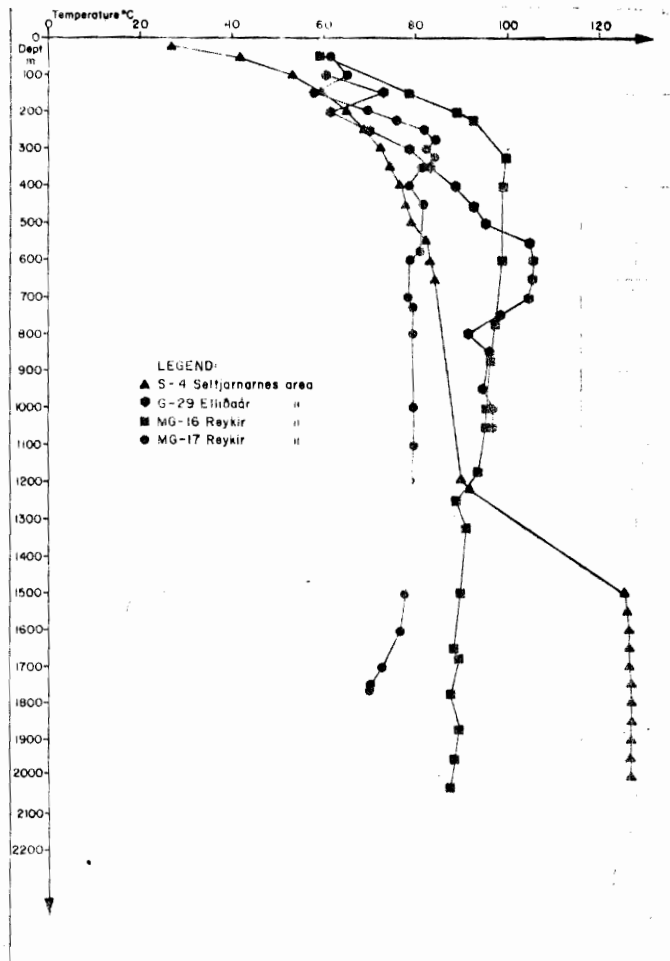


Fig. 3.

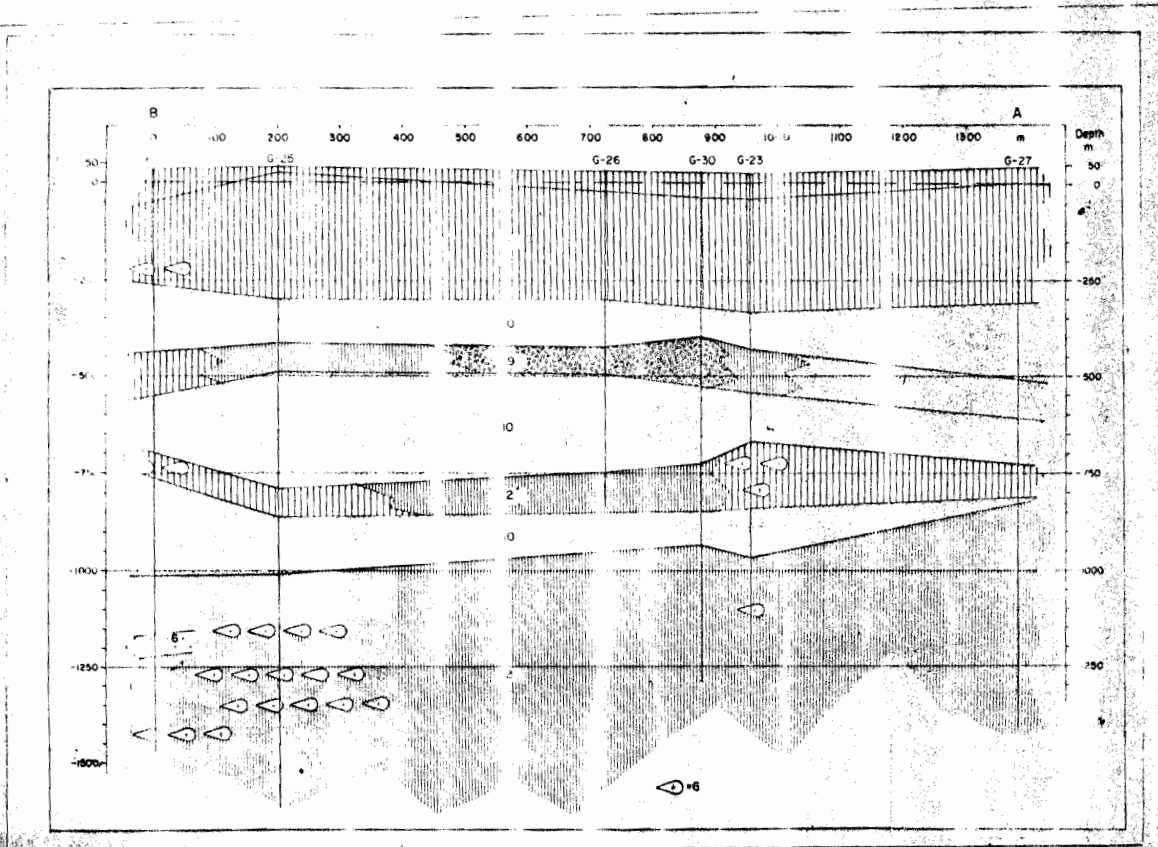


Fig. 4.

