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Thermal and mineral springs of southern Spitsbergen

Tomasz OLICHWER* and Robert TARKA

Institute of Geological Sciences, University of Wrocław, Maksa Borna 9, 50-204 Wrocław, Poland

* *corresponding author <tomasz.olichwer@uwr.edu.pl>*

Abstract: In the southern Spitsbergen area, thermal and mineral waters are primarily associated with subpermafrost deep circulation, being mixed with shallow circulation and glacial waters. Four thermal springs, located in the region of Stormbukta (Sørkappland), were studied and analyzed. In the thermal waters, the main cation is sodium, while the main anions are chloride and bicarbonate. The temperatures of the mineral and thermal waters range from 3.4 to 15.1°C. The pH values are between 7.43 and 8.41. The total dissolved solids (TDS) content of the geothermal waters is in the range of 346–4031 mg/l and the Olsok thermal spring has the highest TDS values. Based on the variation in physicochemical characteristics, two thermal water types were distinguished in the study area. The first type is associated with thermal waters originating from deep circulation waters. The second type is associated with the thermal and mineral waters originating from the mixture of subpermfrost hot brines with glacial waters.

Key words: Arctic, Svalbard, thermal water, water chemistry.

Introduction

Various types of natural groundwater springs to the land surface are found in the area of southern Spitsbergen, from commonly occurring ephemeral springs related to snow and permafrost melt through outflows at glacier termini (Krawczyk 1992), karst springs (Leszkiewicz 1982; Pulina 1977), to perennial thermal springs with an outflow temperature of more than 16°C (Orvin 1934, 1944; Krawczyk 1989; Pociask-Karteczka 1990; Olichwer *et al*. 2013). In this group of outflows, mineral and thermal springs are the rarest and most interesting.

Thermal and mineral springs of the southern Spitsbergen are linked to the deep circulation zone, which is associated with systems of tectonic discontinuities, where the waters from the shallow and intermediate circulation zones can infiltrate to significant depths (>1500 m) and subsequently escape to the land surface through these tectonic discontinuities.

Near the bay of Stormbukta (Fig. 1), there are the outflows of thermal waters with variable temperature and Total Dissolved Solids (TDS). The thermal water outflows are associated with pre-Devonian crystalline rocks belonging to the Hecla Hoek succession and with sedimentary rocks of Carboniferous and Jurassic age.

Investigations of the chemical composition of thermal and mineral waters in the study area, were conducted during the 19th Scientific Expedition to Spitsbergen organized by the University of Wrocław in 2006. The objective of

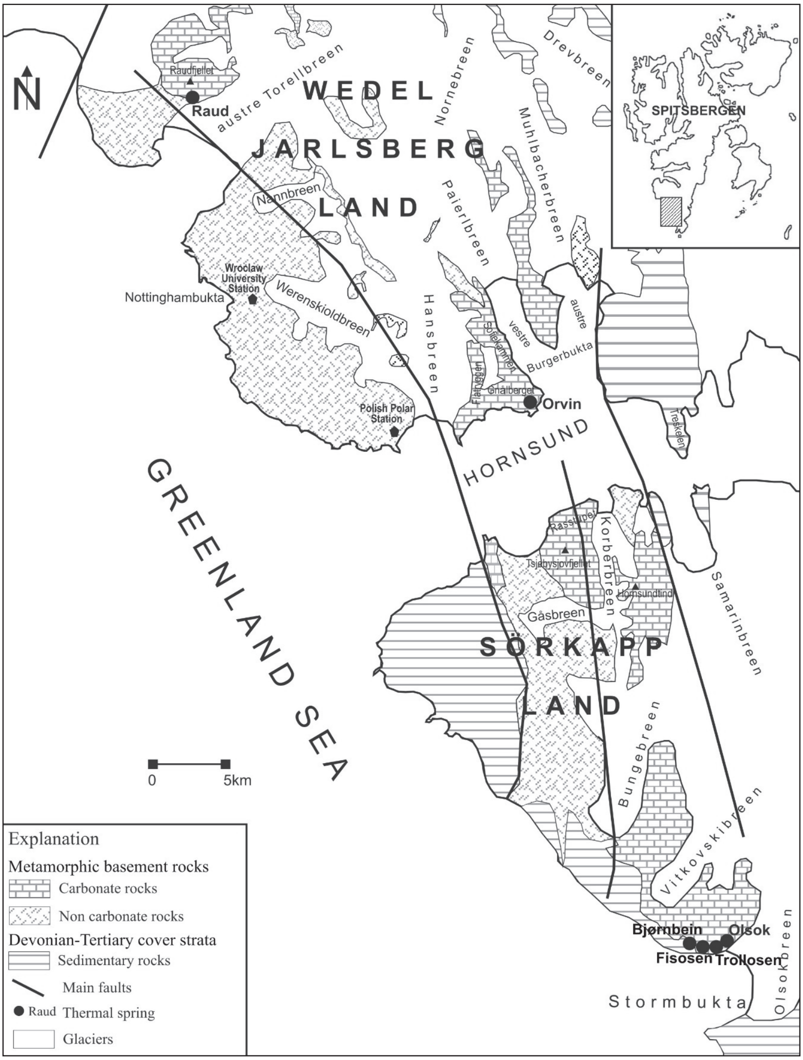

Fig. 1. The location of thermal outflows on the background of a geological structure, modified from Olichwer *et al.* (2013).

this article is the hydrochemical characterization of thermal springs of southern Spitsbergen (Sørkappland), based on new results of chemical analyses, hitherto not published widely, derived from studies of the period 1970s to 1990s (Postnov 1983; Krawczyk 1989, 1996; Lauritzen and Bottrell 1994; Lauritzen 1996). The authors focused on the description of the four sites located in the southernmost part of Spitsbergen (Fig. 1). In addition, the results are compared to two thermal water springs located to the north of the study area at the foot of the Gnalberget (Orvin) and Raudfjellet (Raud) (Fig. 1). Both sites were characterized by the authors in an earlier publication (Olichwer *et al*. 2013).

