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Isotopic Characteristics ($\delta^{18}O$, δD, $\delta^{13}C$, ^{14}C) of Thermal Waters in the Mosfellssveit and Reykjavík Low-Temperature Areas, Iceland

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ABSTRACT

The paper focuses on the isotopic composition of thermal waters in five low-temperature areas within the Reykjavik region, Iceland. The waters have been utilized for decades and very little change in oxygen and hydrogen isotope ratios have been observed with time. The thermal waters are depleted in the stable isotopes of oxygen and hydrogen compared to the local precipitation but to a different degree. This is explained by the origin of the waters, which may either be represented by precipitation in the mountainous areas northeast of the Reykjavik region where isotopic composition of local precipitation is similar to the isotopic composition of the thermal waters or by the presence of a pre-Holocene component in some of the thermal fields. For the first time carbon isotopes are systematically studied within the areas. A clear and systematic difference is observed both in the $\delta^{13}C$ and ^{14}C values for different fields. Accordingly, the carbon isotopes help in defining the systems and the origin of thermal waters. However, further studies are needed to conclude whether or not a pre-Holocene component is present in some of the geothermal waters.

1. INTRODUCTION

The thermal energy of low-temperature geothermal resources (T_{max}=130°C) within the city of Reykjavik and the neighbouring county of Mosfellssveit has been utilized for bathing, laundry-washing and space heating for decades. Five distinct thermal areas, Laugarnes, Ellidaár and Seltjarnarnes within and adjacent to the city of Reykjavik, and Reykir and Reykjahlíd in the neighbouring county of Mosfellssveit (Figuer 1) have been recognized on the basis of hydrological, thermal, chemical and hydrogen isotope data (Tómasson et al., 1976).

The study area is situated just west of the active rifting and volcanic zone in SW-Iceland. The geology is characterized by early Quaternary volcanics, consisting of thick successions of low porosity lavas intercalated by high porosity subglacial volcanics (hyaloclastites). It has been proposed that water may flow at depths from the highland areas towards the coast through this high porosity subglacial volcanics (Tómasson et al., 1976). Three central volcanoes have been identified in the area, thus explaining the thick successions of volcanics in the area as well as the abundance of shallow level dykes and sheets on one hand and fissures on the other.

The present thermal activity is located by the caldera rims of the central volcanoes of the area and active fissures and faults with northeasterly direction, which have formed as a consequence of dilation in the volcanic zone of the Reykjanes peninsula (Figure 1). These fissures and faults break up older rock formations and thus produce secondary permeability.

The origin of the thermal waters has been traced by deuterium to the mountainous areas northeast of the Reykjavik district, where isotopic composition of local precipitation is similar to the isotopic composition of the thermal waters, but considerably lighter than the local precipitation in Reykjavík (Árnason, 1976). A different hydrological model for the thermal areas was proposed by Arnórsson et al. (1991). In the case of Mosfellssveit the water is assumed to flow along the Krísuvík fissure swarm, both from the southwest and the northeast, where the origin of the depleted water is considered (Figure 1). The thermal water in the Laugarnes system is assumed to flow from southwest along the Reykjanes fissure swarm (Figure 1). The depleted nature of the Laugarnes water is explained by a pre-Holocene component. In the model of Arnórsson et al. (1991) the thermal systems are all considered to be convection systems drawing heat from the roots of old central volcanoes in the area. Maximum temperature is

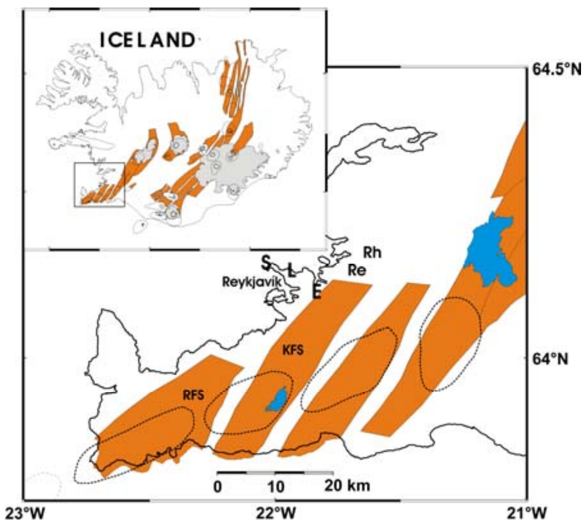

Figure 1. Loacation map of the five low-temperature geothermal areas within the city of Reykjavík and the neighbouring county of Mosfellssveit. The capital letters indicate the location of the different areas; L **(Laugarnes),** E **(Ellidaár),** S **(Seltjarnarnes),** Re **(Reykir) and** Rh **(Reykjahlíd). The Reykjanes fissure swarm (**RFS**) and the Krísuvík fissure swarm (**KFS**) are also shown.**

presently around 130°C, however the occurrence of the alteration mineral epidote suggests higher temperatures at earlier times. Stable isotopes have been measured in the thermal waters occasionally since 1963 and altogether the number of measurements is ~100. Very little change has been observed with time and only in the case of the Reykir and Ellidaár fields, have enriched surface waters been observed infiltrating the systems, accompanied by decrease in temperatures.

