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Hydrogeochemical Data Report: the Sampling of Selected Localities in Kemerovo Oblast' and Tomsk Oblast’, Siberia, Russian Federation

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RAPPORT

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Hydrogeochemical Data Report: the Sampling of Selected Localities in Kemerovo Oblast' and Tomsk Oblast', Siberia, Russian Federation

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This report documents the hydrochemical analyses performed on water samples collected during a field expedition during the summer of 2010 to the Martaiga gold mining province (Kemerovo Oblast'), the Goryachii Istochnik and Chazhemto spas (based on deep oil exploration wells) in the north of Tomsk Oblast' and various sites in and around the city of Tomsk – all in south-western Siberia. Data have been obtained from groundwater (wells, boreholes and springs), rivers, lakes and discharges from abandoned mines and mine wastes. Of particular interest are the following observations:

(i) The shallow groundwaters of the Tomsk region are typically dominated by relatively high concentrations of Ca^{++} and bicarbonate alkalinity, and slightly alkaline pH. The high concentrations may reflect high partial pressures of CO_2 in recharge water. They also result in the degassing of CO_2 at spring discharges, the formation of travertine in some springs and high pH (> 8) in spring-fed streams.

(ii) The urban springs in Tomsk are characterised by elevated concentrations of nitrate, sulphate, potassium, chloride and sodium. In one spring (Voskresenskii spring), chloride reaches 70 mg/L (compared with a background of <2 mg/L in uncontaminated waters) and nitrate is recorded as 160 mg/L, rendering it potentially unsafe to drink, especially for infants.

(iii) Especially aggressive mine tailings leachate was found at the tailings ponds in Komsomolsk, Martaiga, with concentrations ranging up to 13.5 g/L sulphate, 4.8 g/L iron, 399 mg/L Al, 556 mg/L As, 232 mg/L Zn, 18.8 mg/L Cu, 5.9 mg/L Cd and pH values as low as 1.68.

(iv) The > 2 km deep abandoned oil exploration boreholes at Goryachii Istochnik (near Parabel') and at Chazhemto Spa (near Kolpashevo) yield saline Na-(Ca)-Cl waters with salinities around 40% and 18% of seawater, respectively. The waters were characterised by sulphate reduction and, at least in the case of Goryachii Istochnik, by methanogenesis. Temperatures are broadly consistent with a normal geothermal gradient. The waters exhibit very low Mg/Ca ratios, elevated Sr/Ca ratios, and elevated concentrations of, e.g. Si, Zn, B, Li and Ba. At Goryachii Istochnik, arsenic concentrations of around 120 μg/L were recorded and it is recommended that the spa be informed that the water is not suitable for potable use.

Emneord: Geokjemi	Hydrogeologi	Borebrønn
Gruvevann	Elvevann	Mikrobiologi
Grunnvannskvalitet	Innsjøer	Olje

CONTENTS

1 INTRODUCTION

1.1 Previous studies and sampling activities

Tomsk State University (TGU) has long enjoyed an informal yet fruitful collaboration in the field of hydrochemistry with Norges geologiske undersøkelse (NGU) and Holymoor Consultancy (UK), now trading as D Banks Geoenvironmental Services. This collaboration initially supported a joint project between TGU and the Khakassian State Committee for Environmental Protection (SCEP) to produce the geological section of an "Environmental Atlas of Khakassia" (Parnachev et al. 1998a,b, 2000). Previous groundwater sampling was carried out in Khakassia during the periods:

- 16th - 21st August 1996, by David Banks (NGU), Prof. Valerii Petrovich Parnachev (Dept. of Dynamic Geology, Tomsk State University) and Alexander Y. Berezovsky (Tomsk State University / Shira Regional Administration). Results of this sampling round are published by Banks et al. (1998) and Parnachev et al. (1997, 1999).
- 9th-15th June 1999 by David Banks (Holymoor Consultancy), Prof. Valerii Petrovich Parnachev (Dept. of Dynamic Geology, Tomsk State University), Bjørn Frengstad (NTNU/NGU) and Anatoly A. Vedernikov (Khakassian SCEP, Abakan office).
- 7th - 12th September 2000, by David Banks (Holymoor Consultancy), Prof. Valerii Petrovich Parnachev (Dept. of Dynamic Geology, Tomsk State University), Wayne Holden (URS Dames & Moore, UK), Olga V. Karnachuk (Dept. of Plant Physiology and Biotechnology, Tomsk State University) and Anatoly A. Vedernikov (Khakassian SCEP, Abakan office). Results of these last two sampling rounds have been published by Banks et al. (2001) and by Banks et al. (2004).

In more recent years, the focus has been transferred to new projects: in particular, (i) a series of projects involving the characterisation of microbial communities in mine waters, mine wastes and oil boreholes, managed by Prof. Olga V. Karnachuk (Dept. of Plant Physiology and Biotechnology, Tomsk State University), and (ii) a new project between Professor Valerii P. Parnachev (Department of Dynamic Geology, TGU) and the Tomsk Oblast' Committee for Ecology, to produce an atlas and characterisation of water quality in Tomsk Oblast'. Further sampling rounds have thus been carried out in the periods:

- July 2006, by David Banks (Holymoor Consultancy), Prof. Valerii Petrovich Parnachev (Dept. of Dynamic Geology, Tomsk State University), Prof. Olga V. Karnachuk (Dept. of Plant Physiology and Biotechnology, Tomsk State University) and Dr. Bjørn Frengstad (NGU). In this period, sampling was undertaken of therapeutic waters in the vicinity of Lake Shira, Khakassia; waters in the vicinity of a former alluvial gold mining area at Malii Anzas, south of Abaza, Khakassia; mine waters from the former underground gold mining area around Berikul', in Kemerovo oblast'; mine waters from working and abandoned coal mines in the Kuzbas coal basin of Kemerovo oblast'.

- In August 2007, staff from TGU and Holymoor Consultancy, together with Prof. Marc Solioz (Department of Clinical Pharmacology, University of Berne, Switzerland) and Prof. Nikolai V. Pimenov (S.N. Vinogradskii Institute of Microbiology of the Russian Academy of Science) returned to two sampling localities to collect additional samples: namely, mine waters from the former gold mining area around Berikul', in Kemerovo oblast' and mine waters from the silver-gold-zinc mining area around Salair, on the western fringes of the Kuzbas.

Results of these last two sampling rounds have been published by Banks et al. (2008) in NGU report NGU 08.013.

1.2 Sampling activities - August 2010

This report documents the most recent round of field work, in the period 8th to 21st August 2010, undertaken by:

- Prof. Valerii Petrovich Parnachev (Dept. of Dynamic Geology, Tomsk State University),
- Prof. Olga V. Karnachuk (Dept. of Plant Physiology and Biotechnology, Tomsk State University),
- David Banks (D Banks Geoenvironmental Services, UK),
- Sasha L. Arkhipov (Dept. of Dynamic Geology, Tomsk State University),
- Prof. Marc Solioz (Department of Clinical Pharmacology, University of Berne, Switzerland),
- Prof. Nikolai V. Pimenov (S.N. Vinogradskii Institute of Microbiology of the Russian Academy of Science)

and a number of research students of TGU’s Departments of Dynamic Geology and Plant Physiology and Biotechnology, including:

- Anna L. Gerasimchuk
- Olga P. Ikkert
- Yekaterina Komleva
- Marina B. Kazakovtseva
- Polina A. Bukhtiyarova
- Dmitrii S. Kulizhskii

Invaluable logistical assistance was provided by the Tomsk Oblast’ Committee for Ecology. Sampling was carried out in the following three areas:

- The *Martaiga (Mariinskaya Taiga)* former gold mining area around and to the south of Tisul' town, Kemerovo Oblast'. In particular, the mining areas of Tsentralnaya, Novii Berikul' and Komsomolskaya were sampled. The TGU Department of Plant Physiology and Biotechnology is currently engaged in research projects to characterise and isolate heavy-metal tolerant extremophile bacteria and Archaea from mine waters.
- Springs, wells, lakes and rivers, selected by the Tomsk Oblast' Committee for Ecology, in and around the city of Tomsk, Tomsk Oblast'. The TGU Department of Dynamic Geology is currently engaged in a collaborative project with the Committee for Ecology to produce a hydroenvironmental characterisation / "atlas" of Tomsk Oblast's aquatic environment.
- Two deep, abandoned, former oil exploration boreholes in the northern part of Tomsk Oblast', now taken into private ownership and developed as spas of varying degrees of sophistication. The TGU Department of Plant Physiology and Biotechnology is currently engaged in a research project to characterise the microbiota of such wells.

During the sampling of August 2010, alkalinity, pH and temperature were measured in the field at all sites, with electrical conductivity and Eh, where meaningful, being measured in the field at selected sites.

Field-filtered (0.45 μm) samples of water from Tomsk Oblast' were returned to NGU for analysis by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) and Ion Chromatography (IC) methods.

Field-filtered (0.45 μm) samples of mine water from Kemerovo Oblast' were returned to the laboratory of the Hydrogeochemical Engineering Research & Outreach (HERO) group, Civil Engineering and Geosciences, Newcastle University, UK, for analysis by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) and Ion Chromatography (IC) methods.

Staff time has been provided to the project by:

- TGU (Prof. Valerii P Parnachev, Prof. Olga V Karnachuk, A.L. Arkhipov and their research students)
- NGU (Dr. Pål Gundersen and staff of the analytical laboratory). Dr. Bjørn Frengstad is thanked for facilitating NGU's continued collaboration.
- David Banks Geoenvironmental Services, Chesterfield, UK (Mr David Banks)
- Newcastle University (Ms Jane Davis)

This report is intended to document the raw data produced during the study. This raw data report will form the documentation basis for scientific papers interpreting the data collected during the study.

2 SAMPLING AND ANALYSIS ROUTINES: YEAR 2010

The sites sampled in August 2010 are detailed in Sections 3 to 5 of this Report.

2.1 Groundwater Sampling

As in the previous sampling rounds, groundwater samples were taken, to the extent possible, from flowing sources (springs), artesian (flowing) boreholes or regularly-used wells and boreholes, to ensure that "fresh" groundwater was sampled.

In the case of waters from Goryachii Istochnik (see Section 5), samples were taken from a free-flowing rubber pipe leading directly from the (artesian) borehole head. In the case of water from Chazhemto (see Section 5), the sample was taken from a tap in a spa bathroom fed directly by untreated water from the deep borehole in question.

For each sample site the following samples were taken:

- 1 x 100 ml polyethene flasks, of water filtered at 0.45 µm, using a Millipore filter capsule and hand-held polypropene syringe. No acidification was carried out in the field. These samples were carried in baggage to Norway and delivered to the Norwegian Geological Survey. Except during periods of transport, samples were stored in the dark at c. 4°C.
- In some cases, a selection of samples for bacteriological analysis at TGU and additional chemical analysis at Russian organisations (see Chapter 5)

2.2 Mine Water Sampling

Mine waters were sampled either from freely discharging mine water adits, seepages of mine waste leachate or puddles / pools of mine waste leachate. Samples were collected as in 2.1. No acidification was carried out in the field. These samples were carried in baggage to the UK and posted to the laboratory of Newcastle University. Except during periods of transport, samples were stored in the dark at c. 4°C.

2.3 Lake and River Water Sampling

The lake /stream water samples from Tomsk Oblast' were collected by wading out as far as safely possible into the lake (typically c. 60 cm depth of water) and submerging the sampling syringe to a depth of some 20-30 cm in water free of disturbed sediment.

The River Chulym water sample was taken from a stable river bank by submerging the sampling syringe to a depth of some 20-30 cm in fast-flowing river water.

Filtration was then carried out as in 2.1. No acidification was carried out in the field. These samples were carried in baggage to Norway and delivered to the Norwegian Geological Survey. Except during periods of transport, samples were stored in the dark at c. 4°C.

2.4 Field Measurements

Field measurements of groundwater were taken either in the flowing water source or, if this was not possible, in a large (c. 15 L) bucket filled directly from the source. In lakes and rivers, the electrodes were submerged to maximum extent below the lake surface (c. 5-10 cm) for measurements to be taken. In the case of alkalinity, reaction vessels were filled either from the flowing source, or (e.g. in the case of lakes/rivers) directly from the lake/river or from a large bucket filled with the water from the source.

