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Helium in the thermal springs of Ûnartoq, South Greenland

by

Francis Persoz, Elfinn Larsen and Klaus Singer

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by

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Abstract

In South Greenland, the Ûnartoq hot springs (40° C) yield about 250 l/min. water with a salinity of 1 g/l, and 5 l/min. of gas. A study of 8 samples taken over a period of 100 years shows very little chemical fluctuation. On the basis of the salt content of different types of water, there is a similarity between the hot spring waters and waters of mixed origin (meteoric and sea water). The gas content (principally N_2) also presents some analogy with that of meteoric and sea water with the exception of helium (2.25 vol. % of the gases; 54 m^3/yr) which gives these waters their distinctive character. The technique of gas determination by mass spectrometry and gas chromatography is presented in some detail. The possible origin of water, gas and heat flow are briefly discussed.

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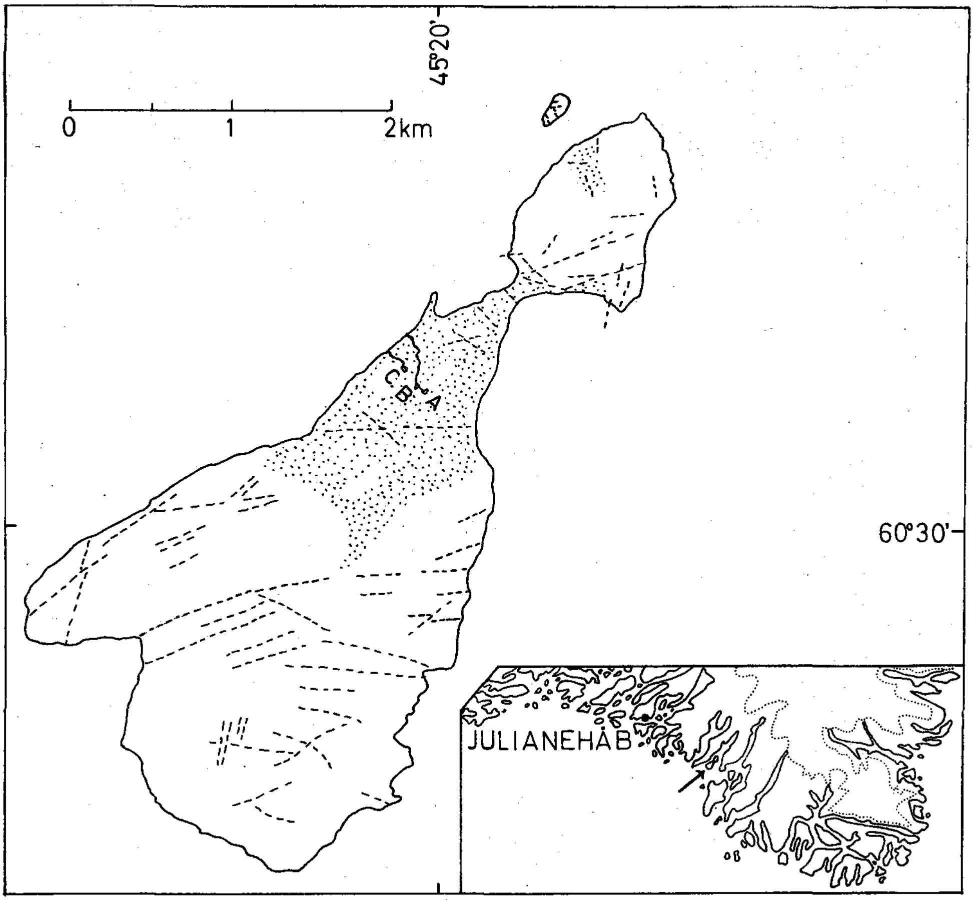

Fig. 1. The island Ûnartoq in the mouth of Ûnartoqfjord. The three points of emergence of the springs are marked A, B and C. The broken lines indicate the main joint and fracture lines. Shading: moraine and beach deposits.

INTRODUCTION

It is to Ivar Bárðarson, who was in charge of the bishop see at Garðar from 1341 to 1363, that we are indebted for the information that the thermal springs on the island of Ũnartoq were known for their therapeutic properties at the time of the Norsemen.

The first scientific observations date from 1806 with Giesecke's observations (1910, p. 351–352). Graah (in 1828), Rink in 1852 & 1853 (1857)), Laube (on Koldewey's expedition 1870) and Eberlin in 1885 (1888) also visited the springs during the last century and made observations and took samples. Jessen (1896) was the first to look for an explanation of their existence and Hartz (1894, p. 20) discovered, on the immediate border of the springs, 31 species of plants that are not generally found on the coasts of Greenland; he also discovered a species of bluegreen alga *Lyngbya thermalis.* Another species, *Tolypothrix lanata,* was discovered by Vahl in 1828.