In the present study 25 water samples were collected for isotopic and chemical measurements. In this paper only the isotopic results will be discussed and used to shed light on the origin and relative age of the thermal waters.

2. ANALYTICAL METHODS

Oxygen was extracted from the water samples following the method of Epstein and Mayeda (1953) and for the hydrogen isotope analyses, the H_2-water equilibration method using a Pt-catalyst was applied (Horita, 1988). The sample preparation for carbon isotopes was done in accordance with McNichol et al. (1994), i.e. the water samples were acidified in a vacuum system and CO_2 extracted directly by nitrogen flow through the water sample. The collected CO_2 was then partly used for $\delta^{13}C$ measurements and partly converted to graphite for AMS ^{14}C measurements (Sveinbjörnsdóttir et al., 1992). ^{14}C results are normalised to a $\delta^{13}C$ value of -25‰ PDB and expressed in "percent modern carbon" (pMC) relative to 0.95 times the ^{14}C concentration of the NBS oxalic acid standard (HoxI) or conventional radiocarbon years BP.

Stable isotope analyses for oxygen, hydrogen and carbon were performed on a Finnegan MAT 251 mass-spectrometer. The results are defined in the conventional δ-notation in ‰, relative to the standards VSMOW for oxygen and hydrogen, and VPDB for carbon. The accuracy of the measurements is better than 0.05, 0.7 and 0.1‰ for oxygen, hydrogen and carbon, respectively.

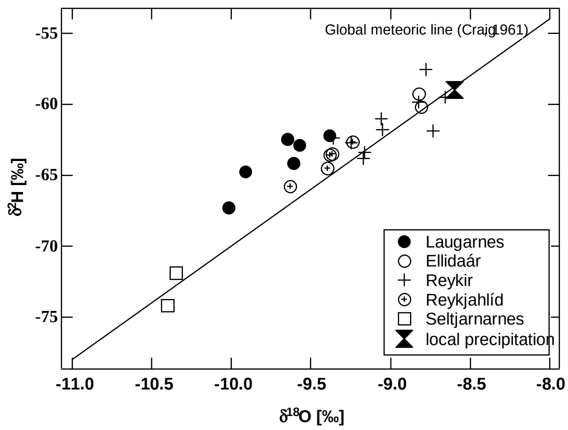

Figure 2. The relation between the oxygen and hydrogen isotope composition of the geothermal waters. The isotopic composition of local precipitation is shown for comparison as well as the global meteoric line (Craig, 1961).

3. RESULTS

3.1 Stable isotopes of oxygen and hydrogen

Table 1 shows the analytical results of the 25 samples collected for this study. It can be seen from the table and Figure 2 that considerable differences exist in the isotopic composition of the thermal waters, circulating in the different geothermal systems. The oxygen isotopic ratios in the Ellidaár (-8.8‰) and partly in the Reykir area (-8.7 to -9.3‰) are similar to present day local precipitation (-8.6‰), but considerably lower in the Laugarnes (-9.6 to -9.9‰), Seltjarnarnes (-10.4‰) and Reykjahlíd (-9.2 to -9.6‰) areas. Hydrogen isotopic ratios lie between -58‰ to -74‰ and the deuterium excess values ($d=8*\delta^{18}O-\delta D$) vary from 10 and 13‰ (in the Laugarnes system). In none of the systems, an oxygen isotopic shift is observed, although the present temperatures are 130°C in Laugarnes, Seltjarnarnes and Reykjahlíd and 90°C in Ellidaár and Reykir. In many of the other Icelandic thermal systems, the oxygen shift is observed at temperature as low as 80°C (Arnórsson et al., 1995).

A good correlation is observed between $\delta^{18}O$ and water temperature in the Mosfellssveit systems (Reykir and Reykjahlíd) as depicted in Figure 3. The waters become more depleted in $\delta^{18}O$ with increasing temperature, which is in accordance with a mixing model between depleted, hot deep water and local, colder groundwater. Two samples do not fit this model (5 and 30), where water temperatures are exceptionally low compared to $\delta^{18}O$.