Study area

The study area is located in the Sørkappland (South Cape Land) region of southern Spitsbergen, near the bay of Stormbukta (Fig. 1). Over the period from 2005 to 2016, the multiannual yearly mean air temperature at Hornsund weather station, located in this area, was -2.34°C. The coldest month in Hornsund was March with a temperature of -8.6°C while the warmest month was July with a temperature of 4.8°C (Fig. 2) (Cisek *et al*. 2017). The average annual sum of precipitation in the period from 1979 to 2014 was 453 mm. The highest precipitation is measured in September, with an average of 71 mm (Osuch and Wawrzyniak 2017).

The study area is characterized by a few major geologic units: Quaternary covers, Carboniferous through Jurassic platform cover sequence, Devonian basin sediments and metamorphic basement rocks (Harland 1997). The oldest formations, the so-called Basement, include Precambrian, Cambrian

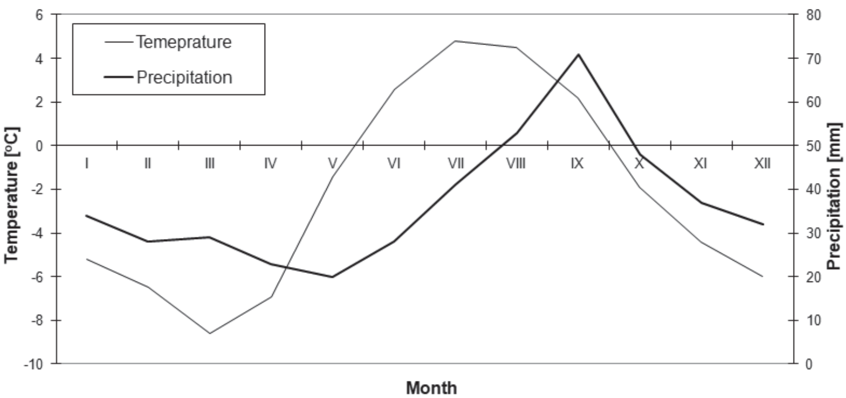

Fig. 2. Multiannual monthly mean of air temperatures (2005–2016) and precipitation (1979–2014) in the Polish polar station Hornsund after Cisek *et al.* (2017), Osuch and Wawrzyniak (2017).

and Ordovician rocks. Research area consist of strongly metamorphosed Proterozoic part of the Heckla Hoek succession (rocks older than Devonian). The thickness of the Precambrian through Lower Ordovician stratigraphic column in the Spitsbergen totals 15–17 km. This lithostratigraphic complex is represented by paragneisses, mica-schists with marbles, quartzites, schists, amphibolites, greenschists, gneisses, conglomerates, limestones and dolostones (Birkenmajer 1990). The Devonian succession (1 km thick) at South Spitsbergen begins with fluvial red conglomerates, sedimentary breccias and sandstones, limestones and schists. Beginning with the Lower Carboniferous, the study area became part of the continental platform. Conglomerates, sandstones, shales, mudstones, limestones, dolomites and evaporites represent this period (Dineley 1958). Stable platform conditions prevailed in the study area through most of Triassic and Jurasic age. This stage represents conglomerates, shales, mudstones, sandstones and limestones. No Cretaceous sediments and Tertiary formations have been found. Pleistocene and Holocene glacial deposits and Holocene raised marine beaches, terraces and cliffs, are characteristic coastal features of the Hornsund area (Birkenmajer 1990). The youngest Quaternary age is represented by mostly unconsolidated: moraines, fluvial deposits, beach deposits, talus and scree that formed during and after the last ice age, which ended about 10,000 years ago.

The area in question has a rich tectonic history, with its origins dating back to the Precambrian. Its effect is a large number of faults and discontinuities that significantly influence the groundwater circulation. It applies in particular to subpermafrost and thermal waters associated with the deep groundwater circulation. The geothermal studies in central and southern parts of Spitsbergen indicate a heat flow value about 70 mW/m^2 and geothermal gradient of 3.5°C/100 m (Braathen *et al*. 2012; Wawrzyniak *et al*. 2016).

The thermal and mineral springs in the study area are associated with Ordovician carbonates (limestones) and Carboniferous – Jurassic sedimentary rocks (sandstones, siltstones and shales) (Fig. 3). Thin layers of evaporites occur in the Carboniferous and Permian shales covered with glaciers to the north and east of the thermal and mineral springs. Moreover, the largest limestone shore belt of southern Spitsbergen extends in the study area and it is situated within several elevated sea terraces, which are the effect of littoral karst (Pulina 1977).