GEOGRAPHICAL AND GEOLOGICAL LOCATION

Ũnartoq island lies 50 km south-east of Julianehåb, off the south coast of Greenland (fig. 1), constituting, with the island of Tugtutuarssuk, a partially submerged divergent arm of Akuliaruseq peninsula. 80 % of the surface of its 6·5 km^2 is exposed rock, and the remaining 20 % is composed of moraines, detrital material, waste, more or less autochthonous rubble, and ancient marine beaches elevated to an altitude of approximately 50 m. The drainage network consists of a few torrents, fed from innumerable small lakes found in the higher regions, a large proportion of whose water evaporates during the summer. The morphology is old (lowland of Wegmann, 1938), and the landscape is undulating, with the maximum altitude approximately 240 m. Ketilidian migmatites, generally granodioritic, and more alkaline young granites constitute the rock substratum. A few dark gneisses and amphibolites are to be found in varying stages of granitisation (Persoz, 1969).

The permeability is due to a very dense and widespread network of oblique, subhorizontal, and vertical fractures and a complex system of joints. The springs (fig. 1) emerge at an altitude of between 30 and 40 m onto an old marine beach composed of sandy gravel and including great blocks which were probably ancient moraines reworked by waves. At the site of the springs the thickness of the old beach varies between 3 and 6 m.

The three principal points of emergence (A, B, C of fig. 1) are aligned on a fracture zone which extends at least 10 km from the peninsula of Akuliaruseq to the fjord Angmalortup tunua (Persoz, 1969).

The springs A and C seem to have been active at least back to 1806, while spring B probably stopped flowing between 1850 and 1885. In the immediate neighbourhood there is some seepage and scattered gaseous emanation from helocrenes.

The springs are formed of partially artificial, small basins, 9·5, 9·0 and 8·5 m in diameter and 40 to 50 cm in depth. A detailed sketch of the basins and helocrenes is given by Røen (in press). The bottom is sandy. In basins B and C there is a carpet of blue algae and the rocks in contact with the water are covered with a thin, crusty, whitish layer.

THE THERMAL WATER

The yield

We know of no evaluation preceding our own measurements. The spillway technique was very broadly applied and the results must be considered as approximate: A 120 l/min., B 90 l/min., C 30 l/min., a total of ca. 250 l/min., if other seepage is taken into consideration. Obviously such a technique cannot reveal the smaller variations of the yield. The springs are charged with gas, the yield of which is approximately 5 l/min. under normal pressure.

Temperatures

The techniques of measurements (using alcohol and mercury thermometers) as well as the site at which they were made, could explain the slight variations of temperature shown in table 1. Since 1961, the measurements have been taken at 3 cm in the sand in the centre of the basin.

Table 1. Temperatures registered in the basins from 1806 to 1962.

Year	A	B	C	Exterior temperature	Reference
1806 10/8 & 1809 11/7	40·0 °C	?	?	? °C	Giesecke, 1910
1828 14/7	40-41·9†	32·5***	33·8***	?	Graah, 1832
1852 & 1853**	41·9*	—	40·0*?	?	Rink, 1857
1870 20/6	33·8††	—	39·4††	5·6	Laube, 1874
1880 7/8	40	—	?	?	Holm†††
1885 22/4	40·6	—	?	?	Eberlin, 1888
1889 29/8	40·0‡	—	—	5	Hartz, 1894
1894 (April)	41·4[b]	37·7[a]	38·1[c]	-2	Jessen, 1896
1948 8-10/7	41·5	—	—	—	Vibe, 1953
1961 (July)	40·0	37·2	38·0	7	
1961 (Aug.)	40·0	35·0	38·0	14	
1962 (Aug.)	40·0	41·0	39·5	8	
Mean	40·01	36·9	38·0		

* 33$^1/_2$° and 32° Réaumur (Rink, 1857, p. 351-352).

** Summer 1852 and autumn 1853 (Eberlin, 1888).

*** It is not specified which basin is which.

† J. Vahl 40·0° (unpublished diary in the Botanical Library, Copenhagen); Graah 41·9° (Eberlin, 1888).

†† +27°R at 18 cm below the surface of the water and an air temperature of +4·5°R; 20 paces to the west another spring, 31·5°R.