In the case of waters from the deep Chazhemto and Goryachii Istochnik boreholes (Chapter 5), field measurements were taken from electrodes submerged in an ad-hoc throughflow cell comprising a plastic container through which borehole water was allowed to overflow from a submerged discharge tube.

Field determinations included:

- determination of alkalinity (by average of multiple determinations, typically three determinations) using a standard solution of 0.05 N HCl, prepared by TGU's Department for Plant Physiology and Biotechnology, an indicator comprising Hach bremocresol green / methyl red powder portioned in foil pillows (with an end point, in the region 4.3 to 4.6, depending on the alkalinity value, giving a measure of t-alkalinity), and a sampling syringe / container from the AquaMerck 11109 alkalinity test kit. This arrangement was due to strict air carriage regulations prohibiting carriage of acid and indicators in flammable organic solutions by aircraft from the UK.
- pH and temperature (T) using TGU Department for Plant Physiology and Biotechnology's Hanna Instruments HI8314 pH meter, regularly calibrated against solutions of known pH around 4, 7 or 10 as appropriate. Measurements were manually corrected for drift (assumed to be linear with time) on the basis of daily calibrations.

2.5 Analysis at Norges Geologiske Undersøkelse

Samples (a single flask of filtered water from each site) were transported by David Banks and Bjørn Frengstad to the NGU analytical laboratory in Trondheim. Prior to analysis, samples were stored in a refrigerator at around +4°C, except for brief periods of transport. Upon arrival, the samples were stored in the NGU cool-room at 4°C. For analysis, the following procedure was followed:

1 Homogenise flask contents by gentle shaking.

2 Modest sub-sample extracted from each flask, stored in a new lab-clean container and used directly for ion-chromatography (Dionex 120 DX machine) analyses of anions.

3 The remaining water was acidified with 0.5% concentrated Ultrapur HNO_3 *in the original flask*. This was done to hinder absorption / precipitation (and dissolve already sorbed/precipitated) of elements. This acidified quantum was used for ICP-AES (Perkin Elmer Optima 4300 Dual View machine) analyses.

In the cases of samples TOM26, 27 and 28 (deep saline groundwaters from Goryachii Istochnik and Chazhemto), standard dilutions (100 x dilution for Na, Ca and Sr by ICP-AES and between 10x and 800 x for anions) had to be used to reduce the sample salinity to manageable levels for determination of some parameters. This resulted in correspondingly raised limits of detection for these parameters.

Standard methods are documented in NGU's **NGU-SD 3.4:** *IC-analyse av anioner* and **NGU-SD 3.1:** *ICP-AES -analyse av vann.* Results are reported in NGU's analytical reports 20100351 (dated 22/11/10 for ICPAES and 7/1/11 for IC).

The following data are presented by NGU for analytical precision and detection limits:

ICP-AES lower limits of quantification (LLQ), assuming 1 mg/l = 1 ppm (ignoring dilution)

Si mg/l	Al mg/l	Fe mg/l	Ti mg/l	Mg mg/l	Ca mg/l	Na mg/l	K mg/l	Mn mg/l	P mg/l	Cu mg/l	Zn mg/l	Pb mg/l	Ni mg/l	Co mg/l	V mg/l
0.02	0.02	0.002	0.001	0.05	0.02	0.05	0.5	0.001	0.05	0.005	0.002	0.005	0.005	0.001	0.005

Mo mg/l	Cd mg/l	Cr mg/l	Ba mg/l	Sr mg/l	Zr mg/l	Ag mg/l	B mg/l	Be mg/l	Li mg/l	Sc mg/l	Ce mg/l	La mg/l	Y mg/l	As mg/l	Sb mg/l
0.005	0.0005	0.002	0.002	0.001	0.002	0.005	0.02	0.001	0.005	0.001	0.02	0.005	0.001	0.01	0.005

(1 mg/l = 1 ppm)

ICP-AES analytical uncertainty

<u>i) Lower area of determination (LLQ to 5*LLQ):</u>
± 50 rel. %: As, Sb (S, Se, Sn) ± 37.5 rel. %: K, Pb
± 25 rel. %: Ag, Al, B, Ba, Be, Ca, Cd, Ce, Co, Cr, Cu, Fe, La, Li, Mg, Mo, Mn, Na, Ni, P, Si, Sc, Sr, Ti, V, Y, Zn, Zr
<u>ii) Upper area of determination (> 5*LLQ):</u>
± 20 rel. %: As, Sb (S, Se, Sn) ± 15 rel. %: K, Pb
± 10 rel. %: Ag, Al, B, Ba, Be, Ca, Cd, Ce, Co, Cr, Cu, Fe, La, Li, Mg, Mo, Mn, Na, Ni, P, Si, Sc, Sr, Ti, V, Y, Zn, Zr

The stated uncertainties have a coverage factor of 2 (2 standard deviations), corresponding to a confidence interval of 95%

IC lower limits of quantification (LLQ) and analytical uncertainty, assuming 1 mg/l = 1 ppm (ignoring dilution)

	F^-	Cl^-	NO_2^-*	Br^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
LLQ:	0.05 mg/l	0.1 mg/l	0.05 mg/l	0.1 mg/l	0.05 mg/l	0.2 mg/l	0.1 mg/l
Uncertainty LLQ to 30*LLQ	20%	20%	20%	20%	20%	20%	20%
Uncertainty > 30*LLQ	10%	10%	10%	10%	10%	10%	10%
INFO: 30*LLQ =	1.5 mg/l	3 mg/l	1.5 mg/l	3 mg/l	1.5 mg/l	6 mg/l	3 mg/l

The stated uncertainties have a coverage factor of 2 (2 standard deviations), corresponding to a confidence interval of 95%

*) NGU-lab is not accredited for NO_2^- (nitrite)

Dr. Pål Gundersen and Dr. Bjørn Frengstad are thanked for organising sample analysis at the Geological Survey of Norway.

2.6 Analysis at Newcastle University

Samples (a single flask of filtered water from each site) were transported by David Banks to Chesterfield, UK, and then dispatched via courier postal service to the HERO analytical laboratory at Newcastle University. Prior to analysis, samples were stored in a refrigerator at around +4°C, except for brief periods of transport. Upon arrival, the samples were stored in a cool-room at +4°C. For analysis, the following procedure was followed:

1 Homogenise flask contents by gentle shaking.

2 Modest sub-sample extracted from each flask, and used directly for ion-chromatography (Dionex DX320 for Gradient Anion Analysis) analyses of anions.

3 The remaining water was acidified with concentrated Ultrapur HNO_3 *in the original flask*. This was done to hinder absorption / precipitation (and dissolve already sorbed/precipitated) of elements. This acidified quantum was used for ICP-AES analysis (Varian Vista MPX with simultaneous charged coupled device).

Jane Davis is thanked for organising sample analysis at the University of Newcastle.

3 TOMSK OBLAST' (ТОМСКАЯ ОБЛАСТЬ): IN AND AROUND THE CITIES OF TOMSK (ТОМСК) AND ASINO (АСИНО)

Water samples were collected at three types of locality, as prioritised by the Tomsk Oblast' State Committee for Ecology:

1) A number of well-known (and in some cases travertine-depositing) springs from Carboniferous / Devonian terrain to the south of Tomsk city, some of which are within designated nature reserves.
2) Selected springs within Tomsk city and suburbs, some of which may be used by the public as water sources.
3) Three lakes in or near nature reserves within the forested area between the Tomsk-Jurga road and the village of Kirek (southwest of Tomsk city)
4) Two oxbow lakes in the floodplain of the River Chulym, north of Asino, and the River Chulym itself, near Asino.

The geology of Tomsk region, and its control over the landscape and geology of the area, is admirably documented by Parnachev & Parnachev (2010). Broadly speaking, however, Tomsk lies on the south-eastern margin of the Western Siberian megabasin, which contains Mesozoic and Cenozoic sediments and sedimentary rocks, which outcrop and thicken towards the north and west of Tomsk.

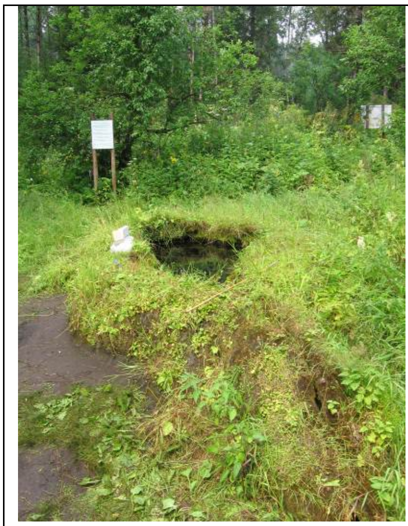
Towards the south and east of Tomsk, the subcropping rocks comprise a series of lithified Devonian and Carboniferous sedimentary rocks, broadly belonging to the Kuznetsk-Alatau orogenic belt. The downwarping of the Palaeozoic basement in the region of Tomsk is often referred to as the Kolyvan'-Tomsk Plicate Zone. The stratigraphy of the Carboniferous and Devonian rocks is not simple, as structural geology comprises a number of nappe structures, leading to stratigraphic repetition. The strike of the stratigraphy and nappes is NNE-SSW The units recognised as comprising the sequence are, however, in descending stratigraphic order:

- Basandaiskaya suite (C_1) – sandstones, siltstones and shales
- Lagernosadskaya suite (C_1) – dominated by greyish siltstones and mudstones, with some argillaceous shales, sandstones and marly limestones.
- Yarskaya suite (C_1) – argillaceous shales, sandy limestones and carbonaceous sandstones
- Tugoyakovskaya / Salomatovskaya suite (D_3 - C_1) –siltstones, marly argillaceous shales, sandy limestones and carbonaceous sandstones
- Yurginskaya suite (D_3) – mixed series of mudstones/shales, siltstones, some sandstones, limestones and even volcanic rocks.
- Pachinskaya suite (D_{2-3}) – flysch sequence dominated by phyllites, shales and some marls, limestones

- Omutninskaya / Mitrofanskaya suite (D_{1-2}) – volcanic rocks

In the Tomsk, region, the Cenozoic sediments overstep the Devonian-Carboniferous sequence. In addition, the area is overlain to varying degree by superficial Quaternary deposits of varying age (various alluvial and river terrace deposits, peat, lacustrine deposits) and, in Tomsk, anthropogenic deposits. In the area mapped as being underlain by Devonian / Carboniferous rocks, it is not always clear whether the water from a spring or well is derived from a Palaeozoic aquifer or a more recent horizon (or a mixture of the two). The geological associations of the sampled springs documented in this report must thus be regarded as tentative, in some cases.