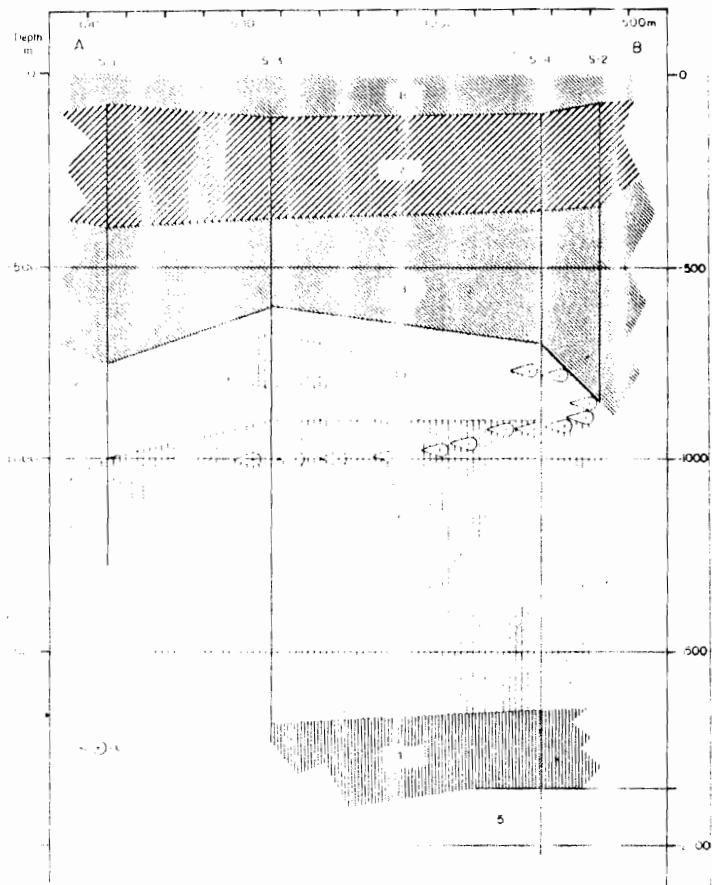


Fig. 5.

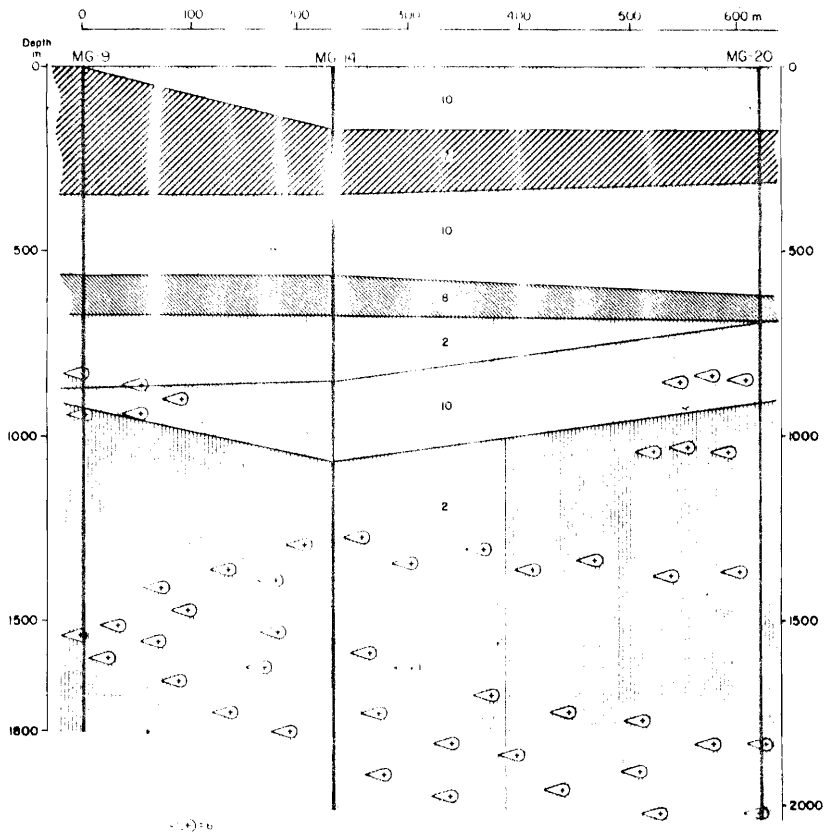


Fig. 6.