††† [Personal] communication from Captain Holm (Eberlin, 1888).

‡ Jessen, 1896, p. 129 says that according to a personal communication from Hartz the temperature of 40·0° was found in all three basins.
Hartz, 1894, p. 19; temperature measured in the bubbling-up water.

[a] Basin A of Jessen; [b] basin B of Jessen; [c] basin C of Jessen; all bottom measurements.

The low temperatures of spring B (36·9 ° C) are due to the fact that the water of basin A (39·8° C) empties into basin B. The temperature in C (38·0° C) is constantly lower than in A. Mediaeval accounts of bathing in these waters indicate that the temperatures are approximately the same now as in the eleventh century.

The chemistry of the encrustation

The crusty deposits were analysed by Rørdam (Jessen, 1896 p. 132). Present were SiO_2 54·83 %, Al_2O_3 0·92 %, Fe_2O_3 2·52 %, MgO 1·64 %, CaO 16·56 %, Na_2O 0·79 %, CO_2 8·69 %, Cl 0·90 %, traces of SO_3 and 13·16 % of organic matter together with water. According to Rørdam from a mineralogical point of

Table 2. Chemical analyses of the Ûnartoq waters from 1873 to 1970, and analyses of fjord water, in mg/l (except salinity g/l)

Year	1873	1894	1952	1961	1961	1961	1963	1963	1970	1963	1963	
Spring	?	?	?	A	B	C	A	C	A	Fjord water		Mean sea water
Samples	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	52	38	30	37	—	—	57	38	36	1·9	1·5	1·3
Ca^{2+}	111	116	115	115	114	111	116	119	112	333	365	400
Na^+	232	184	232	234	237	234	223	230	232	9050	9330	10500
K^+	21	15·7	—	6·6	7·5	8·7	5·6	6·9	6·7	353	356	380
Mg^{2+}	2·8	8·0	1·8	1·9	1·9	1·9	trace	trace	0·93	1180	1185	1350
Fe^{2+}	—	—	0·24	—	—	—	—	—	<0·1	—	—	0·01
R_2O_3 (mostly Fe_2O_3)	—	—	—	2·7	—	—	—	—	—	—	—	—
Zn^{2+}	—	—	—	—	—	—	—	—	0·08	—	—	0·01
SO_4^{2-}	88	85	43	48	47	46	—	—	43	—	2420	2655
Cl^-	517	511	521	525	529	522	—	—	520	—	—	19000
HCO_3^-	—	(43)	24	24	30	30	—	—	18	—	—	140
PO_4^{3-}	—	—	0·3	—	—	—	—	—	<0·02	—	—	0·03
F^-	—	—	—	—	—	—	—	—	4·3	—	—	1·3
O_2	—	—	1·84	—	—	—	—	—	1·5	—	—	0–8.5
H_2S (free)	—	—	—	—	—	—	0	trace	—	0	0	—
CO_2 (free)	—	—	6·6	4·4	3·1	2·2	—	—	NH_4^+ 0·8	—	—	34–56
pH	—	—	6·90	7·18	7·80	8·15	9·15	5·25	6·60	7·75	7·55	7·5–8·4
Salinity	1·02*	1·00*	0·98*	1·12**	0·97*	0·95*	—	—	0·83*	—	38·59*	33–38

1 Analyst: Gintl 1873 on a sample drawn by Laube in 1870 (Gintl, 1874).
2 Analyst: Rørdam 1895 on a sample drawn by Jessen in 1894 (Jessen, 1896).
3 Analyst: K. Skousbøll Hansen, DGU 1952
4 Analyst: B. I. Borgen 1961 on a sample drawn by Persoz in 1961.
5 Analyst: B. I. Borgen 1961 on a sample drawn by Persoz in 1961
6 Analyst: B. I. Borgen 1961 on a sample drawn by Persoz in 1961
7 Analyst: B. I. Borgen 1963 on a sample drawn by Persoz in 1962.
8 Analyst: B. I. Borgen 1963 on a sample drawn by Persoz in 1962.
9 Analyst: W. Christensen, DGU 1971 on a sample drawn by Røen in 1970 (Røen, in press).
10 Analyst: B. I. Borgen 1963: fjord water at 5 m depth.
11 Analyst: B. I. Borgen 1963: fjord water at 15 m depth.
12 Mean sea water, based on material from Goldberg (1963) and Rankama & Sahama (1950).
* calculated
** measured

view 78 % would be zeolitic substances, 19 % calcite and 1·5 % NaCl. From the point of view of chemical balance these deposits are of little importance.