Figure 3.1. Photographs of sample sites in Tomsk area



Tom01 Talovskaya Chasha and travertine "crater"

Tom03 Spring at km 41

Tom04 Kapitanovskii Spring

Tom05 Larinskii Spring

Tom06 River Targanak

Tom07 Dizvestnii Spring

Tom07 Dizvestnii Spring (close-up of spring mouth)

Tom08 Voskresenskii Spring, Tomsk

Tom10 Stepanovskii II spring-fed stream

Tom11 Akademicheskii Spring

Tom23 Larinskoe Lake

Tom24 Khardinskoe Lake

Tom25 Kirek Lake at sampling point (Kirek village in background)

Tom29 Turgoiskoe Lake

Tom30 Shuch’e Lake

Tom31 River Chulym, just S of Asino

3.1 Sampling Sites

8/8/10: Springs southeast of Tomsk. Heavy rain during previous night and on day of sampling

Sample Tom01: Talovskaya Chasha. This spring emerges in the base of a broad deep depression in the terrain, in an extensive area of taiga forest. The spring has formed a crater of travertine around 1 m high above the natural terrain level and overflows through a channel in the lip of the crater. The immediate area of the spring is designated a nature reserve. The water is believed to be derived from Neogene carbonate sediments and the spring is believed to be at least 10,000 years old. There are several other springs in the base of the depression (not associated with craters of travertine) and it is estimated that the flow from Talovskaya Chasha "proper" constitutes around 30% of the total flow.
Field appearance of water: Clear / colourless. No odour.
On filtration at 0.45µm: No clogging or sediment.
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

Sample Tom02: Other spring flow adjacent to Talovskaya Chasha. This sample was taken from a minor stream draining from other springs emerging from the same broad forest depression as Talovskaya Chasha, but without the same, obvious travertine crater.
Field appearance of water: Clear / colourless. No odour.
On filtration at 0.45µm: A few particles on filter.
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

Sample Tom03: Spring at km 41
This sample was taken from a spring in wetland area at the floor of a valley just below the extensive community of dachas known as "km 41", as it lies 41 km along the railway track between Tomsk and Taiga. The spring lies in the valley of a stream forming the headwaters of the River Ushaika. The valley is forested, although within c. 400 m of the spring is a large community of dachas, with their latrines and vegetable plots. The spring has been enclosed by a wooden structure to form a well, although it still overflows through a small channel in the structure towards the stream. The well / spring is used as drinking water by the inhabitants of km 41. The elevation of this spring is the same as Talovskaya Chasha and *may* be derived from the same Neogene formation. It is reported that there were travertine deposits here before the well was constructed.
Field appearance of water: Colourless, no odour. A little cloudy.
On filtration at 0.45µm: Some particles retained by filter.
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

9/8/10. Springs south of Tomsk in the area of the River Tugoyakovskaya. Dry weather

Sample Tom04: Kapitanovskii Klyuch (Капитановский Ключ)

This is a c. 150 m long, narrow, shallow valley in forested terrain, gradually accumulating spring water along its length. The spring flow then passes through a cylindrical catch-pit, where water can be collected by the public. The flow from this spring is reported to drain directly into the Tom' River, rather than entering the Tugoyakovka River. No obvious travertine deposits are recorded. Flow = c. 0.3 to 0.5 L/s. The sample was taken from the iron pipe overflowing from the catch-pit.

Field appearance of water: Clear / colourless water. No odour.

On filtration at 0.45µm: A little green algae on the filter.

Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

Sample Tom05: Larinskii Klyuch (Ларинский Ключ)

This is a small spring (c. 0.1 L/s) within the Larinskii Zakaznik (Ларинский Заказник) nature reserve, flowing down the valley side towards the Tugoyakovka River (Река Тугояковка). Believed to derive from C_1 sedimentary rocks.

Field appearance of water: Clear / colourless water.

On filtration at 0.45µm: No clogging or sediment

Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

Sample Tom06: River Targanak (Река Тарганак)

This is a small spring-fed river, running down from the hills to flow into the River Tugoyakovka (Река Тугояковка). Sampled just upstream of the confluence with the River Tugoyakovka within the Larinskii Zakaznik (Ларинский Заказник) nature reserve. The flow in the Targanak was crudely estimated at around c. 180 L/s.

Field appearance of water: Clear / colourless water.

On filtration at 0.45µm: Some fine sediment retained on filter

Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

Sample Tom07: Zvyozdnii (Dizvestnii) Spring (Звёздный (Дызвестный) Ключ)

This spring emerges from 3-4 discrete holes or seepages in a (3 m high) rock face in the hills of the Larinskii Zakaznik (Ларинский Заказник) nature reserve. The total spring flow is c. 1-2 L/s. The spring water can be seen to deposit travertine at the base of the rock face. Lower down the hillside, the stream draining from the spring has deposited an impressive complex of travertine terraces. The spring was sampled at the spring discharge point from the rock face. The horizon from which the spring emerges appears to be the Kochkovskaya (Кочковская) Suite, a partially cemented conglomerate containing gravel-sized clasts of a few mm to 1 cm. This formation is at the boundary of the Neogene and Quaternary.

Field appearance of water: Clear / colourless water.

On filtration at 0.45µm: No clogging, precipitate or sediment.

Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

10/8/10: Springs in Tomsk city and suburbs. A hot, dry day

<u>Sample Tom08: Svyatoi (Voskresenskii) Spring (Святой (Воскресенский) Ключ).</u>

This spring lies on one of the low terraces of the River Ushaika's north bank in Central Tomsk. The spring comprises a wooden spring house, at the foot of a river terrace slope. The spring discharges from a pipe appearing to emerge from the terrace slope. A main road runs along the top of the terrace and there are buildings in the vicinity.
Field appearance of water: Clear, colourless.
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

<u>Sample Tom09: Stepanovskii 1 (Степановский I) spring</u>
This is a small spring-fed stream in the suburb of Stepanovka, to the southeast of Tomsk. The stream runs through a built area and discharges into the River Ushaika. The stream was sampled some distance upstream of its discharge to the Ushaika, in an industrial/residential/ garden area.
Field appearance of water: Slightly turbid
On filtration at 0.45µm: Much sediment retained on filter.
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

<u>Sample Tom10: Stepanovskii 2 (Степановский II) spring</u>
This is another spring-fed stream near the suburb of Stepanovka, to the southeast of Tomsk. The stream runs from a residential area and discharges into the River Ushaika. The stream was sampled in a small wooded area, downstream of the residences; a lot of fly-tipping of waste could be seen on the stream banks. The flow was estimated at around or slightly over 1 L/s.
Field appearance of water: Clear, colourless.
On filtration at 0.45µm: No clogging or sediment.
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

<u>Sample Tom11: Akademicheskii 1 Klyuch (Академический I ключ)</u>
This is a very small seepage spring on the northeast bank of the Ushaika River, emerging from the river terraces upon which the Tomsk suburb of Akademgorodok is built. The immediate area was wooded and meadow. The spring is located around 300 m upstream along the Ushaika from the railway bridge. The spring may be derived from Carboniferous C_1 sandstones, siltstones and argillites (although there is also likely to be a component of much more superficial groundwater). The flow was estimated at only a few tens of mL/s.
Field appearance of water: Clear, colourless.
On filtration at 0.45µm: Much organic sediment retained on filter.
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

16/8/10: Lake waters in the southwest corner of Tomsk oblast'. Dry day

<u>Sample Tom23: Larinskoe Lake (Ларинское озеро)</u>

This is a low-pH lake, rich in humic materials, that is reportedly devoid of fish. The catchment of the lake is entirely natural and largely forest. The sample was obtained from the bank of the lake, where the water depth was c. 40 cm. The sample was taken from a depth of c. 5 cm below the water surface. It proved difficult to obtain a wholly stable pH reading in the field.

Field appearance of water: Clear, but pale brown in colour.

On filtration at 0.45µm: Some brown precipitate on filter.

Water sample after filtration and storage to 1/9/10: Clear, pale brown colour, no precipitate.

<u>Sample Tom24: Khardinskoe (Chernovskoe) Lake (Хардинское (Черновское) озеро)</u>

This is a large lake of clear water, with fish life. The catchment of the lake is largely natural forest, although a small resort (several cabins) exists on the shore not far from the sampling point. The sample was obtained by wading around 10 m into the lake to a water depth of c. 60 cm and the sample was taken from a depth of c. 10 cm.

Field appearance of water: Clear, but very pale yellow.

On filtration at 0.45µm: Significant filter clogging with slightly buff material

Water sample after filtration and storage to 1/9/10: Clear, very pale yellow/brown, no precipitate.

<u>Sample Tom25: Kirek Lake (Кирекское озеро)</u>

This is a large lake of clear water, in an area of mixed forest. A small "Tartar" village exists on the eastern shore of the lake. The sample was taken from the sandy northeast shore of the lake, some distance away from the village. The sample was obtained by wading into the lake to a water depth of c. 60 cm.

Field appearance of water: Clear, colourless.

On filtration at 0.45µm: A little clogging of the filter, with some precipitate retained on filter.

Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

20/8/10: Lake and river waters in the Asino region of Tomsk oblast'. Dry, warm day

<u>Sample Tom29: Turgoiskoe Lake (Тургойское озеро)</u>

This is a long (2-3 km) oxbow lake in the valley of the River Chulym (Река Чулым) - and about 2 km west of the current river channel. The lake lies to the north of Asino (Асино) and around 4 km south of Minaevka (Минаевка). The sample was taken on the south shore of the lake, about 4 m from the bank, where the water depth was around 60 cm. The lake contains fish.

Field appearance of water: Pale greenish-brown colour (algae?)

On filtration at 0.45µm: Brown organic fragments retained on filter, but no noticeable clogging.

Water sample after filtration and storage to 1/9/10: Very pale yellowish brown colour, no precipitate.

<u>Sample Tom30: Shuch'e (Pike) Lake (Щучье озеро)</u>
This is a much smaller oxbow lake in the valley of the River Chulym, adjacent to, and around 100 m south of Turgoiskoe Lake (Tom 29). This lake appears to be at a higher level than Turgoiskoe Lake and the water is browner in colour. The sample was taken on the south shore of the lake, about 2 m from the bank, where the water depth was around 50 cm.
Field appearance of water: Clear, pale brownish colour (humic)
On filtration at 0.45µm: Filter becomes clogged with pale brownish precipitate - two filter units required.
Water sample after filtration and storage to 1/9/10: Very pale yellowish brown colour, no precipitate.

<u>Sample Tom31: River Chulym (Река Чулым) just south of Asino (Асино)</u>
The Chulym is one of the major rivers of Tomsk Oblast' and one of the most significant tributaries of the River Ob'. The river rises in Khakassia. 131 km from its confluence with the Ob', the flow is recorded as varying from 108 to 8220 m^3/s (Wikipedia entry for Чулым (приток Оби) accessed 14/4/11). The Chulym was sampled from its west bank, a few km upstream (south) of Asino at a location close to Voznesenka (Вознесенка). The area around the sampling point was natural: mostly forest/wood, some meadow and a few cabins. The water quality may well be affected by the major towns of Nazarovo and Achinsk (Назарово, Ачинск), which lie upstream of Asino on the River.
Field appearance of water: Somewhat turbid with suspended sediment.
On filtration at 0.45µm: Filter becomes clogged with pale brownish sediment - two filter units required.
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

20/8/10 (evening): Springs in Tomsk city and suburbs. Warm, dry day

<u>Sample Tom32: Spring, Ruzskovo Street (Улица Рузского), central Tomsk</u>
This is a spring-fed stream running through an area of wooden houses, along Ruzskovo Street, down past Altaiskaya Street (Улица Алтайская) to the River Ushaika. The spring is on the south bank of the Ushaika and is presumably related to the terrace deposits of that river. The water is clearly very polluted (smell) and there is rubbish in the stream and on the banks. The flow was estimated to be several L/s.
Field appearance of water: Odour of pollution, colourless, not obviously turbid.
On filtration at 0.45µm: Filter becomes clogged with sediment.
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