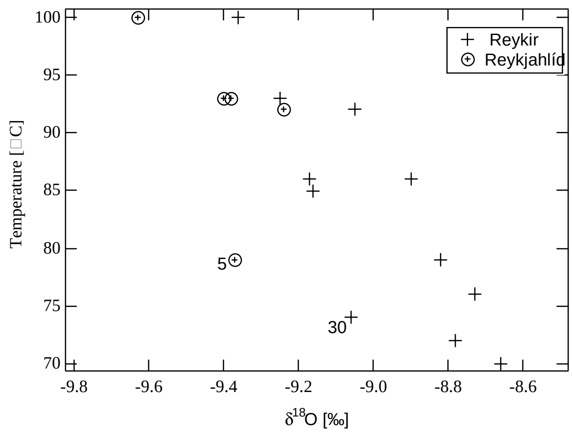

Figure 3. Relation between water temperature and $\delta^{18}O$ in the Mosfellssveit geothermal fields, Reykir and Reykjahlíd.

3.2 Carbon isotopes

A systematic difference is observed in the $\delta^{13}C$ values of the thermal waters circulating the different geothermal fields as seen in Table 1 and Figure 4, where a correlation between $\delta^{13}C$ and $\delta^{18}O$ is shown. The waters in the Ellidaár system and some of the waters in the Reykir system have the lowest $\delta^{13}C$ values (most negative) and highest $\delta^{18}O$ values i.e. they correspond to local precipitation. The waters in the Seltjarnarnes and Reykjahlíd systems have the highest $\delta^{13}C$ values (least negative) and the lowest $\delta^{18}O$. The water in the Laugarnes area is similarly depleted in $\delta^{18}O$, whereas its $\delta^{13}C$ is considerably more negative (~ –10 ‰).

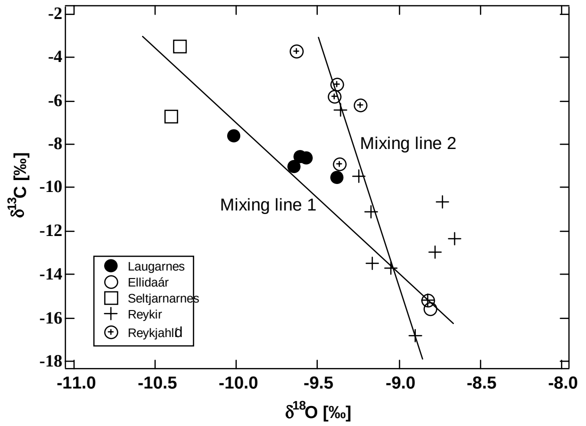

Figure 4. The relation between δ^{18}O and δ^{13}C of the thermal waters.

A possible explanation for the observed δ^{18}O and δ^{13}C correlation (Figure 4) is that the waters flowing into the Ellidaár and Reykir areas is local precipitation which contains organic carbon from the soil zone, most likely young, whereas a deep groundwater flows into the thermal systems of Seltjarnarnes and Reykjahlíd. The Seltjarnarnes system contains thermal water that is about 1‰ more depleted in δ^{18}O than the Reykjahlíd system, whereas the carbon isotopes in the two systems are very similar, suggesting two distinct deep relatively old groundwater currents that flow into the systems. The Laugarnes system lies between the two in δ^{18}O but has very different carbon isotopic ratios; more depleted in δ^{13}C and higher in ^{14}C activity. Figure 4 indicates that the water in the Laugarnes area is a mixture of deep water on one hand (similar to the water in the Seltjarnarnes system) and younger water richer in organic carbon on the other (similar to the water in the Ellidaár system) (mixing line 1). The high deuterium excess values found in Laugarnes (d=13‰) but not in Seltjarnarnes nor in Ellidaár. It seems to contradict the mixing model. A possible explanation for this discrepancy is that the original water in Seltjarnarnes had high deuterium excess similar to the present Laugarnes water (13‰) but due to water-rock interactions oxygen shift has occurred which subsequently lowered the d-value.

A mixing line between the two Mosfellssveit areas, Reykir and Reykjahlíd is also indicated in Figure 4 (mixing line 2). The most δ^{18}O depleted end-member is about 1‰ enriched compared to the Seltjarnarnes end member of mixing line 1 and the enriched end-member is heated local rainwater and has high organic carbon from the soil zone. The carbon isotopes confirm that the boundaries between the Reykir and Reykjahlíd systems are not distinct, as seen in Figure 4 where one of the Reykir well plots among the wells in Reykjahlíd and one of the Reykjahlíd well is more close to the wells in Reykir. This is in agreement with Tómasson et al. (1976) who pointed out the good hydrological connection between the systems.