In the study area, groundwater is generally accepted to occur within three zones (Williams and van Everdingen 1973); *i.e.* above the permafrost (suprapermafrost), inside the permafrost (intrapermafrost), and below the permafrost (subpermafrost). The groundwater flow in the suprapermafrost zone occurs in the active layer that thaws during spring and early summer. Precipitation and thawing permafrost are the main source of water for this system. Subglacial water discharge from the glaciers is also related to this zone. The water temperature in this system is close to 0°C (Olichwer *et al*. 2013).

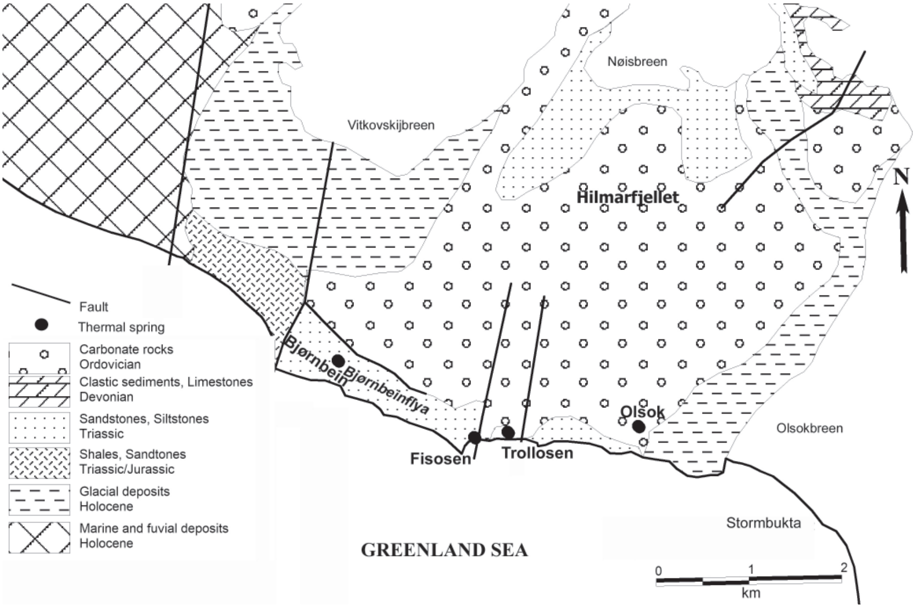

Fig. 3. The geological map study area, modified from Norwegian Polar Institute (2014).

Groundwater within the permafrost occurs in zones of unfrozen ground (taliks). Taliks form in places where the heat from large rivers or lakes prevents permafrost formation or where perennial springs maintain open unfrozen flow pathways. Alternatively, taliks may be associated with the occurrence of groundwater with high salinity (Van Everdingen 1990).

Groundwater recharge below the permafrost is predominantly related to open taliks, being transmitters of water from the lakes and to glaciers (Haldorsen and Lauritzen 1993). The glaciers in Spitsbergen primarily belong to the subpolar type. Their accumulation part (firn) has the character of warm-based glaciers, whereas the tongue remains partly or entirely strongly frozen. The water occurring underneath the warm-based part of the glaciers and originating from the subglacial systems can penetrate into pores or crevices in the bedrock, recharging the groundwater circulation system beneath the permafrost. The water below the permafrost is isolated from the land surface by a layer of frozen ground. Hence, the groundwaters of this system are regarded as confined by an overlying aquiclude of permafrost (Haldorsen and Lauritzen 1993; Haldorsen *et al*. 1996; Lauritzen 1996). Therefore, under favourable conditions, if the piezometric head in the confined subpermafrost groundwater system exceeds the ground level, the groundwaters of this system can discharge to the surface, either via karst systems or via tectonic fracture zones or faults (Van Everdingen 1990). The groundwater circulation depth in this subpermafrost system ranging from 100 meters near coasts to more than 500 m in interior mountains (Humlum *et al*. 2003). The water outflow temperature is typically about 4°C. The groundwater circulation zone above the permafrost can be termed as the shallow circulation zone, whereas the waters inside and below the permafrost as the intermediate zone. In the study area, the permafrost is typically 100–150 m thick (Wawrzyniak *et al*. 2016).

A deep circulation zone can additionally be distinguished in the study area. This zone is defined by systems of tectonic discontinuities where the waters from the first two zones can infiltrate to significant depths and subsequently escape to the land surface through these tectonic discontinuities (Van Everdingen 1990; Olichwer *et al*. 2013). Numerous thermal and mineral springs, with outflow temperatures ranging from 8–14°C (southern Spitsbergen) (Olichwer *et al*. 2013) to more than 25°C (northern Spitsbergen), are associated with this zone (Banks *et al*. 1998, 1999, 2001).

History of research on springs in Sørkappland

Sørkappland is one of several locations where thermal waters are found in Spitsbergen. Several points where thermal water is discharged can be distinguished at the foot of the Hilmarfjellet Massif (Fig. 3). These outflows differ in water chemical composition and temperature. These springs were known already from the beginning of the 20th century. The first observations were carried out by Werenskiold (1920), who recorded that the temperature of the waters found there ranged from 10 to 15°C. Later on, observations were conducted by Major and Wisnes (1955), who recorded the highest water temperature in this area of 16.3°C. Moreover, numerous authors conducted studies in the 1970's, 1980' and 1990's (Pulina 1977; Leszkiewicz 1979; Postnov 1983; Krawczyk and Pulina 1991; Lauritzen and Bottrell 1994; Krawczyk 1996; Lauritzen 1996). When conducting a study in this area in the 1990's, Lauritzen found a previously unknown point of thermal water outflow, which was called Fisosen (Lauritzen and Bottrell 1994).