Chemistry of the waters

Table 2 shows 9 chemical analyses made since 1873, as well as 2 analyses of fjord water drawn at 5 and 15 metres depth and 100 metres off-shore. The samples were stored for a period of between 2 months and 3 years before being treated. All of the analyses were made by classical methods of analytical chemistry.

Salinity

The salinity, defined as the number of grams of dissolved salts in 1 litre of water, is approximately 1. According to Clarke (1924), 73 % of the thermal springs (68 analyses) show salinities of 1 to 50, and 26 % salinities of 10 to 50.

Classification

The waters are sodium chloride waters (Clarke, 1924; Moret, 1946) or, according to Schoeller (1962), oligochloric waters with $r\,Cl > r\,SO_4 > r\,CO_3$ and $r\,Na > r\,Ca > r\,Mg$ (r = milliequivalent per litre).

Chemical fluctuation

The chemical fluctuation with time is relatively low. For the first two analyses it is difficult to judge how much is true variation and how much is due to the analytical methods used at the time. Certain discrepancies, such as the higher silica content of analysis 1, could be due to the storage of the samples for nearly three years with solution of silica from the glass containers, or, in analysis 7, by the greater alkalinity of the water.

Mg^{2+} shows a true variation with time; the excess of K^+ and SO_4^{2+} may be explained as a true variation. The fluctuations of pH in the recent analyses could be due to artificial pollution, such as the introduction of soap by visitors, a factor which is not easy to eliminate.

Comparison between the chemistry of the water and the rocks

We know that the chemical reaction between rocks and water is strongly influenced by diverse factors such as the salinity of the solution, the pH, temperature, pressure, renewal of the water at the contact, and the nature of the minerals (Correns, 1949; Schoeller, 1962). The chemical zonarity, often very complex at the interior of the relatively simple ground water systems, gives an idea of the difficulty in evaluating such factors. The surest method of demonstrating certain relationships is the use of comparisons.

Table 3. Comparison between diverse waters circulating in the granites and granodiorites of chemical analogy to migmatites in the Ûnartoq region.

	1	2	2a	2b	3	4
r Mg/r Ca..................	0·382	0·287	1·14	0·13	0·028	13·64
r Ca/r Na..................	0·324	1·49	10·8	0·603	0·553	0·586
r Na/r K....................	2·26	10·08	10·08	3·9	45·7	0·05
r SO_4/r Cl	—	3·33	44·6	0·06	0·065	—

1. Granodiorite from Greenland (Lauerma 1964, anal. 2, p. 42).
2. Deep sea water of Butte, Montana mines (Schoeller, 1962, p. 354).
2a. Maximum of 15 analyses of water circulating in granites (Schoeller, 1962).
2b. Minimum of 15 analyses of water circulating in granites.
3. Ûnartoq water (analysis 6).
4. Ratio between 1 and 3.
r = milliequivalent weight per litre.

In table 3 we show some ratios between milliequivalents using Schoeller's method (Schoeller, 1956). According to Schoeller (1962), the majority of the waters circulating in granites have a ratio of r Mg/r Ca close to that existing in rocks. The ratio r Ca/ r Na is generally close, but can diverge to a large extent. The ratio r Na/ r K is always higher in the waters than in the rocks, due to a retention of K in the weathered zones. The Na^+ is more abundant than Cl^-. The scarcity of iron and the abundance of silica are other characteristics of such waters. This is due, naturally, to the slight alkalinity of the solution.

In the case of Ûnartoq (table 3), the similarity is reasonable for r Ca/r Na; this it not so for the other ratios. This discrepancy indicates that the influence of reaction with wall rock in determining the composition of the source waters has not been important.

Comparison between the waters of Ûnartoq and sea water

The origin of the Ûnartoq waters could be due to marine infiltration; we have, therefore, attempted a chemical comparison between the waters of the springs and those of the fjord (tables 2 and 4). The samples 10 and 11 (table 2) were taken at 100 m to the SE of the island, the first at 5 m depth, the second at 15 m. The lower Na content in sample 10 (table 2) is due, naturally, to the mixing with meteoric water as well as the melt water from the numerous icebergs in the region. As the analyses of fjord waters are incomplete that of mean sea water is given as analysis 12.

As can be seen in table 2 the total content of salt in the fjord water is about 38 g/l and in the source waters about 1 g/l. When the ion concentrations of the sea water are divided by 38 the quotients for Na, K, Cl and SO_4 are very similar to the concentrations of these ions in the source waters. The quotients for Ca and the total of the HCO_3^- and CO_3^{2-} ions are ten times smaller than the concentrations of

Table 4. Comparison between fjord water, sea water and Ûnartoq water.