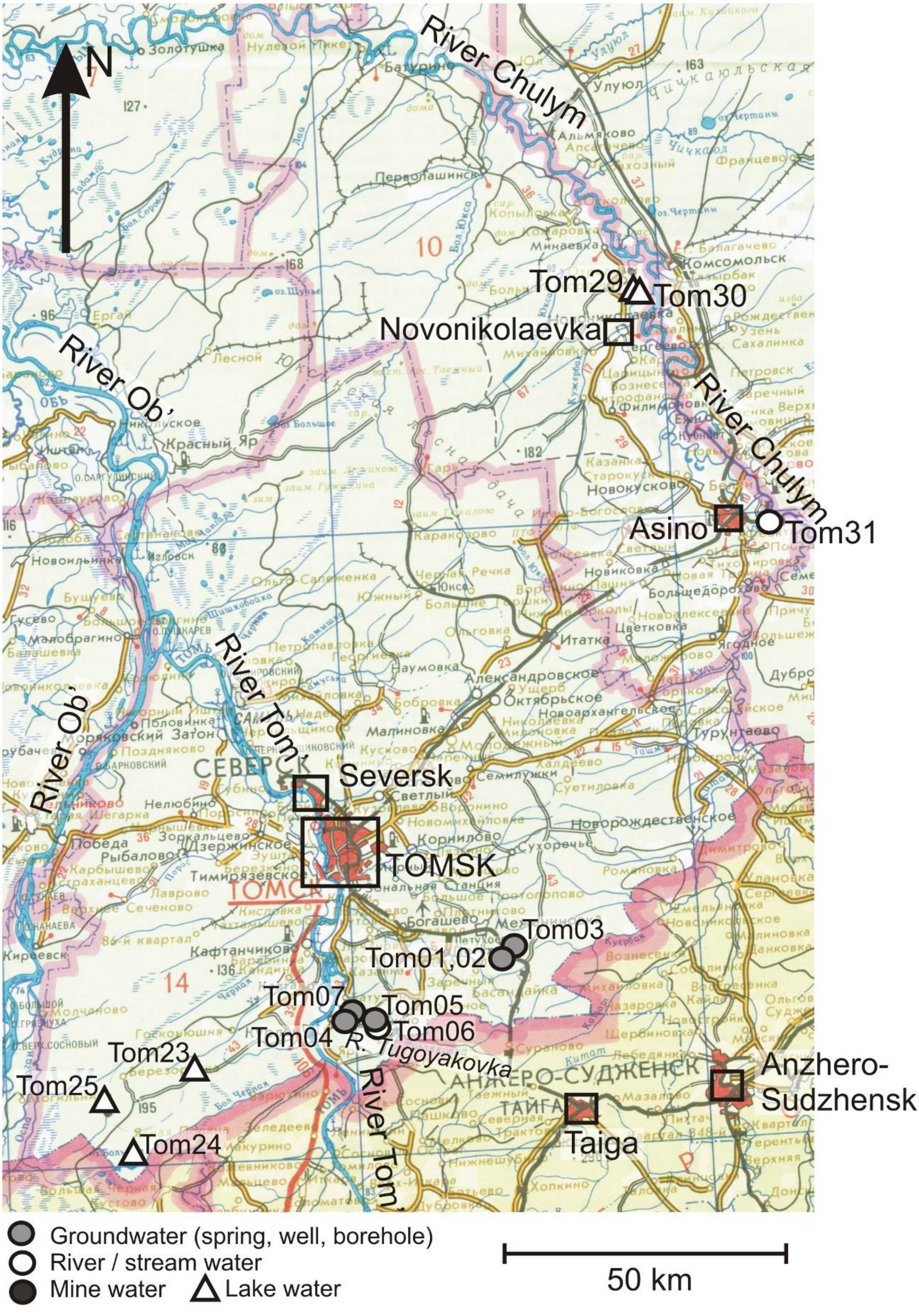


Figure 3.2. Sample locations around Tomsk

Figure 3.3. Sample locations in Tomsk city

3.2 Field Analyses of Waters (pH, Temperature, Eh, Alkalinity)

Sample	Date / time	Location	Latitude	Longitude	Elevation	Type	Land use	Flow	TAlk1	TAlk2	TAlk3	T_alk	Temp	pH_{corr}
		Unit			m asl			L/s	meq/L	meq/L	meq/L	meq/L	°C	
TOM1	08/08/10 12:40	Talovskaya Chasha main spring	56°17.8530	85°25.2888	218	S	F		11.2	11.3		11.3	5.5	7.29
TOM2	08/08/10 13:00	Spring-fed stream, Talovskaya Chasha	56°17.8512	85°25.3020	222	SFS	F		9.1	9.2		9.2	8.8	7.57
TOM3	08/08/10 14:35	Spring at km 41	56°19.2486	85°27.3198	218	S	F (D)		9.3	9.3		9.3	5.3	7.64
TOM4	09/08/10 10:50	Kapitanovskii Klyuch	56°13.6674	84°57.2880	91	SFS	F	0.3 to 0.5	6.5	6.8	6.7	6.7	8.4	8.19
TOM5	09/08/10 12:20	Larinskii Klyuch	56°12.6072	85°02.3796	128	S	F	0.1	7.4	7.5		7.5	5.1	7.46
TOM6	09/08/10 12:55	River Targanak, just upstream of Tugoyakovka	56°12.4762	85°02.7672	126	SFS	F	c. 180	6.7	6.9		6.8	11.1	8.62
TOM7	09/08/10 15:15	Zvezdnii (Dizvestnii) Klyuch	56°14.0388	84°58.8558	121	S	F	1 to 2	7.1	6.9		7.0	6.5	7.46
TOM8	10/08/10 09:35	Svyatoi Klyuch (Voskresenskii), Tomsk	56°29.2506	84°57.1998	70	S	U		12.5	13.0	13.2	12.9	6.4	6.91
TOM9	10/08/10 10:30	Stepanovskii 1, Tomsk	56°27.1728	85°00.8376	94	SFS	U		6.8	6.8		6.8	13.9	8.41
TOM10	10/08/10 11:15	Stepanovskii 2, Tomsk	56°27.2964	85°01.8804	97	SFS	U (F)	c. 1	8.4	8.3		8.4	10.5	8.32
TOM11	10/08/10 12:35	Akademicheskii Klyuch 1, Tomsk	56°28.4826	85°02.0220	94	S	F (B)	Few tens of mL/s	6.5	6.5		6.5	12.1	7.82
TOM23	16/08/10 11:10	Larinskoe Lake	56°09.106	84°32.548	188	L	F		0 to 0.3	0 to 0.3		0.15	17.3	4.40
TOM24	16/08/10 13:05	Khardinskoe / Chernovskoe Lake	56°00.868	84°20.996	139	L	F		0.3 to 0.6	0.3 to 0.6		0.45	17.4	6.40
TOM25	16/08/10 15:50	Lake Kirek	56°06.946	84°14.232	106	L	F/U		2.2	2.3		2.3	18.1	8.49
TOM29	20/08/10 13:45	Lake Turgoiskoe	57°21.4723	85°53.3075		L	F		2.35	2.35		2.35	17.8	7.25
TOM30	20/08/10 14:45	Lake Shuch'e	57°21.5567	85°54.7327		L	F		1.3	1.4		1.4	17.8	7.23
TOM31	20/08/10 16:35	River Chulym, at Voznesenka				R	F/D		3.2	3.3		3.3	16.1	7.63
TOM32	20/08/10 19:30	Ulitsa Ruzskovo spring, Tomsk	56°28.9117	84°57.6235		SFS	U		7.3	7.2		7.3	20.7	7.25

TAlk1 etc. represent individual determinations of total alkalinity. T_alk is the average. pH_{corr} is corrected for daily drift. S = spring, SFS = spring-fed stream, L = lake, R = river; F = forest, D = dacha settlement, U = urban, B = bog.

3.3 Analyses of Anions by Ion Chromatography at Geological Survey of Norway

Sample		F^-	Cl^-	Br^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TOM1	Talovskaya Chasha main spring	0.26	0.66	0.32	< 0.05	< 0.2	10.5
TOM2	Spring-fed stream, Talovskaya Chasha	0.22	0.55	< 0.1	0.19	< 0.2	7.17
TOM3	Spring at km 41	0.25	0.42	< 0.1	< 0.05	< 0.2	1.24
TOM4	Kapitanovskii Klyuch	0.20	0.83	< 0.1	< 0.05	< 0.2	6.86
TOM5	Larinskii Klyuch	0.26	0.62	< 0.1	5.62	< 0.2	2.99
TOM6	River Targanak, just upstream of Tugoyakovka	0.25	0.68	< 0.1	< 0.05	< 0.2	1.68
TOM7	Zvezdnii (Dizvestnii) Klyuch	0.26	2.59	< 0.1	5.76	< 0.2	2.96
TOM8	Svyatoi Klyuch (Voskresenskii), Tomsk	0.13	70.0	< 0.1	160.0	< 0.2	91.8
TOM9	Stepanovskii 1, Tomsk	0.26	40.8	< 0.1	1.37	< 0.2	28.4
TOM10	Stepanovskii 2, Tomsk	0.27	30.0	< 0.1	11.0	< 0.2	50.0
TOM11	Akademicheskii Klyuch 1, Tomsk	0.23	1.29	< 0.1	< 0.05	< 0.2	2.81
TOM23	Larinskoe Lake	0.06	0.34	< 0.1	0.22	< 0.2	3.71
TOM24	Khardinskoe / Chernovskoe Lake	0.05	0.61	< 0.1	< 0.05	< 0.2	1.58
TOM25	Lake Kirek	0.16	1.00	< 0.1	< 0.05	< 0.2	0.44
TOM29	Lake Turgoiskoe	0.13	0.66	< 0.1	< 0.05	0.35	0.51
TOM30	Lake Shuch'e	0.07	0.90	< 0.1	< 0.05	0.48	3.07
TOM31	River Chulym, at Voznesenka	0.11	1.61	< 0.1	< 0.05	< 0.2	7.53
TOM32	Ulitsa Ruzskovo spring, Tomsk	0.23	16.8	< 0.1	20.6	< 0.2	10.1

All determinations on filtered samples at 0.45 µm

Note that concentrations of nitrite, nitrate, phosphate and sulphate are cited as mg/L NO_3^-, PO_4^{3-} and SO_4^{2-} and *not* mg/L N, P and S.

3.4 Analyses of 32 Elements by ICP-AES at Geological Survey of Norway

Sample		Ca	Mg	Na	K	Fe	Mn	Al	Si	Ba	Sr	B	P
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TOM1	Talovskaya Chasha main spring	134	26.2	15.2	0.53	0.0026	2.62	<0.02	10.0	0.0415	0.726	0.069	0.130
TOM2	Spring-fed stream, Talovskaya Chasha	110	19.9	11.4	0.99	0.118	1.52	<0.02	7.54	0.0360	0.556	0.052	0.128
TOM3	Spring at km 41	107	22.4	14.4	0.52	0.0324	0.689	<0.02	8.95	0.0152	0.527	0.065	0.143
TOM4	Kapitanovskii Klyuch	88.8	10.6	6.64	0.64	0.0138	0.160	<0.02	7.24	0.0506	0.399	<0.02	0.154
TOM5	Larinskii Klyuch	96.8	13.9	5.97	<0.5	<0.002	0.0047	<0.02	7.21	0.0589	0.449	0.026	0.154
TOM6	River Targanak, just upstream of Tugoyakovka	85.0	13.0	9.64	0.64	0.0175	0.0404	<0.02	5.51	0.0697	0.432	0.039	0.135
TOM7	Zvezdnii (Dizvestnii) Klyuch	89.4	11.5	6.16	0.67	<0.002	<0.001	<0.02	6.91	0.0868	0.383	0.026	0.132
TOM8	Svyatoi Klyuch (Voskresenskii), Tomsk	210	32.5	75.6	11.4	<0.002	0.0058	<0.02	7.90	0.142	0.763	0.072	0.127
TOM9	Stepanovskii 1, Tomsk	108	14.9	21.0	2.07	0.0792	0.155	<0.02	4.64	0.102	0.513	0.053	0.131
TOM10	Stepanovskii 2, Tomsk	133	16.3	15.8	3.11	0.0225	0.101	<0.02	6.41	0.0573	0.595	0.070	0.146
TOM11	Akademicheskii Klyuch 1, Tomsk	84.7	10.0	7.06	1.49	0.228	0.136	<0.02	5.07	0.0699	0.352	0.034	0.127
TOM23	Larinskoe Lake	1.55	0.603	0.661	<0.5	0.954	0.0524	0.372	1.10	0.0117	0.0137	<0.02	<0.05
TOM24	Khardinskoe / Chernovskoe Lake	5.91	1.33	1.36	0.67	0.0296	0.0015	0.027	0.093	0.0063	0.0291	<0.02	<0.05
TOM25	Lake Kirek	22.3	4.66	6.10	1.89	0.0927	0.0121	<0.02	3.33	0.0318	0.131	<0.02	0.053
TOM29	Lake Turgoiskoe	27.6	4.79	5.13	0.75	1.07	0.214	<0.02	6.27	0.0381	0.167	<0.02	0.090
TOM30	Lake Shuch'e	17.4	3.30	2.71	1.63	0.270	0.0580	<0.02	0.555	0.0197	0.104	<0.02	0.054
TOM31	River Chulym, at Voznesenka	40.5	7.85	7.14	1.06	0.0276	0.0192	<0.02	4.39	0.0298	0.291	<0.02	0.086
TOM32	Ulitsa Ruzskovo spring, Tomsk	81.7	14.6	21.9	5.13	0.191	0.538	<0.02	9.01	0.0991	0.448	0.059	0.304

All determinations on water samples were on samples filtered at 0.45 µm. Laboratory-acidified, in original flask.