The four spring discharges discussed in this article are: (1) Olsok – a karst spring of thermal and mineral water, near the moraine of the Olsok Glacier, with a strong hydrogen sulfide odor; (2) Trollosen – a karst mineral spring with a very high discharge, outflowing from a cave adjacent to the shoreline; (3) Fisosen ("smelly spring" in Norwegian) – a karst spring with thermal and mineral water and (4) Bjørnbein – a karst spring of thermal water in the Bjørnbeinflya marine terrace.

The first of the four outflows considered in this article is the Olsok spring, with a discharge ranging between 150 and 450 l/s and with water temperature of 10–11.2°C (Table 1) (Werenskiold 1920; Leszkiewicz 1979). In this spring, Pulina (1977) recorded a mineralization of 8.6 g/l, which is the highest value found so far in Spitsbergen. The Trollosen spring, the second spring, is located in the central part of the study area (Fig. 3), with a discharge of 10000 l/s, is the largest spring in Spitsbergen (Lauritzen and Bottrell 1994; Reigstad *et al*. 2011). Its water outflow temperature is 4°C. The third spring, a small thermal spring called Fisosen, is located about 400 m to the west of the Trollosen spring. With a diameter of 20 cm and a low discharge (about 1 l/s), it is situated in the coastal zone at an altitude of 1–2 m above sea level (a.s.l.). This spring is characterized by a high specific conductivity of 6200 µS/cm, similar to that of the Olsok spring, and a water temperature of 12.9–15.1°C (Lauritzen and Bottrell 1994). In the waters of Olsok and Fisosen springs, the researchers found the presence of hydrogen sulfide and fragments of yellow organic slime with sulfide-metabolizing bacterias (Archea, *Sulfurovum*, *Thiotrix*) (Reigstad *et al*. 2011). Additionally, the presence of fungal hyphae was confirmed by scanning electron microscope, but their taxonomy remains unknown (Lauritzen and Bottrell 1994). The fourth spring considered in this article is a vast discharge zone, called Bjørnbein, located west of both the Olsok and Fisosen sites, in a marine terrace (Bjørnbeinflya). This spring zone, with a water temperature of 15.2–16.5°C (Table 1), was described in the 1970's and 80's. These waters were of the Cl^--Na^+ type and had a TDS of more than 1 g/l (Pulina 1977; Krawczyk 1996), but during a study conducted in the 1990's the location of these outflows was found to be dry (Lauritzen 1996). In 2006, on the other hand, the authors found thermal waters with a water temperature of 13.9°C and a TDS of 350 mg/L to occur in this zone.

Table 1

Variation in water temperature and pH in the thermal springs of the study area; archive data after [1]Werenskiold (1920), [2]Postnov (1983), [3]Migała and Sobik (1983) and [4]Krawczyk (1989, 1996).

	Raud		Orvin		Bjørnbein		Fisosen		Trollosen		Olsok	
Year	T (°C)	pH	T (°C)	pH	T (°C)	pH	T (°C)	pH	T (°C)	pH	T (°C)	pH
[1]1920											10.0	
[4]1972			12.0	7.5								
[4]1973			12.5	7.4	16.5	7.2					11.2	6.7
[4]1979					15.2	7.2					10.4	6.8
[2]1980			12.4	7.4								
[4]1981											10.5	7.1
[3]1982	12.3											
[3]1983	12.1	8.3										
[4]1986			12.4	8.6								
[4]1992							14.8	7.6	4.1	7.2		
[4]1996							15.1					

Methods

Our investigations of the chemical composition of thermal and mineral waters were conducted during the 19th Scientific Expeditions to Spitsbergen organized by the University of Wrocław in 2006. In addition, to recent data from the four springs, data from two additional thermal water springs in the study area, *i.e.* Orvin and Raud, were added. They had been the subject of a previous publication of the authors (Olichwer *et al*. 2013). The water samples from all 6 sites were collected in the same summer period (Table 2).

During the field investigations, at all these sites, water temperature, pH, oxidation-eduction potential (ORP) and water electrical conductivity (EC) were measured *in situ*. In the field work, we used an Elmetron CX401 multiparametric meter that was one-point calibrated with a solution of 141 $\mu S\ cm^{-1}$, two-points calibrated with 4 and 7 pH buffers at temperature of 10°C, using combined electrode ERP_t-13 for ORP determination. ORP was measured in the field with a platinum – Ag/AgCl electrode containing 3 M KCl+AgCl. Measurement precision was 0.05 for pH, 1 $\mu S\ cm^{-1}$ for EC, and about 5 mV for ORP determination. The pH and ORP has been automatically standardized to a fixed temperature 20°C and EC to a temperature 25°C. To determine alkalinity *in situ*, colorimetric titration (against 0.1 M hydrochloric acid) was employed using an indicator with a pH = 4.3. The average from three titrations was determined in

Table 2

Physico-chemical data of thermal waters on the basis of field measurements. ORP readings were converted to Eh by correcting for the electrode potential of the reference electrode.