	1	2	3	4
rNa/rCl	—	0·85	0·691	1·2
rMg/rCa	5·35	5·56	0·028	198·5
rCa/rNa	0·045	0·044	0·544	0·08
rNa/rK	44·6	47·0	45·7	1·03
rSO_4/rCl	—	0·10	0·065	1·54
rSO_4/rCa	2·77	2·77	0·173	16·0
$rCa/rHCO_3$	—	8·70	11·26	0·77
$rMg/rHCO_3$	—	48·39	0·318	152·2

1. Ûnartoq fjord water at 15 m depth, 100 m SE of the island (table 2, analysis 11).
2. Mean sea water (table 2, analysis 12).
3. Ûnartoq water (table 2, analysis 6).
4. Ratio between 2 and 3.

r = milliequivalent weight per litre.

these ions of the source waters. In other words the Ca^{2+}, HCO_3^- and CO_3^{2-} ions are proportionally ten times more strongly represented in the source waters than in sea water. However, the ratios r Ca/r HCO_3 of sea water and of the source waters are about the same (table 4). The Mg concentrations are, relatively as well as absolutely, very meagrely represented in the source waters.

These considerations affirm Jessen's (1896) theory of alimentation of the source waters by marine infiltration. It is however necessary to admit a dilution of the sea water by meteoric fresh waters in the ratio of 1 to 38. The variation of the concentrations of Mg^{2+} and its occasional disappearance is not understood.

Trace elements

The semi-quantitative analysis by optical spectrography of the trace elements permits the completion of the preceding data:
Sr = 1 %, Si = 1 %, Al ~ 1000 ppm, Ag = 10 ppm, Li = 100 ppm,
Cr = 10 ppm, Pb = 1 – 10 ppm, Fe <1000 ppm, B = trace.

These values were calculated on the basis of the dry residue after evaporation of the waters of spring A.

THE NATURE OF THE GASEOUS EMANATIONS

The gas emergence is confined to the three basins and their immediate margins. The positions of the points of emergence seem to have been relatively constant between the observations made in 1961 and those made in 1963.

Methods

The gas samples amounting to approximately 200 cm^3 each, were drawn during the summers of 1962 (2 samples) and 1963 (3 samples, dated July 14, August 6 and September 3). The gas was collected in glass bottles which had been previously filled with water from the spring. These bottles were then sealed with a plastic stopper and paraffined while still containing some water, after which they were stored, bottom up, until opened for analysis.

The five gas samples were analysed 2 to 10 months later by mass spectrometry and gas chromatography; in addition, the spring water contained in the 1963 bottles was examined for radioactivity.

In order to avoid atmospheric contamination, the 1962 gas samples to be analysed were removed in the following manner. While the bottle was placed with the bottom up in a waterfilled container, the plastic stopper was replaced by a rubber stopper which had been provided with a glass tube with a stop-cock. The bottle was then removed, up-ended, and connected to two gas pipettes in series, each provided with two stop-cocks. The pipettes were evacuated to a pressure of less than 1 mm Hg, and after the connection to the vacuum pump had been interrupted, the gas in the bottle was allowed to expand into the two gas pipettes one of which was used for mass spectrometry, and the other, for gas chromatography.

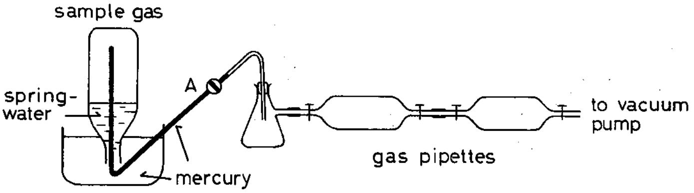

Fig. 2 Method used in the laboratory for drawing gas samples.

For the 1963 samples, the procedure was somewhat changed. In order to collect the spring water for radioactivity measurements, the bottle, bottom up, was opened under mercury. While remaining in this position, a mercury-filled glass tube with a stop-cock was introduced into the bottle and connected at the other end to the two gas pipettes through a Büchner flask (see fig. 2). After evacuation of the pipettes and the flask, the stop-cock *A* was opened and the mercury in the glass tube was collected in the Büchner flask while the sample gas, being replaced in the sample bottle by ascending mercury, expanded into the gas pipettes.