Analyses of 32 Elements by ICP-AES at Geological Survey of Norway (continued)

Sample	Ti	Cu	Zn	Pb	Ni	Co	V	Mo	Cd	Cr	Zr	Ag	Be	Li	Sc	Ce	La	Y	As	Sb
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TOM1	0.0015	<0.005	0.0185	<0.005	0.0107	0.0032	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	0.0122	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM2	0.0014	<0.005	0.0171	<0.005	0.0071	0.0020	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	0.0077	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM3	0.0012	<0.005	0.0171	<0.005	0.0075	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	0.0143	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM4	0.0012	<0.005	0.0165	<0.005	0.0074	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	<0.005	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM5	0.0012	<0.005	0.0167	<0.005	0.0081	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	<0.005	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM6	0.0011	<0.005	0.0155	<0.005	0.0057	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	<0.005	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM7	0.0011	<0.005	0.0161	<0.005	0.0066	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	<0.005	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM8	0.0020	<0.005	0.0210	<0.005	0.0089	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	0.0124	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM9	0.0014	<0.005	0.0187	<0.005	0.0086	<0.001	<0.005	0.0123	<0.0005	<0.002	<0.002	<0.005	<0.001	<0.005	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM10	0.0015	<0.005	0.0186	<0.005	0.0073	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	0.0051	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM11	0.0013	<0.005	0.0163	<0.005	0.0060	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	0.0056	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM23	0.0027	<0.005	0.0086	<0.005	<0.005	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	<0.005	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM24	<0.001	<0.005	0.0042	<0.005	<0.005	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	<0.005	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM25	<0.001	<0.005	0.0089	<0.005	<0.005	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	<0.005	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM29	<0.001	<0.005	0.0098	<0.005	<0.005	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	<0.005	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM30	<0.001	<0.005	0.0077	<0.005	<0.005	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	<0.005	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM31	<0.001	<0.005	0.0117	<0.005	0.0064	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	<0.005	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005
TOM32	0.0012	<0.005	0.0179	<0.005	0.0061	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	<0.005	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005

All determinations on water samples were on samples filtered at 0.45 µm. Laboratory-acidified, in original flask.

3.5 Ion Balance Error and Water Type calculated from NGU analyses

Prøve ID	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Sr^{++}	Ba^{++}	Al^{+++}	Fe^{++}	Mn^{++}	Cl^{-}	NO_3^{-}	$SO_4^{=}$	Alk	Br^{-}	F^{-}	H^{+}
	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L
TOM01	6.69	2.16	0.661	0.014	0.0166	0.0006		0.0001	0.0954	0.019		0.219	11.25	0.0040	0.0137	0.0001
TOM02	5.49	1.64	0.496	0.025	0.0127	0.0005		0.0042	0.0553	0.016	0.003	0.149	9.15		0.0116	0.0000
TOM03	5.34	1.84	0.626	0.013	0.0120	0.0002		0.0012	0.0251	0.012		0.026	9.30		0.0132	0.0000
TOM04	4.43	0.87	0.289	0.016	0.0091	0.0007		0.0005	0.0058	0.023		0.143	6.67		0.0105	0.0000
TOM05	4.83	1.14	0.260		0.0102	0.0009			0.0002	0.017	0.091	0.062	7.45		0.0137	0.0000
TOM06	4.24	1.07	0.419	0.016	0.0099	0.0010		0.0006	0.0015	0.019		0.035	6.80		0.0132	0.0000
TOM07	4.46	0.95	0.268	0.017	0.0087	0.0013				0.073	0.093	0.062	7.00		0.0137	0.0000
TOM08	10.48	2.67	3.288	0.292	0.0174	0.0021			0.0002	1.975	2.580	1.911	12.90		0.0068	0.0001
TOM09	5.39	1.23	0.913	0.053	0.0117	0.0015		0.0028	0.0056	1.151	0.022	0.591	6.80		0.0137	0.0000
TOM10	6.64	1.34	0.687	0.080	0.0136	0.0008		0.0008	0.0037	0.846	0.177	1.041	8.35		0.0142	0.0000
TOM11	4.23	0.82	0.307	0.038	0.0080	0.0010		0.0082	0.0050	0.036		0.059	6.50		0.0121	0.0000
TOM23	0.08	0.05	0.029		0.0003	0.0002	0.0414	0.0342	0.0019	0.010	0.004	0.077	0.15		0.0032	0.0401
TOM24	0.29	0.11	0.059	0.017	0.0007	0.0001	0.0030	0.0011	0.0001	0.017		0.033	0.45		0.0026	0.0004
TOM25	1.11	0.38	0.265	0.048	0.0030	0.0005		0.0033	0.0004	0.028		0.009	2.25		0.0084	0.0000
TOM29	1.38	0.39	0.223	0.019	0.0038	0.0006		0.0383	0.0078	0.019		0.011	2.35		0.0068	0.0001
TOM30	0.87	0.27	0.118	0.042	0.0024	0.0003		0.0097	0.0021	0.025		0.064	1.35		0.0037	0.0001
TOM31	2.02	0.65	0.311	0.027	0.0066	0.0004		0.0010	0.0007	0.045		0.157	3.25		0.0058	0.0000
TOM32	4.08	1.20	0.953	0.131	0.0102	0.0014		0.0068	0.0196	0.474	0.332	0.210	7.25		0.0121	0.0001

Prøve ID	Cations	Anions	Ion balance error	Water type
	meq/l	meq/l	%	
TOM01	9.63	11.50	-8.9	Ca - (Mg) - HCO_3
TOM02	7.72	9.33	-9.4	Ca - (Mg) - HCO_3
TOM03	7.86	9.35	-8.7	Ca - (Mg) - HCO_3
TOM04	5.62	6.84	-9.8	Ca - HCO_3
TOM05	6.24	7.63	-10.0	Ca - (Mg) - HCO_3
TOM06	5.76	6.87	-8.8	Ca - (Mg) - HCO_3
TOM07	5.70	7.24	-11.9	Ca - (Mg) - HCO_3
TOM08	16.75	19.37	-7.3	Ca - (Na,Mg) - HCO_3 - (NO3-SO4-Cl)
TOM09	7.60	8.58	-6.0	Ca - (Mg,Na) - HCO_3 - (Cl)
TOM10	8.76	10.43	-8.7	Ca - (Mg) - HCO_3 - (SO4)
TOM11	5.42	6.61	-9.9	Ca - HCO_3
TOM23	0.27	0.24	5.8	Ca - (Mg, Al, H) - HCO_3 - (SO4) - very dilute
TOM24	0.49	0.50	-1.7	Ca - (Mg) - HCO_3
TOM25	1.82	2.30	-11.6	Ca - (Mg) - HCO_3
TOM29	2.06	2.39	-7.2	Ca - (Mg) - HCO_3
TOM30	1.31	1.44	-4.7	Ca - (Mg) - HCO_3
TOM31	3.01	3.46	-6.9	Ca - (Mg) - HCO_3
TOM32	6.40	8.28	-12.8	Ca - (Mg,Na) - HCO_3

3.6 Discussion of water chemistry

Ion balance errors

The ion balance errors of the samples are almost all negative and typically in the range -5 to -10%. The one sample with a positive ion balance error was TOM23, the only sample with negligible alkalinity. The other sample with very low alkalinity (TOM24) had a very low (-1.7%) ion balance error. This is strongly suggestive of the alkalinity component of the ion balance being systematically slightly overestimated. This may be due to the alkalinity "test kit" being self assembled, using a standard acid solution prepared in the laboratory (rather than importing a test kit - problematic due to difficulties transporting acid as an air cargo).

Water type

All the waters from the springs, rivers and lakes around Tomsk are dominated by calcium and bicarbonate. Magnesium is typically the subsidiary cation.

In three cases, the content of sodium begins to be significant in terms of cation balance (TOM08, 09 and 32 - all urban springs, potentially impacted by urban run-off).

In Tom23, a very dilute lake water, the mineral content is so low (and the pH is also low) that a surface run-off / rainfall signature is reflected in the high proportions of Al, H^+ and $SO_4^{=}$ in the ionic composition.

Nitrate begins to be a significant component of the TOM08 water's ion balance. This is an urban spring, with the nitrate potentially being derived from urban run-off. **In absolute terms, the nitrate concentration (160 mg/L) in this spring is very high, exceeding commonly accepted drinking water norms, to an extent that could be hazardous for human health.**

In TOM32 (Ruzskovo Street) the nitrate concentration is also high at 20.6 mg/L.

pH values range from 6.9 to 8.4 in the groundwaters. The higher values (8.3 to 8.4 in TOM09 and TOM10 - the Stepanovskii Springs - and 8.2 in TOM04 - Kapitanovskii Spring), all represent springs which have discharged into a stream channel and have had the opportunity to degas carbon dioxide, resulting in a pH rise. Similarly, a high pH of 8.6 is observed in the Targanak River (TOM06). In the springs that have been sampled directly, pH ranges from 6.9 to 7.8.

Alkalinities in the groundwaters range from 6.5 to 12.9 meq/L, which are considered rather high values.

Impact of urbanisation

If we consider the impact of urbanisation, the four urban springs (TOM08, 09, 10 and 32) exhibit a range of nitrate concentrations from 1.4 to 160 mg/L, with a median of 15.8 mg/L. The highest value occurs in TOM08, Voskresenskii Klyuch, in central Tomsk. The seven non-urban springs exhibit a range from <0.05 to 5.8 mg/L, with a median of <0.05 mg/L. The rivers and lakes contain negligible nitrate (<0.05 to 0.22 mg/L).

The four urban springs (TOM08, 09, 10 and 32) exhibit a range of potassium concentrations from 2.1 to 11.4 mg/L, with a median of 4.1 mg/L. The highest value occurs in TOM08, Voskresenskii Klyuch, in central Tomsk. The seven non-urban springs exhibit a range from <0.5 to 1.5 mg/L, with a median of 0.64 mg/L. The rivers and lakes contain <2 mg/L potassium.

If we consider two other possible indicators of general urban contamination - chloride and sulphate - a similar picture emerges.

The four urban springs exhibit a range of chloride concentrations from 17 to 70 mg/L, with a median of 35.4 mg/L. The highest value again occurs in TOM08, Voskresenskii Klyuch. The seven non-urban springs exhibit a range from 0.4 to 2.6 mg/L, with a median of 0.66 mg/L. The rivers and lakes contain <2 mg/L chloride.

The four urban springs exhibit a range of sulphate concentrations from 10.1 to 92 mg/L, with a median of 39.2 mg/L. The highest value again occurs in TOM08, Voskresenskii Klyuch. The seven non-urban springs exhibit a range from 1.2 to 10.5 mg/L, with a median of 3.0 mg/L. The rivers and lakes contain <8 mg/L sulphate.

On the basis of these indicators (nitrate, potassium, chloride and sulphate) we can conclude that urbanisation appears to have had an impact on all four of the urban springs, there being almost no overlap between the two subsets for potassium, chloride and sulphate.

TOM08 also exhibits a particularly high value of alkalinity of 12.9 meq/L, which could conceivably relate to the biodegradation of organic compounds.

The urban spring TOM08 has a pH of 6.91, which is lower than the other groundwaters. This should not *necessarily* be taken as an indicator of pollution in itself: it may be that the low pH reflects a relatively rapid groundwater flow system, which is especially vulnerable to pollution.

The rivers and lakes exhibit relatively few indications of significant non-atmospheric pollution.

Surface waters

The three lake waters from the Kirek region are all very different in their chemistry.

Lake Larinskoe (TOM23) has a low pH of only 4.4 and a negligible alkalinity.

Lake Khardinskoe (TOM24) has a higher pH of 6.4 and a low alkalinity of around 0.45 meq/L

Lake Kirek (TOM25) itself has a high pH of 8.5 and an alkalinity of 2.3 meq/L.

These differences *may* be ascribable to geology, but are much more likely to reflect the sources of run-in to the lake. One would strongly suspect that Larinskoe Lake is fed by rainfall and/or surface run-off from boggy areas, with a high content of organic acids. One might suspect that Lake Kirek is largely groundwater-fed.