Sample symbol	Co-ordinates WGS84	Date of water sampling	T (°C)	EC (μS/cm)	TDS (mg/L)	pH	ORP (mV)	**Eh (mV)
Olsok	76°42.781' 16°18.141'	11.07.2006	9.3	7600	4031	6.96	-322	-104
Bjørnbein	76°43.136' 16°10.458'	11.07.2006	13.9	509	346	8.41	117	332
Fisosen	76°42.738' 16°13.986'	11.07.2006	15.1	6201	3420	7.6	–	–
Trollosen	76°42.764' 16°14.838'	11.07.2006	3.4/ 6.3*	3150	1638	7.43/ 7.0*	-68	154
Orvin**	77°00.962' 15°52.286'	19.07.2006 20.06.2008	13.0 11.7	775 648	378 551	7.51 7.82	176 164	391 380
Raud**	77°11.102' 15°03.764'	01.08.2003 21.07.2006	10.8 11.9	286 368	149 228	7.65 8.03	149	365

* after Reigstad *et al*. (2011); ** after Olichwer *et al*. (2013)

order to characterize alkalinity. The overall analytical precision of this analysis was better than 1%.

Two replicates of 100 ml water samples were collected in polyethylene bottles from each sampling point. Before sampling, each bottle was rinsed several times with the water from the sampling site and rinsed twice with the filtered water from the spring. The samples were filtered using filters with a 0.45 µm diameter nitrocellulose membrane. Next, one sample was acidified with 0.5 ml/100 ml HNO_3 and was used for the ICP MS and ICP OES analyses. The analyzes were carried out in accredited hydrogeochemical laboratory of University of Science and Technology in Cracow.

The water chemical composition was analyzed using an ICP-MS Elan 6100 spectrometer and ICP-OES Plasm 40 spectrophotometer after one month from the time of sampling. Until the time of analysis, the samples were kept frozen. Chemical analyses were expanded and included 17 elements. Contents of Br^- (as Br) and I^- (as I) were determined using an ICP-MS Elan 6100 spectrometer. Contents of Na, K, Li, Ca, Mg, Ba, Sr, Fe, Mn, P (assumed to be present as, and cited as PO_4^{3-}), S (assumed to be present as SO_4^{2-}), Si (cited as SiO_2^-) and B were determined using an ICP-OES Plasm 40 spectrophotometer. The chloride ion was determined argentometrically and nitrate ion photometrically. TDS were determined in the laboratory by adding all analyzed components.

Major and minor ions concentrations were used for the purpose of interpretation together with physical–chemical data recorded during field work. The results of the water analyses are largely presented graphically in Figs 4 through 8 and in Tables 3 and 4. The ionic balances were found to be very good, all within 3% (Table 3).

Table 3

The major ion composition of the sampled spring water. All units are in mg/l unless otherwise stated.

Spring	Ca	Mg	Na	K	HCO_3^-	S as SO_4^{2-}	Cl^-	Si as SiO_2	Balance error [%]
Olsok 2006	173.3	36.53	1260.7	53.2	305.0	31.60	2145	3.14	1.39
Bjørnbein 2006	40.42	10.08	43.33	5.07	136.0	63.50	43.1	3.68	0.78
Fisosen 2006	146.68	39.04	1050	43.18	271.5	3.08	1867.2	5.48	1.58
Trollosen 2006	79.43	12.23	501.5	20.64	225	12.93	775	1.68	2.93
Orvin 2006*	29.91	16.13	64.25	2.87	105.0	47.48	107.6	3.28	-0.7
Orvin 2008*	41.37	23.53	112.40	2.88	112	53.52	196	4.25	2.56
Raud 2003*	15.03	7.54	31.95	1.6	62.24	22.6	46.09	–	2.09
Raud 2006*	17.14	10.15	35.75	2.17	79.3	30.62	49.2	2.86	-0.6

* after Olichwer *et al.* (2013)

Table 4
Selected secondary ion composition of the sampled spring water from the study area. All units are in µg/l.

Spring	Fe	Mn	Ba	Sr	Li	Br^-	NO_3^-	B as BO_3^{3-}	B
Olsok 2006	10	16	2033	7940	1201	6540	200	4380	806
Bjørnbein 2006	5	0.5	20	293	41	8	100	320	58
Fisosen 2006	–	–	940	6	1100	930	220	–	–
Trollosen 2006	1	21	1076	3002	444	2470	800	1310	241
Orvin 2006*	8	0.4	28	203	19	180	400	270	50
Orvin 2008*	5	5.5	89	282	39	80	2400	540	100
Raud 2003*	–	–	–	–	–	–	600	–	–
Raud 2006*	8	0.6	7	284	11	7	100	160	30

* after Olichwer *et al*. (2013)

Results

The major elemental composition of the thermal waters from southern Spitsbergen is given in Table 3. The water temperature of the thermal spring discharges from the Stormbukta bay region ranges from 9.3 to 15.1°C. The pH values for the mineral and thermal waters are between 7.43 (Trollosen) and 8.41 (Bjørnbein). The dissolved solids content of the geothermal waters is in the range of 346.6–4031 mg/l, whereas the Olsok thermal and mineral spring has the highest TDS values (Table 2).