The mass spectrometer analyses were performed with an Atlas CH 4 mass spectrometer. The gas chromatographic investigations were carried out with an F and M Scientific Corporation Model 500 apparatus provided with two columns: a 3·5 m silicagel column for the determination of air, CO, CH_4, C_2H_6 and CO_2, and a 2 m molecular sieve (5A) column for the separation of N_2 from O_2 + Ar.

Table 5. Analyses of 1962 gas samples (vol. %).

Component	1962/1		1962/2	
	Mass Spec.	Gas Chrom.	Mass Spec.	Gas Chrom.
H_2	<0·01		<0·01	
He	n.d.		2·17	
Ne	<0·01		<0·01	
N_2	88·1	ca. 98	92·6	ca. 98
CO		0·02		0·02
O_2	0·016	1·8-2·0	0·42	1·8-2·0
Ar	1·37		1·36	
CO_2	0·12	0·1-0·5	0·19	0·1-0·5
CH_4	0·04	0·03	0·03	0·03
H_2S	<0·01		<0·01	
	89·65		96·78	
H_2O*	2·6	2·6	2·6	2·6
Total	92·25	103	99·38	103

n.d. not determined
* calculated values

Table 6. Analyses of 1963 gas samples (vol. %).

Component	1963/July 14		1963/Aug. 6		1963/Sept. 3	
	Mass Spec.	Gas Chrom.	Mass Spec.	Gas Chrom.	Mass Spec.	Gas Chrom.
H_2	<0·01		0·01		<0·01	
He	2·21		2·25		2·27	
Ne	<0·01		0·01		0·01	
N_2	96·1	95	95·8	96	95·9	96
CO		<0·02		<0·02		<0·02
O_2	0·004	1·7	0·02	1·8	0·02	1·7
			—		—	
Ar	1·44		1·47		1·47	
CO_2	0·27	0·5	0·49	0·6	0·40	0·5
CH_4	0·04	0·03	0·04	0·03	0·04	0·03
H_2S	<0·01		<0·01		<0·01	
H_2O*	—	3·1*	—	2·6*	—	4·2*
Total	100·07	100·33	100·07	101·03	100·1	102·43

* determined by a modified Karl Fischer method. Analyst: A. Thorboe.

Results

In tables 5 and 6 the results are given for the mass spectrometric and gas chromatographic measurements on the five samples. As the water vapour content could not be measured by either of these two methods, the values shown in table 5 are those calculated on the basis that the gas was saturated with water vapour at room temperature and that a new gas-liquid equilibrium was not established during the opening of the bottle and the expansion of the gas into the gas pipettes. If a change in this equilibrium occurs, this would cause the determined water vol. percent in the gas to increase slightly. This seems in fact to be the case as seen from the H_2O values in table 6 as obtained by a modified Karl Fischer determination on the gas samples.

The gas chromatographic values for N_2 and $O_2 + Ar$ in the 1962 samples, as shown in table 5, are probably too high due to the fact that these samples were introduced into the apparatus by means of a Hamilton syringe thus exposing the sample to contamination by air. The 1963 samples were injected with a special gas sampling valve in order to avoid air contamination.

The most unexpected and interesting result of these measurements is the relatively high helium content of approximately 2·2 %. In order to determine a possible correlation between the presence of this element and natural radioactivity, the spring water from the 1963 samples was examined for α-activity from uranium decay. An α-counting was made on the evaporation residue of 10 cm^3 of each water sample and the results were compared with corresponding activity measurements on samples of drinking water taken at approximately the same time at different geographical locations: Godthåb in Greenland, Rønne on the island of Bornholm, and on the island of Lolland in Denmark.

The results are shown in table 7 expressed as the equivalent amount of natural uranium per litre of water and per gram of dry matter.

Table 7. Natural radioactivity of spring water measured by α-counts.

Sample	α-activity counts/h*)	Evaporation residue per 10 ml of spring water mg	Equivalent μg U per litre	Equivalent μg U per gram dry matter
1963/July 14	3·0	13·5	9·1	7
1963/August 6	3·3	12·5	10·0	8
1963/September 3	4·1	13·5	12·4	9
Godthåb—Sept. 1963	0·6	0·5	1·7	35
Bornholm—Sept. 1963	1·5	1·36	4·2	31
Lolland—Sept. 1963	15·0	10·0	45	45

*) Counting time: 24-48 hours, corrected for background = 8·2 counts/hour.

Table 8. Composition of gas samples exclusive of water vapour (vol. %).