The concentrations of several pH-sensitive metals reflect the pH of the waters and may in turn affect the ecology of the lakes, in particular, aluminium and iron:

	pH	Al	Fe
		mg/L	mg/L
TOM23	4.40	0.372	0.954
TOM24	6.40	0.027	0.030
TOM25	8.49	<0.02	0.093

Base cations, on the other hand, increase with increasing pH, suggesting increasing amounts of water-rock interaction and a greater groundwater component. Chloride concentrations also increase, suggesting that the lower pH lakes are partly fed by rainfall that has not undergone the evaporative up-concentration that groundwaters are subject to during recharge in the soil zone:

	pH	Ca	Mg	Na	Cl^-	$SO_4^=$	NO_3^-
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TOM23	4.40	1.55	0.60	0.66	0.34	3.7	0.22
TOM24	6.40	5.91	1.33	1.36	0.61	1.6	< 0.05
TOM25	8.49	22.3	4.66	6.10	1.00	0.4	< 0.05

The other two lakes north of Asino are oxbow lakes and have relatively high pH values of 7.2 to 7.3 and contain modest concentrations of base cations.

Groundwaters

The groundwaters have very high alkalinities and calcium concentrations. The calcium concentrations generally increase in parallel with alkalinity (Figure 3.4).

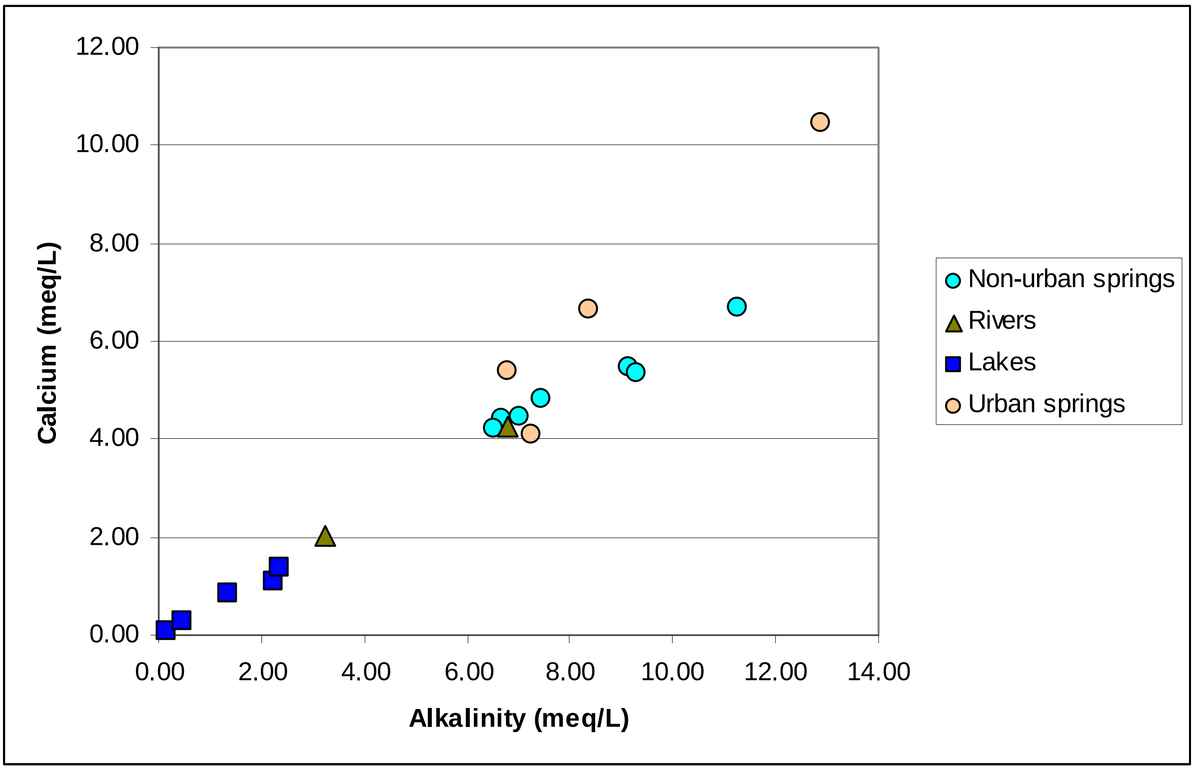


Figure 3.4. Plot of calcium versus alkalinity (meq/L) for groundwaters, river waters and lake waters of the Tomsk area.

This relation suggests that calcium bicarbonate dissolution is the main hydrochemical process. The high concentrations of calcium and bicarbonate suggest evolution from a recharge water containing a high partial pressure of CO_2. Reasons for this may include the biodegradation of humic organic acids from boggy recharge areas, or may even be temperature-related. On exposure to the atmosphere, CO_2 would be expected to degas, leading to a rise in pH and precipitation of calcite - and it is no coincidence that travertine is observed in several of the spring areas. In the above diagram, it is also noteworthy that the urban springs lie above the trend for the rest of the springs, suggesting a possible alternative source of solutes in urban areas.

As regards sodium, there is a substantial excess of sodium over chloride in many of the samples, and this excess increases with alkalinity. This suggests that sodium is accumulating in the water from a lithological source - either ion exchange or hydrolysis of sodium-containing silicates. The urban springs lie well below the trend, with a very low sodium/chloride ratio. This suggests that the sodium (and chloride) in these samples are dominantly *not* lithologically derived but may result from effluent or leachate in the urban environment (Figure 3.5).

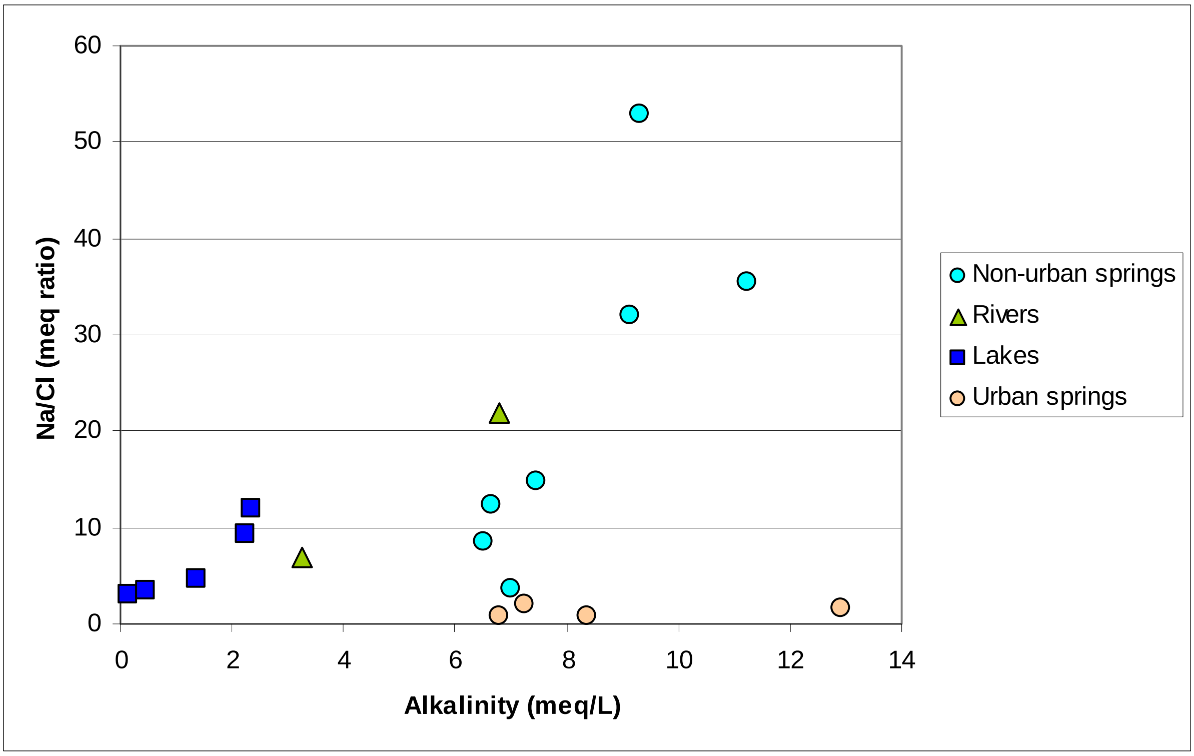


Figure 3.5. Plot of sodium/chloride meq ratio versus alkalinity (meq/L) for groundwaters, river waters and lake waters of the Tomsk area.

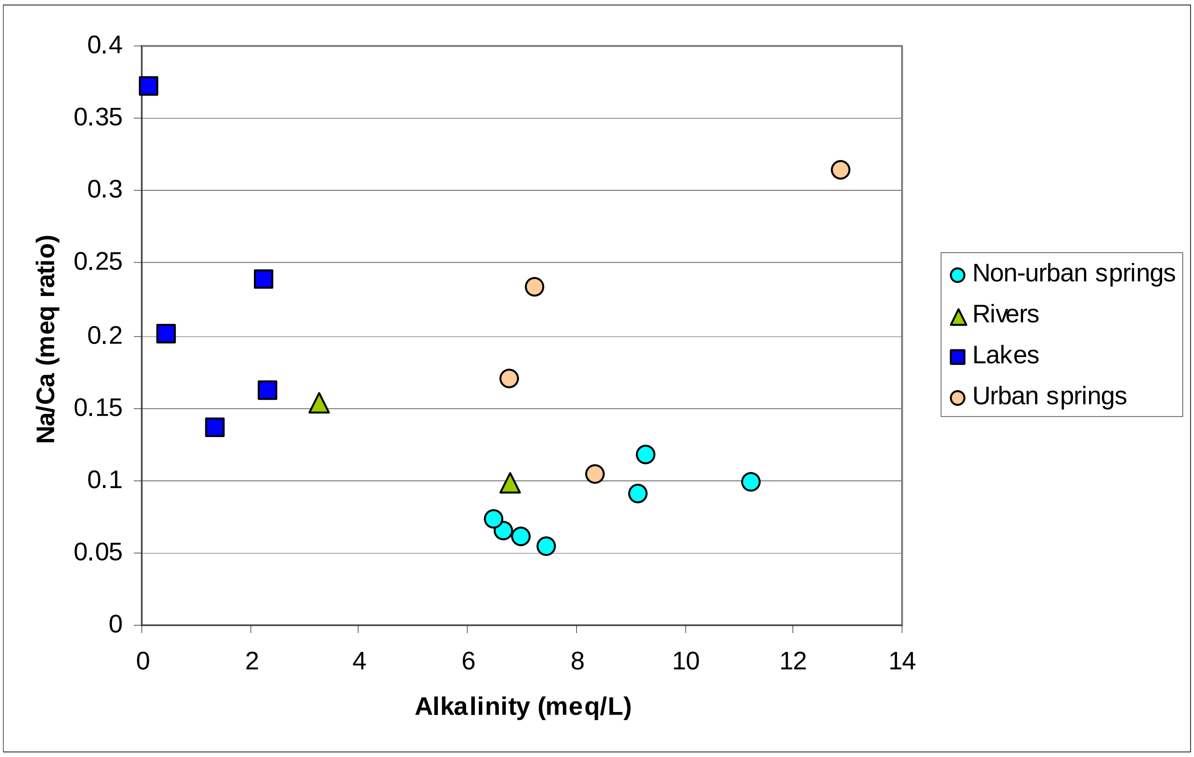


Figure 3.6. Plot of sodium/calcium meq ratio versus alkalinity (meq/L) for groundwaters, river waters and lake waters of the Tomsk area.

If the Na/Ca ratio is plotted against alkalinity (Figure 3.6), we see that the highest ratios are observed in the lake waters and there is a general decrease with increasing alkalinity, suggesting that Ca is accumulating in preference to Na during hydrochemical evolution. The urban spring waters again buck the trend, suggesting excess accumulation of sodium, possibly from effluent / leachate sources.