In the thermal and mineral waters, the main cation is sodium, while the main anions are chloride and bicarbonate. The low SO_4^{2-} content in the Olsok, Fisosen and Trollosen samples (Fig. 4) could be due to bacterial reduction of SO_4^{2-} (Lauritzen and Botrell 1994). These springs have a H_2S smell. Moreover, the Bjørnbein site is characterized by greater variation in the chemical composition because, apart from the Cl^- and Na^+ ions, the HCO_3^-, SO_4^{2-}, Ca^{2+} and Mg^{2+} ions have quite high percentages, similar to the Orvin and Raud sites (Table 5). The detailed studies on thermal characteristic and chemistry of Orvin spring from 2006 and 2008 demonstrated that this is water of Cl^--Na^+ type with TDS 378 mg/l and with water temperature 13°C (Olichwer *et al*. 2013). In turn, waters from Raud were of the Cl^--HCO^{3-}-Na^+ type with TDS 228 mg/l and with water temperature 11.9°C.

Based on field measurements of the physicochemical parameters of the thermal and mineral waters, an increasing trend in pH and Eh values can be seen with increasing water temperature (Fig. 5). As far as all springs are concerned, most of the ion mass ratios are not close to the values characterizing modern seawater (Table 6).

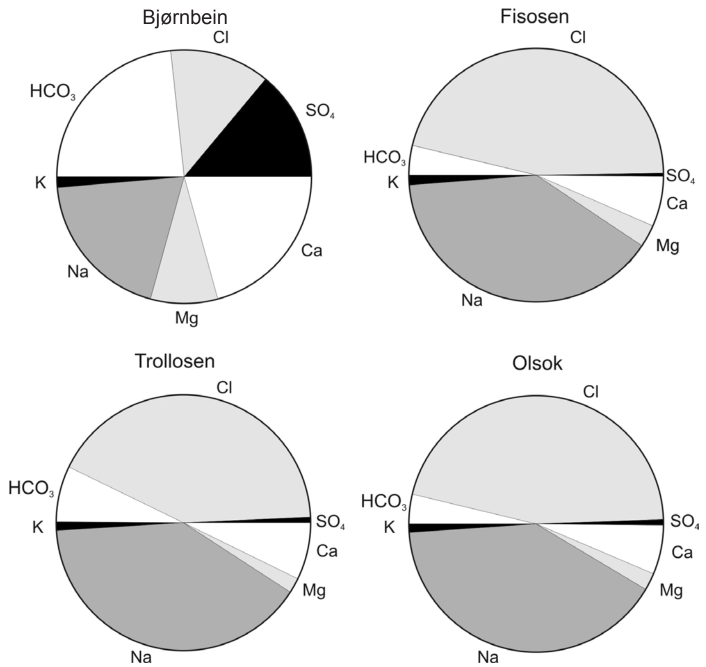

Fig. 4. Pie diagrams showing the major ion composition of the groundwater from the springs in the study area.

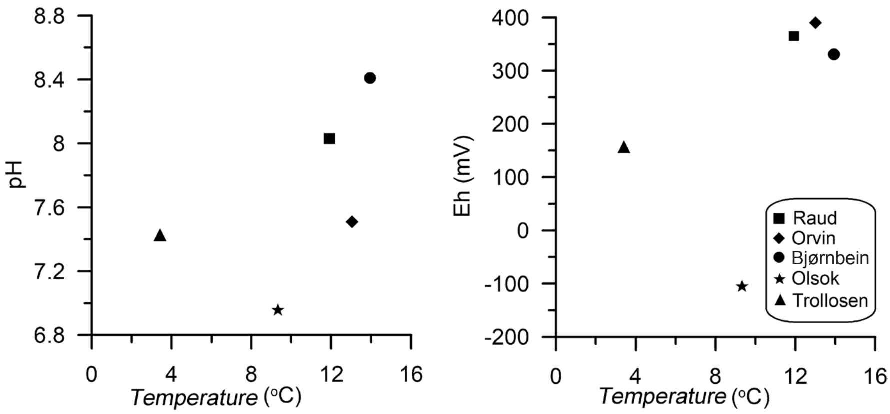

Fig. 5. Plots showing the relationship of temperature to pH and Eh from the study area springs with archive data of the Raud and Orvin sites from Olichwer *et al.* (2013).

Table 5

Percentage of main ions in % meq.

Spring	Ca	Mg	Na	K	HCO_3^-	SO_4^{2-}	Cl^-
Olsok	12.7	4.5	80.8	2.0	7.6	1.1	91.3
Bjørnbein	41.5	17.1	38.7	2.7	46.8	27.8	25.4
Fisosen	12.8	5.6	79.7	1.9	7.8	0.1	92.1
Trollosen	14.6	3.7	79.8	1.9	14.4	1.1	84.5
Orvin 2006*	26.2	23.3	49.2	1.3	30.1	17.3	52.6
Orvin 2008*	23	21.7	54.5	0.8	21.8	13.2	65
Raud 2003*	26.8	22.1	49.6	1.5	36.6	16.9	46.5
Raud 2006*	26.1	25.4	46.8	1.7	39.2	19.3	41.5

* after Olichwer *et al*. (2013)

Table 6

The ions mass ratios of the spring waters from the study area. Seawater mean values from Summerhayes and Thorpe (1996).