Component*	1962/2	1963 July 14	 Aug. 6	 Sept. 3
He	2·29	2·21	2·25	2·27
N_2	96·0	96·1	95·8	95·9
Ar	1·44	1·44	1·47	1·47
CH_4	0·04	0·04	0·04	0·04
CO_2	0·21	0·27	0·49	0·40
Total	99·98	100·06	100·05	100·08

* H_2, Ne, CO & H_2S: below the limit of detection <0·01 %

Evaluation of the results

In general, the mass spectrometer measurements must be considered somewhat more accurate than gas chromatography. On the other hand, under the conditions used for the present analyses, the mass spectrometer was not able to separate nitrogen from carbon monoxide, having nearly the same mass. This is, however, of no importance in these studies since the gas chromatographic measurements show that the CO content is less that 0·02 vol. %.

From the mass spectrometer measurements it appears that the oxygen content in all but one sample (1962/2), is less than 0·02 % which supports the assumption that all the gas samples did not originally contain oxygen. It is probable that sample 1962/2 was contaminated by air during the opening procedure. In table 8, showing the best values of the different measurements, the nitrogen content of sample 1962/2 is corrected in accordance with this supposed air content.

The water content of the different samples is somewhat difficult to explain. In some of the samples (table 6) the total of the other measured components gives approximately 100 % without taking into account the water content, while in the other samples, the addition of the water per cent gives a total of 100 %. It is known, however, that without making special arrangements, the mass spectrometer cannot be used for accurate water vapour determinations, as the vapour condenses on the internal surfaces of the sampling system and is only very slowly removed from this system. This leads to an extremely inaccurate pressure measurement on water-containing samples, and involves, furthermore, that the measured value of the water content of a specific sample depends on the water content of previously measured samples. Due to this uncertainty, the water content is not reported in table 8, giving the best values for the dry gas samples normalised to 100 %.

Owing to the absence of a helium determination, the 1962/1 is also not included.

The yield in gas

As shown on table 8, the composition of the natural gas emerging from the springs at Ûnartoq, has been constant for approximately one year.

The content of 2·25 vol. % of helium is the most remarkable observation. The total absence of O_2 can be explained by oxidation in the weathering zones and in the rocks. H_2S and CO are below the limit of detection. The low content of CH_4 can be interpreted as due to the putrefaction of organic matter which covers the floor of the basins.

The gas production in relation to water flow leads to the following figures:

Nitrogen	19·16	ml gas/l water
Argon	0·294	
Helium	0·5	

The total discharge of helium is of the order of 54 m^3/yr.

CONCLUSIONS

The origin of the waters and their zones of alimentation, the nature of the thermal spring, as well as its localisation in the crust, the geometry of the zone of the outflow, the time of circulation of the waters and the chemical variation are the principle questions posed in connection with thermal springs.

The models which can be proposed are many and it would be an illusion to try to make a choice on the basis of the few parametres we have. Such a study should be carried out by a precise analysis of the yield, by a prolonged investigation of the chemistry of the waters and gases as well as by a study of the isotopic ratios.

Origin of the water

The ionic ratios as well as the proportions of dissolved gas speak in favour of a mixed origin of the water: marine and meteoritic in a ratio of 1 to 38. This hypothesis is supported by the almost complete absence of B, CO, H_2 and CH_4 which are indicators of juvenile water (Rittmann, 1963 and Schoeller, 1956), and by the geological environment of South Greenland which excludes any connection with recent magmatic or volcanic activity.

Chemical aggressivity

The similarity existing between hot springs and mixed waters, such as we have proposed, implies a great inertia of chemical aggressivity between water and rock. This similarity is not, however, absolute since an excess of Ca and Si and a deficiency of Mg with respect to the anions, exist. The chemical stability of the hot springs, another characteristic of these sources, has been advanced by diverse authors (e. g. White, 1969).

The gas

We have seen that the gas relationships, with the exception of helium, are very similar to those of sea water and meteoric water.

Thermogenesis and flow of the waters

Multiple models of heat sources have been proposed (see among others: Heim, 1919; Adams, 1924; Allen & Day, 1924; van Ortsrand, 1924; Moret, 1946; Borwardsen, 1960; Elder, 1965): decompression of the dissolved gases toward the surface, chemical reactions in the solutions, normal geothermic gradient, magmatic or volcanic activity (past and present day), large concentration of radiogenic rock mass, convection currents in the mantle. These different possibilities need not be discussed here. A few remarks will suffice.

The geothermal gradient (Nielsen, 1971) was measured in borings at Ivigtut, 200 km north-west of Ûnartoq in a geological and geographical situation similar to that of Ûnartoq. The measured gradient is 67 m/° C which is normal for a Precambrian basement (Gordon-Smith, 1963).