A good correlation is observed between the δ^{13}C and ^{14}C age where δ^{13}C increases with decreasing ^{14}C age (Figure 5). The Reykjahlíd and Seltjarnarnes systems contain water with very low ^{14}C activity (around 10 pMC) whereas waters from Ellidaár (80 pMC) and Reykir (57 pMC) have the highest ^{14}C activity. The drillhole from Reykir that contains high δ^{13}C similar to the drillholes from the Reykjahlíd area has also lower ^{14}C activity than the other drillholes in Reykir but very similar to the Reykjahlíd drillholes. The Laugarnes system (25 pMC) lies in between.

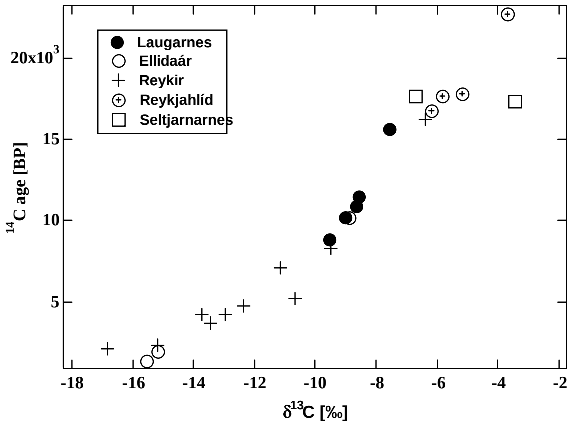

Figure 5. The relation between measured radiocarbon age [BP] and the stable carbon isotopic ratios in the thermal waters.

The value of δ^{13}C decreases (becomes more negative) and ^{14}C activity increases with decreasing temperature as demonstrated in figures 6 and 7 respectively. However, the coldest wells (31, 23 and 5) do not fit these trends.

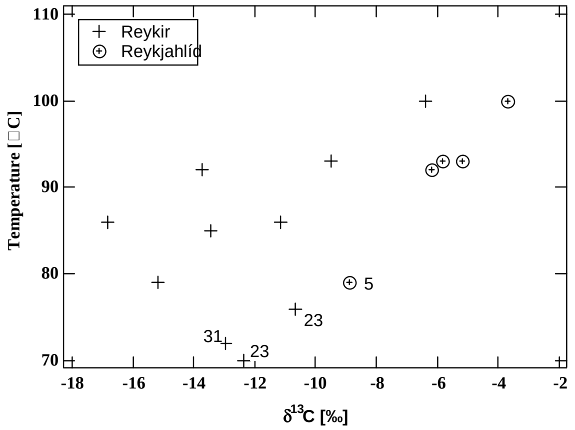

Figure 6. The relation between water temperature and δ^{13}C in the Mosfellssveit fields, Reykir and Reykjahlíd.

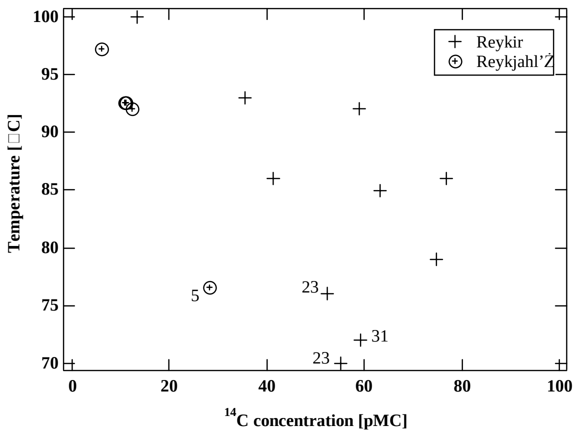

Figure 7. The relation between water temperature and ^{14}C in the Mosfellssveit fields, Reykir and Reykjahlíd.

4. DISCUSSION AND CONCLUSIONS

Isotopic composition (δ^{18}O and δD) of the thermal waters within the city of Reykjavík and the neighbouring county of Mosfellssveit has been remarkably stable the last 50 years, despite of utilization of the waters for decades. As explained in Figure 2, 4 and 5 distinct differences are observed in the isotopic composition of the geothermal waters circulating in the different systems. Most of the waters collected are more depleted in ^{2}H than the local precipitation in the Reykjavík region. This is explained either by the presence of a component of a pre-Holocene depleted waters or waters derived from the mountainous areas to the northeast of the Mosfellssveit areas.