Spring	SO_4^{2-}/ Cl^-	B/Cl^-	Li/Cl^-	Br^-/Cl^-
Olsok	0.015	0.00204	0.000559	0.00305
Bjørnbein	1.473	0.00742	0.00095	0.00019
Fisosen	0.00164	–	0.000589	0.000498
Trollosen	0.0166	0.00169	0.000572	0.00318
Raud 2006	0.622	0.00355	0.00022	0.00014
Orvin 2006	0.441	0.0025	0.000176	0.00167
Seawater	0.137	0.00025	0.000009	0.00348

Interpretation

Fluids were classified according to Piper (Fig. 6). The thermal springs with low TDS (Bjørnbein, Raud and Orvin) are mainly mixed-ion or calcium sodium-bicarbonate-chloride waters. The thermo-mineral springs (Olsok, Fisosen) and mineral spring (Trollosen) are classified as sodium-chloride water. All samples are plotted in the Cl-SO_4-HCO_3 ternary diagram (Fig. 7). It is shown that the waters of the study area plot between the HCO_3 and Cl fields, yielding a mixing along the line between the peripheral and mature water fields.

The relative Cl, Li and B contents in the spring waters from southern Spitsbergen show that the hot springs are near the chloride corner with a low B/Cl ratio (Fig. 7). The quaternary plot of Na-K-Mg-Ca (Fig. 8) clearly shows that the

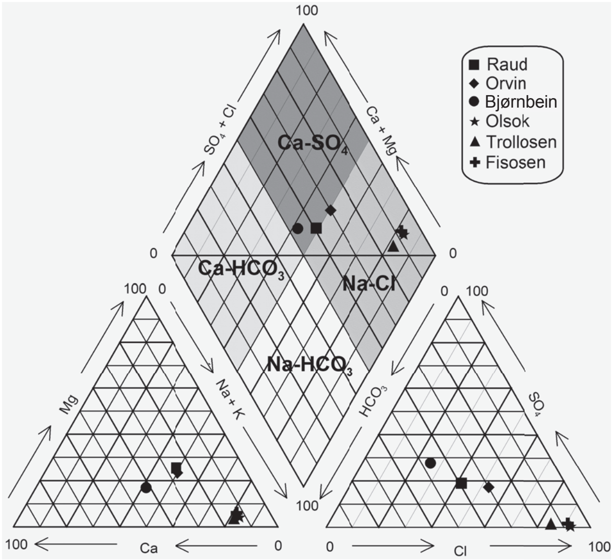

Fig. 6. Piper diagrams illustrating variation in major ion composition of the spring waters from southern Spitsbergen.

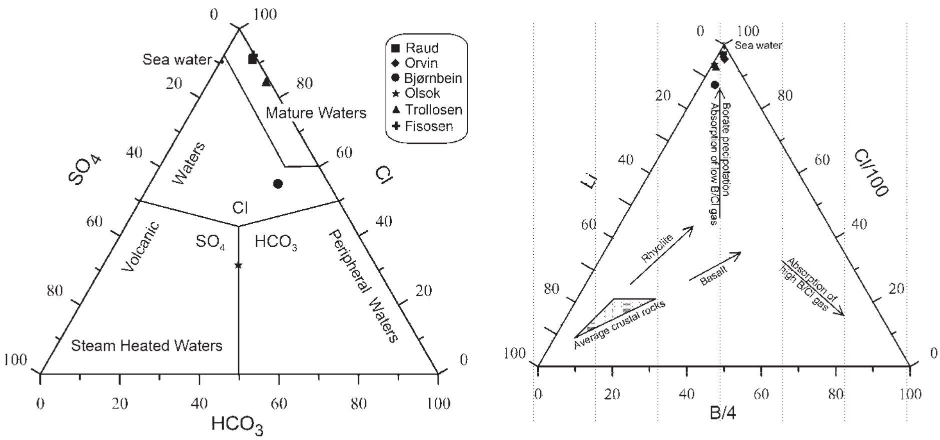

Fig. 7. Relative Cl-SO_4-HCO_3 and Cl-Li-B contents in the spring waters from southern Spitsbergen, modified from Giggenbach (1988). Seawater mean values from Summerhayes and Thorpe (1996).

spring waters are plotted nearer the full equilibrium line, which suggests a more extensive water-rock interaction of the fluids entering the springs. The variations in the 10K/(10K+Na) ratio are much less than those for 10Mg/(10Mg+Ca). The Ca/Mg ratios of the waters show a rather wide range, suggesting the precipitation-dissolution process of Ca- and Mg-bearing minerals, most probably carbonates.

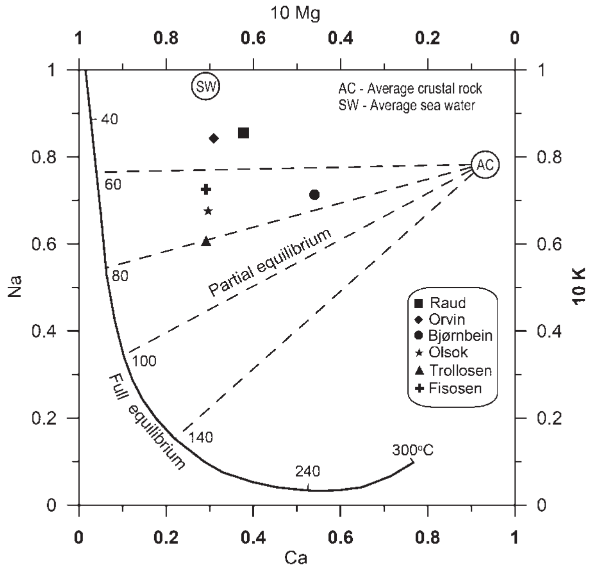

Fig. 8. Relative Na, K, Mg and Ca contents in the spring waters, modified from Giggenbach and Glover (1992).