The geothermal gradient and the lack of volcanic activity force us to seek the location of the heat source very deep in the crust or look for a special source of heat. In the first case the energy of the system stems from a depth of approximately 10 km within the crust. In this case it is necessary to consider that the thermal flux is spread by convection currents in a fluid mass of great volume, the exchanges of fluids and heat being sufficiently important to permit the discharge of the waters at high temperatures at their emergence at the surface (Elder, 1965). Such a model, however, implies a long-term contact of water and rock which appears contradictory to the conclusions drawn concerning the slight aggressivity of these waters and the weak salt content dissolved.

In the second case, we must resort to a radiogenic source of heat. This does not seem impossible (the high concentration of helium would be an argument for such an hypothesis), but a thermodynamic study at this level requires a detailed study of many additional parameters.

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kalâtdlisut imaĸarnersiornera

Ûnartume, Kujatâne, puilassune kíssartune heliume

Ûnartup ĸeĸertâne puilassut kíssartut ĸavdlunâtsiânit ilisimaneĸarsimáput, Ivar Bardarsonivdlo erĸartorpai. (táuna Gardarime - Igalikume - piskorpeĸarfingme pissortausimavoĸ 1341-1363). ilisimatûnit misigssorneĸarnerat siugdleĸ Gieseckep 1806-me tamânînerane pisimavoĸ. Eberlinip (1888) 1800-t nâlernerâne táukunínga pâsisimassat navsuaiarpai.

puilassut erngat tasínguit pingasut, ilâtigut inungnit agdlilerneĸarsimassut, narĸinit pikialavoĸ. tasínguit táuko mêterinik ardlalínguanik silíssuseĸarput ilâtigutdlo mêterip agfâ anguvdlugo itíssuseĸarsínauvdlutik. narĸe sioráuput. imeĸ narĸinit pikialassoĸ katitdlune minútime atautsime 250 lîterit migss. angnertússuseĸarpoĸ, ãmalo siláinaĸ nivdlikâssoĸ minutimut 5 liter migssiliordlugo angíssuseĸardlune. erngup kíssássusia avguaĸatigîgsitdlugo taseĸ A-me 40° C-uvoĸ, B-me 37° C-milo 38° (tabel 1). tatsit táuko nunap ĸupinera ĸeĸertaĸ napivdlugo ingerdlassoĸ atuardlugo inigssisimáput.

tabel 2-me takuneĸarsínáuput puilassut erngisa kangerdlûvdlo imartâta ĸeĸertat erĸánguanĩtup akuisa kemi atordlugo misigssorneĸarnere ãmalo tarajoĸássusîsa angnertússusiat. tabel 4-me puilassut erngisa misigssorneĸarnere sanigdliúneĸarsimáput kangerdlûp imâta misigssorneĸarneranut ãmalo íssigtut imaisa avguaĸatigîgsíneránut. tabel 2-me takuneĸarsínauvoĸ imap tarajoĸássusia lîterimut 38 g migss. angíssuseĸartoĸ, puilassutdle tarajuat 1 lîterimut 1 g migss. angíssuseĸartoĸ.

imaĸ 38-riautânik imermik akugáine tauva natriumimik, kaliumimik, chloridimik sulfatimigdlo akuisa puilassup erngata táukunínga akue angeĸatigísavai, puilassuvdle erngata kalciumimik, bikarbonatimik, karbonatimigdlo akue ímap imâta imermik akussap táukunínga akuisa ĸuleriarnerat migss. angneruvoĸ.

tabelit 5 ãma 6 siláinaup puilassunit puaussartup akuinik erssersitsíput. siláinarmik avdlanut níputdlune akuliútartũngitsumik heliumimik imartússutsine maligdlugo 2.25 %-mik akoĸarnerata puilassut ingmíkordluínaĸ ilersípai.

nunap ĸalerîgsuisa kíssagkiartortarnerat, tássa nunap iluanut ápariartortitdlune kíssarnerup ĸanoĸ súkatigissumik agdliartortarnera, Kalâtdlit-nunâta kujatâne angnikitsuínauvoĸ, tássa nunane ingnermik anitsissartoĸarfiúngitsune píssutsit ássigai. taimáitumik puilassut kíssarnerat nunarssûp ĸalipânit samanerssuaĸ ítunit pissûsimásaoĸ, kisiáne ingnermik anitsissartunêrsûnane. helium ujarĸat radioaktivissut avdlángoriartornerinit pilerfeĸarsimásaoĸ.

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