4 MARIINSKAYA TAIGA (МАРТАЙГА) REGION; KEMEROVO OBLAST' (КЕМЕРОВСКАЯ ОБЛАСТЬ)

Water samples were collected at three mining localities:

1) Tsentral'nii (Центральный), located around 60 km southwest of Tisul' (Тисуль)
2) Berikul' (Берикуль), located around 30 km SSW of Tisul'
3) Komsomolsk (Комсомольск), lying a short distance SSW of Tisul'

in the Mariinskaya Taiga (Martaiga) region of Kemerovo oblast'. The Martaiga region is geologically a bedrock terrane of the Kuznetsk-Alatau mountain belt.

The Mines

The mining area is associated with quartz-sulphide-gold (Qz-Py-Au) ore deposits. The mineralizations are associated with Cambro-Ordovician granite massifs, intruded into Precambrian-Cambrian country rocks. A short distance north of Komsomolsk, the Precambrian/Palaeozoic basement becomes covered with a sequence of Jurassic-Quaternary sediments of the West Siberian Basin, on the fringes of which the town of Tisul' is situated.

Tsentral'nii Mine – sampled 12th August 2010

The Tsentral'nii mines were worked for gold in Qz-Py-Au mineralizations of Devonian age. These tend to be associated with a Cambro-Ordovician granite (known as the Tsentral'nii Massif) intruded into the $€_{1-2}$ Cambrian Berikul'skii suite, which includes basalts, carbonates, silicic rocks and metasediments. The terrane was subsequently intruded by Ordovician and Devonian dolerites. The mines employed up to 12,000 people in the region and comprised several shafts around 300 m deep. No ore processing was carried out on site and thus only coarse mine waste (spoil) tips occur, rather than tailings. The spoil tips contain stones and boulders of the host granite, with massive chunks of pyrite, pyrite veins and secondary mineral coatings of yellow jarosite(?). The mines were closed in the 1990s and fewer than 600 people are reported to remain. The area is drained by the headwaters of the River Kozhukh, which drains south, and then turns north to discharge into the River Kiya.

Komsomolsk – sampled 13th August 2010

At Komsomolsk, it is reported that there was a single mine around 300 m deep, worked only for gold. The quartz-pyrite-gold mineralization is at the boundary of a granite massif, intruded into country rocks of the Riphean-Vendian Yeniseiskii Carbonate Formation (dolomitised limestones) and basalts associated with the Berikul'skii suite. The ore deposit is associated with a high content of arsenopyrite. The mine was wound down at the beginning of the 1990s, and was completely shut by 2000. The water from this mine was sampled in 2006 (Banks *et al.*, 2008).

Komsomolsk tailings dam

The tailings area is located on high ground, at the top of a slope down into the valley, a few km from the mine shaft. It contains tailings both from the Komsomolskii mine and also the pre-1960 tailings that were deposited on the Novii Berikul' processing site and subsequently moved here (see below). According to Prof. V.P. Parnachev, the tailings deposits could be up to 20 m thick and comprise 1 million tonnes of tailings, with a high residual gold content. The tailings area contains numerous pools, typically containing concentrated leachate ranging in yellow-brown to deep red in colour and of typical pH 1.7 to 2.7.

Berikul' – sampled 14th August 2010

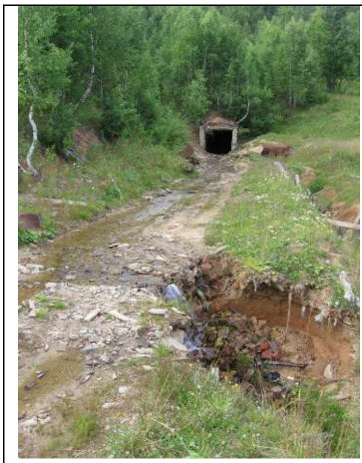
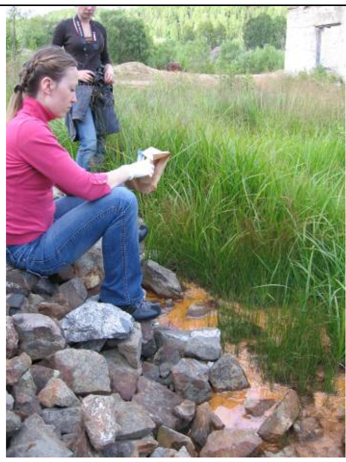
The Berikul' mines were up to 500 m deep in a polymetallic sulphide quartz-pyrite/arsenopyrite-gold deposit, but were also worked only for gold. The ore mineralization at Berikul' is associated with effusive volcanic rocks (the middle Cambrian Berikul'skii Suite), bordering a granite massif. The Berikul' mining areas were all closed in mid-to-late 1990s.

Novii Berikul' Processing Works

Ore material from the mines at Berikul' was transported to the Novii Berikul' processing works for concentration (floatation and cyanidisation). The works lies on the left (west) bank of the Mokrii Berikul (Мокрый Берикуль) River. In the period c. 1952 to the 1960s, tailings from processing at Novii Berikul' were deposited at the Novii Berikul' processing works site itself. These were subsequently (mid-2000s) mostly removed and transported to the tailings deposit at Komsomolsk (see above). Currently, only a relatively thin residue of fine-grained sulphide-rich tailings remains on the flood plain of the Mokrii Berikul' stream, covered by coarse waste rock. The tailings comprise 40-45% fine-grained sulphide (dominated by pyrite, with minor arsenopyrite and smaller amounts of pyrrhotite, sphalerite, chalcopyrite, galena, quartz, albite, chlorite, muscovite, and dolomite - Sidenko et al. 2005). At the foot of the hill-slope behind the processing works, it is possible to observe both pools of relatively clear water (which can be observed to be due to the melting residual ice bodies within the relatively inert waste rock on the hillslope) and seepages of acidic, orange-yellow water from the residual tailings. On the flood plain below the hill-slope, pools of bright orange water have accumulated. Some of these pools seep or discharge to the Mokrii Berikul River.

Environmental sampling at the Novii Berikul' processing works has been documented by Bortnikova et al. (2001), Gieré et al. (2003) and Sidenko et al. (2005). The waste rock overlying the residual tailings and on the hill slopes at Novii Berikul' appears to largely consist of dolerite (and some marble) rock fragments.

Figure 4.1. Photographs of sample sites in Martaiga area

 Tom12 Mine drainage from Tsentral'nii mine adit	 Tom13 Leachate from Tsentral'nii mine spoil tip	 Tom15 Corner "puddle of blood" leachate pond at Komsomolskii tailings dam
 Tom16 "Long brown" leachate pond at Komsomolskii tailings dam	 Tom17 "Bullrush" leachate pond at Komsomolskii tailings dam	 Tom18 Leachate seepage in bank of Mokrii Berikul' stream at Novii Berikul'
 Tom19 "Big orange" leachate puddle at Novii Berikul' processing works	 Tom21 Leachate pool in residual tailings. Novii Berikul' processing works	 Tom22 Surface of Berikul' tailings dam

Berikul' Tailings Dam

After 1960, Berikul' tailings were deposited at a specifically designed tailings dam located a couple of km downstream from the Novii Berikul' processing works site.

4.1 Sampling Sites

12/8/10: Tsentral'nii. Dry, generally sunny day

<u>Sample Tom12: Mine water from mine adit, Tsentral'nii.</u> On the northern margin of Tsentral'nii town a mine adit emerges from the hillside, discharging a relatively large flow of clear, colourless, sediment-free water. Sampled immediately downstream of the tunnel opening. The field pH and temperature were measured at 7.92 and 4.9°C at the adit mouth; these had risen to 8.26 and 5.2°C by 40 m downstream of the adit mouth.
Field appearance of water: Clear / colourless
On filtration at 0.45µm: No clogging or sediment
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate

<u>Sample Tom13: Orange leachate from mine spoil tip, Tsentral'nii</u>
To the south-east of the adit is a large conical heap of waste rock. On the down-gradient, eastern side, this discharges a flow of some 0.1 L/s of ochreous leachate. In the leachate flow itself, a pH of 5.12 and temperature of 9.0°C were measured, although in the static pool of leachate that was actually sampled, the pH was much lower at 3.04 and T = 11°C .
Field appearance of water: Clear / colourless water, ochre precipitate on bed
On filtration at 0.45µm: Orange iron precipitate on filter
Water sample after filtration and storage to 1/9/10: Orange "ochre" precipitate formed in flask

<u>Sample Tom14: Clear seepage from mine spoil tip, Tsentral'nii</u>
Around 50 m north of Tom13, at the foot of the spoil tip, a very small seepage of c. 10 mL/s of water can be seen associated with a blackish algal/bacterial mat.
Field appearance of water: Clear / colourless water, black precipitate/biomat/biofilm on bed
On filtration at 0.45µm: A brown, soily residue was left on the filter.
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

13/8/10: Komsomolsk. Dry, somewhat overcast day

<u>Sample Tom15: Corner "Puddle of Blood" leachate pool in Komsomolskii tailings dam.</u> This comprises a deep red pool of leachate in tailings. The water appears clear but seems to contain suspended material or precipitates, as 2 filters were needed to fill a sample bottle. The sampled water appears deep orange in colour in the flask.
Field appearance of water: Deep orange colour

On filtration at 0.45µm: Pale orange / buff material was precipitated on the filter. 2 filters required.
Water sample after filtration and storage to 1/9/10: Deep orange colour, no precipitate

Sample Tom16: "Long Brown" leachate pool in Komsomolskii tailings dam. This comprises a greenish/greyish/brown pool of leachate in the tailings. The sampled water appears pale straw yellow in colour in the flask.
Field appearance of water: Pale yellow (straw) colour
On filtration at 0.45µm: A bright yellow (jarosite?) precipitate was retained on the filter.
Water sample after filtration and storage to 1/9/10: Pale yellow (straw) colour, no precipitate

Sample Tom17: "Bullrush" leachate pool in Komsomolskii tailings dam. This comprises an extensive pool of leachate in the tailings. Shallower reaches of the pool appear orange, but deeper portions appear red. The water is relatively clear and the pool supports life in the form of a number of *Typha*-like bullrushes and several "water boatman"-like aquatic beetles.
Field appearance of water: Clear / colourless (orange/ochre with depth)
On filtration at 0.45µm: Few problems were experienced filtering the water and very little precipitate was retained on the filter.
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate

14/8/10: Novii Berikul'. Clear sunny day, but had rained overnight. Heavy rainfall later in afternoon between Tom21 and Tom22.

Sample Tom18: Leachate spring in bank of R. Mokrii Berikul' at Novii Berikul processing works. This sample was taken from a seepage of c. 0.2 L/s leachate from the western bank of the Mokrii Berikul' river, towards the northern end of the processing works site. The seepage produced a light orange ochreous precipitate as it enters the river.
Field appearance of water: Clear / colourless, ochre precipitate on bed of river
On filtration at 0.45µm: No clogging or sediment
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate

Tom19: "Big Orange" leachate puddle. Field measurements only. Large, very shallow puddle of leachate on surface of flood plain, underlain by residual tailings, at Novii Berikul' processing plant. Had been sampled in previous years, although the position of the puddle seems to have moved somewhat this year. Ochre precipitate on bed of puddle.

Tom20: "Medium Reddish" leachate puddle. Field measurements only. Large, very shallow puddle of leachate on surface of flood plain, underlain by residual tailings, at Novii Berikul' processing plant. Located several tens of m south of Tom 19, towards the southern end of the processing works site.