Arnórsson et al. (1991) assume that, at least part of the water in Laugarnes is pre-Holocene. At that time precipitation was isotopically lighter than today due to colder climate, thus explaining the isotopically light nature of the thermal waters. Earlier Sveinbjörnsdóttir (1988) had pointed out that the deuterium excess values ($d=8*\delta^{18}O - \delta^2H$) in the waters circulating the Laugarnes system is unusually high (13‰) compared to Icelandic Holocene groundwater, thus suggesting that the waters could represent precipitation from a different climate regime and probably be of pre-Holocene age.

The carbon isotopes suggest that the Laugarnes thermal water is a mixture of ^{2}H depleted deep groundwater and local water. Therefore its origin cannot be traced on deuterium values alone.

Both the deuterium excess values and carbon isotopes suggest that the thermal water in the Laugarnes system is different of origin from other ^{2}H depleted thermal waters in the Reykjavík region i.e. Reykjahlíd and Seltjarnarnes, where all the water isotopes are in accordance with unmixed relatively old deep groundwater flow into the systems.

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Table 1. Results of isotopic measurements of geothermal waters in the Mosfellssveit- and Reykjavík low temperature areas, Iceland.

Sample no	Location	Temp [°C]	$\delta^{18}O$ [‰]	$\delta^{2}H$ [‰]	d [‰]	^{14}C [pMC]	^{14}C [age BP]	$\delta^{13}C$ [‰]
Laugarnes								
140701	Laugarnes-19	128	-9.65	-62.5	14.7	28.3±0.94	10100±270	-9.0
03-0005	Laugarnes-19	127	-9.57	-62.9	13.7	25.9±0.31	10900±100	-8.6
03-0003	Laugarnes-15	122	-9.38	-62.2	12.8	33.2±0.3	8800±80	-9.5
03-0004	Laugarnes-9	125	-10.02	-67.3	12.9	14.3±0.28	15600±150	-7.6
03-0006	Laugarnes-35	129	-9.61	-64.2	12.7	24.1±0.31	11400±100	-8.6
Ellidaár								
03-0001	Ellidaársvædi-39	89	-8.82	-59.3	11.3	78.4±0.43	2000±40	-15.2
03-0002	Ellidaársvædi-23	89	-8.81	-60.2	10.3	84.5±0.51	1400±50	-15.6
Seltjarnarnes								
04-201/1	SN-05	100	-10.4	-74.2	10.9	11.1±0.31	17700±220	-6.7
04-202/1	SN-06	120	-10.35	-71.9	9.0	11.5±0.25	17400±170	-3.5
Reykir								
03-0014	Reykir-9	79	-8.82	-59.9	10.7	74.9±0.41	2300±40	-15.2
140704	Reykir-11	85	-9.16	-63.4	9.9	63.3±1.25	3700±160	-13.5
03-0016	Reykir-15	86	-8.9	-60.4	10.8	76.9±0.45	2100±50	-16.8
03-0011	Reykir-16	100	-9.36	-62.4	12.5	13.3±0.2	16200± 120	-6.4
03-0015	Reykir-20	92	-9.05	-61.8	10.6	59.0±0.34	4200± 50	-13.7
140705	Reykir-22	86	-9.17	-63.8	9.6	41.3±1.73	7100±340	-11.1
901010f11	Reykir-23	76	-8.73	-61.9	7.9	52.4±0.65	5200±100	-10.7
03-0013	Reykir-23	70	-8.66	-59.5	9.8	55.2±0.33	4800± 50	-12.4
140703	Reykir-25	93	-9.25	-62.7	11.3	35.5±0.89	8300±200	-9.5
03-0012	Reykir-30	74	-9.06	-61.0	11.5			
140706	Reykir-31	72	-8.78	-57.6	12.6	59.3±1.22	4200±170	-13.0
Reykjahlíd								
901010f10	Reykjahlíd-35	93	-9.4	-64.5	10.7	11.2±0.28	17600±200	-5.8
03-0007	Reykjahlíd-39	92	-9.24	-62.7	11.3	12.4±0.22	16800± 140	-6.2
03-0008	Reykjahlíd-29	93	-9.38	-63.6	11.4	10.9±0.17	17800± 120	-5.2
03-0009	Reykjahlíd-37	100	-9.63	-65.8	11.3	5.9±0.21	22700± 300	-3.7
03-0010	Reykjahlíd-5	79	-9.37	-63.5	11.5	28.3 ±0.41	10200 ±110	-8.9