In the study area, two groups of thermal waters can be distinguished purely on the basis of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-} and HCO_3^{-}. The Bjørnbein site belongs to the first group, it is calcite-sodium mixed-anion water. This water is also characterized by low electrical conductivity (509 µS/cm). Similar types are Raud and Orvin springs (Olichwer *et al*. 2013), although the Bjørnbein has a more elevated sulfate content. The all ions mass ratios (Table 6) suggest the lack of participation of modern sea water in spring waters. The waters from Bjørnbein site can be a mixture of glacial waters (Vitkovskijbreen, Noisbreen) and melting permafrost, infiltrating through the fissured karst massif to significant depths and subsequently escaping to the land surface through tectonic discontinuities (deep circulation). Strong fissuring of the carbonate rocks (Szczęsny 1993) suggests a deep water circulation within the massif. Increased nitrate content in the Orvin spring (Table 4), may be caused by deep refreezing of the active layer and the activation of the flushing of birth faeces (Dragon and Marciniak 2010). In the vicinity of Orvin spring on the Gnalberget wall there are birds' habitats.

The Olsok springs represents the second type which differs from the Bjørnbein site. This spring is characterized by high electrical conductivity (7600 µS/cm), a pH of less than 7, and a low Eh (-104 mV). It is sodium-chloride water with low content of sulphates. As far as this spring is concerned, most of the ion mass ratios are not close to the values characterizing modern seawater. Probably the salinity is the result of deep inflow of subpermafrost thermal brine (Lauritzen and Botrell 1994) from rocks younger than Ordovician carbonates. The evaporites (gypsum and anhydrite) were found to the east and north of the study area. The presence of hydrogen sulphide in Olsok spring is the effect of bioreduction of sulphates, which also explains its low content in water (Lauritzen and Botrell 1994). Its relatively low silica content with a high mineralization level may also indicate the inflow of shallow water or glacial waters from surrounding glacier to the Olsok spring. Additionally, Olsok spring is located in a zone that separates crystalline carbonate and younger sedimentary rocks. The increased values of strontium, lithium and barium as well as the presence of H_2S from sulphate reduction and a clear impoverishment in magnesium suggest that the water component in this spring related to the subpermafrost circulation and has a different character than in the springs of the first type (predominant deep circulation).

The Fisosen and Trollosen springs are similar to the Olsok spring in many respects. These springs are characterized by high electrical conductivity, but it is lower than in Olsok spring, and the Na^+ and Cl^- ions are dominant. These springs have also higher Eh, pH and HCO_3^- content values than the Olsok spring. Similarly as in the case of Olsok, Fissoen and Trollosen are also a mixture of hot brines and glacial melt waters. Most of the ion mass ratios are not close to the values characterizing modern seawater (Table 6). The exception is the Br/Cl ratio, which in Trollosen spring is similar to seawater. Due to the location of the outflow adjacent to the shoreline, probably plugs of saltwater are presses into the main conduit and are ejected as discrete pulses in spring.

Fisosen and Trollosen springs differ by the fact that in the case of the latter the proportion of glacial melt waters is higher relative to hot brine than in Fisosen spring. This can be evidenced by the higher temperature of the Fisosen spring water (15.1°C) compared to the Trollosen spring (3.4°C). Moreover, a very high discharge of Trollosen (10000 l/s) suggests a higher proportion of glacial melt waters than is the case of the Fisosen spring.

Conclusions

In the southern Spitsbergen, the thermal and mineral waters are primarily associated with the subpermafrost circulation, being mixed with the shallow circulation waters and glacial melt waters. Furthermore, in the case of the thermal waters with the dominant Cl^- and Na^+ ions, hot brines contributed to their chemical composition.

Four thermal and mineral water outflows were studied and analyzed, out of which 3 (Olsok, Fisosen and Trollosen) have an increased TDS level (above 1000 mg/l – mineral waters) and are of the Cl^--Na^+ water type. The remaining site (Bjørnbein), with a TDS 346 mg/L, is characterized by more varied chemical composition, with the HCO_3^-, SO_4^{2-}, Ca^{2+} and Mg^{2+} ions found at significant concentrations. Based on the variations in physicochemical characteristics, two water types were distinguished. The first type is associated with the thermal waters originating from the deep circulation waters. The second type is associated with the thermal and mineral waters originating from the mixture of subpermafrost hot brines with glacial waters.

The Olsok site, located in a fault zone, is the most outstanding one in the study area. It is one of the coldest springs and has the lowest values of pH and Eh; moreover, it gives off a strong H_2S odor. The increased hydrogen sulfide content is the effect of the coincidence of slow leaching of chemical compounds from the rocks by the flowing water and the flow of water through biologically active deposits occurring at the spring.

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