Sample Tom21: Small orange leachate puddle adjacent to road. Small puddle of orange leachate, adjacent to road (on up-slope side) and close to processing works buildings, on upper level at southern end of Novii Berikul' processing works site. The puddle contained a creamy coloured mud / precipitate at its edges.
Field appearance of water: Clear, deep orange, Ochre precipitate on bed of puddle
On filtration at 0.45µm: The filter became slowly clogged with an orange precipitate.
Water sample after filtration and storage to 1/9/10: Clear, deep orange colour, no precipitate

Between Tom21 and Tom22, heavy rainfall occurred

Sample Tom22: Berikul' tailings dam. Comprises extensive artificial tailings down, around 2 km downstream from Novii Berikul' processing works and on western bank of Mokrii Berikul' River. Contains post-1960 tailings from Berikul' mines. Comprises a large flat area of tailings with standing, apparently orange, water on surface. The water sample comprised clear, colourless water from the surface of the tailings, likely mixed with fresh rainfall.
Field appearance of water: Clear / colourless
On filtration at 0.45µm: The filter slowly clogs with a buff-coloured material.
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate

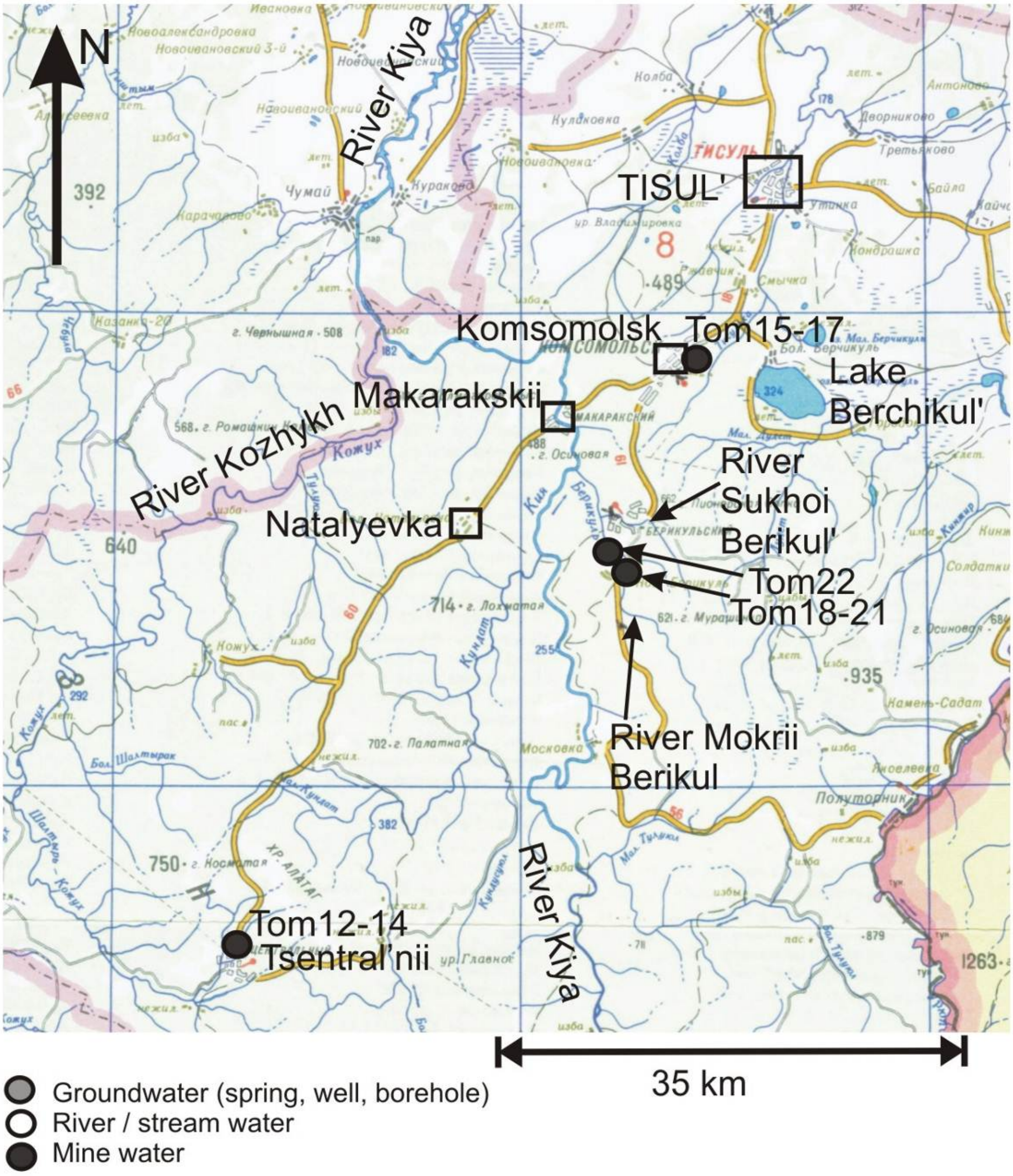


Figure 4.2. Sample locations around Tisul'

4.2 Field Analyses of Waters (pH, Temperature, Eh, Alkalinity)

Sample	Date / time	Location	Latitude	Longitude	Elevation	Type	Land use	Flow	TAlk1	TAlk2	TAlk3	T_alk	Temp	pH_{corr}	Eh
		Unit			m asl			L/s	meq/L	meq/L	meq/L	meq/L	°C		mV
	12/08/10 17:20	Seepage of clear water at base of Tsentral'nii waste tip				ML	M						4.0	7.31	
	12/08/10 17:40	Tsentral'nii minewater c. 40 m downstream from adit mouth				MW	M						5.2	8.26	
TOM12	12/08/10 17:40	Tsentral'nii minewater from adit mouth				MW	M		1.0	0.9	0.9	0.9	4.9	7.92	
TOM13	12/08/10 18:10	Static leachate puddle Tsentral'nii waste tip				ML	M					0	11.0	3.04	+468
Near TOM13	12/08/10 18:15	Flowing orange leachate. Tsentral'nii waste tip				ML	M	0.1					9.0	5.12	
TOM14	12/08/10 18:35	Leachate flow with black ppt. Tsentral'nii waste tip	55°13.206	87°39.353		ML	M	0.01				0	16.2	2.71	+524
TOM15	13/08/10 16:00	Corner "Puddle of Blood", Komsomolskii Tailings	55°38.064	88°11.741	+384	ML	M					0	18.4	1.98	+499
TOM16	13/08/10 16:30	"Long Brown" pool, Komsomolskii tailings				ML	M					0	18.7	1.68	+452
TOM17	13/08/10 17:00	"Bullrush" pond, Komsomolskii tailings				ML	M					0	18.0	2.67	+526
TOM18	14/08/10 13:05	Novii Berikul, seepage in bank of river				ML	M	c. 0.2				0	12.3	2.36	+412
TOM19	14/08/10 00:00	"Big Orange" leachate pool, Novii Berikul				ML	M					0	23.3	2.43	+431
TOM20	14/08/10 00:00	"Medium reddish" leachate pool, Novii Berikul				ML	M					0	24.7	2.86	+422
TOM21	14/08/10 14:15	Small orange puddle, high level Novii Berikul				ML	M					0	22.7	2.02	+482
TOM22	14/08/10 16:20	Novii Berikul tailings dam				ML	M		15.8	15.6		0	20.5	3.20	

TAlk1 etc. represent individual determinations of total alkalinity. T_alk is the average. pH_{corr} is corrected for daily drift. MW = mine water; ML = mine leachate, M = mining

4.3 Analyses of Anions by Ion Chromatography at Newcastle University

Sample		F^-	Cl^-	Br^-	NO_3^-	SO_4^{2-}	PO_4^{3-}
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TOM12	Tsentralnaya minewater from adit mouth	<1	<1	<5	<5	11.6	<10
TOM13	Static puddle of orange leachate. Base of Tsentralnaya waste tip	<1	7	<5	<5	348	<10
TOM14	Flowing leachate with black ppt. Base of Tsentralnaya waste tip	<1	9	<5	<5	1193	<10
TOM15	Corner "Puddle of Blood", Komsomolskii Tailings	<1	20	<5	<5	13473	<10
TOM16	"Long Brown" pool, Komsomolskii tailings	<1	6	<5	<5	5069	<10
TOM17	"Bullrush" pond, Komsomolskii tailings	<1	13	<5	13	811	<10
TOM18	Novii Berikul, seepage in bank of river	<1	12	<5	8	2038	<10
TOM21	Small orange puddle, high level Novii Berikul	<1	13	<5	29	11437	<10
TOM22	Novii Berikul tailings dam	<1	<1	<5	<5	223	<10

All determinations on filtered samples at 0.45 µm

Note that concentrations of nitrite, nitrate, phosphate and sulphate are cited as mg/L NO_3^-, PO_4^{3-} and SO_4^{2-} and *not* mg/L N, P and S.

4.4 Analyses of 20 Elements by ICP-AES at Newcastle University

Sample		Ca	Mg	Na	K	Fe	Mn	Al	Zn
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TOM12	Tsentralnaya minewater from adit mouth	12.3	1.5	3.5	0.3	<0.1	<0.1	<0.5	<0.1
TOM13	Static puddle of orange leachate. Base of Tsentralnaya waste tip	39.6	7.7	3.8	0.6	75.8	2.4	<0.5	1.8
TOM14	Flowing leachate with black ppt. Base of Tsentralnaya waste tip	236	18.3	5.6	1.5	57.6	6.9	12.2	11.1
TOM15	Corner "Puddle of Blood", Komsomolskii Tailings	341	448	2.1	0.2	4802	39.6	399	232
TOM16	"Long Brown" pool, Komsomolskii tailings	461	113	6.7	13.5	1880	7.9	137	46.6
TOM17	"Bullrush" pond, Komsomolskii tailings	102	36.4	4.8	1.5	59.5	5.0	33.2	10.2
TOM18	Novii Berikul, seepage in bank of river	282	63.4	15.4	1.4	468	8.6	51.4	15.8
TOM21	Small orange puddle, high level Novii Berikul	415	372	1.5	<0.1	3797	30.4	355	42.9
TOM22	Novii Berikul tailings dam	85.3	5.1	1.3	0.9	0.9	0.3	0.3	0.6

Sample	Si	B	Li	Sr	As	Pb	Cd	Co	Cr	Cu	Ni	S
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TOM12	9.5	<0.2	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	3.8
TOM13	14.5	<0.2	<0.1	0.2	7.4	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	115
TOM14	42.0	<0.2	0.2	0.6	0.1	<0.2	0.2	0.1	<0.1	5.0	<0.1	380
TOM15	32.6	<0.2	0.3	0.4	556	2.8	5.9	2.5	1.3	18.8	8.5	4346
TOM16	23.0	<0.2	<0.1	0.6	89.9	1.3	1.0	0.8	0.5	4.6	1.6	2110
TOM17	12.0	<0.2	0.1	0.3	0.4	<0.2	0.2	0.2	<0.1	0.8	0.4	261
TOM18	34.1	0.8	<0.1	0.6	2.5	0.4	0.3	0.4	<0.1	3.0	0.7	668
TOM21	22.8	0.8	0.2	0.4	244	1.7	1.0	1.9	1.2	15.9	4.0	3742
TOM22	6.2	<0.2	<0.1	0.1	<0.1	<0.2	<0.1	<0.1	<0.1	0.2	<0.1	75.9

All determinations on water samples were on samples filtered at 0.45 µm. Laboratory-acidified, in original flask.

4.5 Ion Balance Error and Water Type calculated from Univ. of Newcastle analyses

Sample	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Sr^{++}	Al^{III}	Fe^{II}	Mn^{II}	Cl^{-}	NO_3^{-}	$SO_4^{=}$	Alk	H^{+}
	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L
TOM12	0.61	0.12	0.15	0.01							0.24	0.93	0.00
TOM13	1.98	0.63	0.17	0.02	0.00		2.71	0.09	0.20		7.25	0.00	0.91
TOM14	11.78	1.51	0.24	0.04	0.01	1.36	2.06	0.25	0.25		24.84	0.00	1.95
TOM15	17.02	36.86	0.09	0.01	0.01	44.37	171.96	1.44	0.56		280.49	0.00	10.47
TOM16	23.00	9.30	0.29	0.35	0.01	15.23	67.32	0.29	0.17		105.53	0.00	20.89
TOM17	5.09	2.99	0.21	0.04	0.01	3.69	2.13	0.18	0.37	0.21	16.88	0.00	2.14
TOM18	14.07	5.22	0.67	0.04	0.01	5.72	16.76	0.31	0.34	0.13	42.43	0.00	4.37
TOM21	20.71	30.60	0.07		0.01	39.47	135.97	1.11	0.37	0.47	238.11	0.00	9.55
TOM22	4.26	0.42	0.06	0.02	0.00	0.03	0.03	0.01			4.64	0.00	0.63

Iron assumed to be in the +II oxidation state for calculating ion balance errors and milli-equivalent concentrations. Similarly, Mn is assumed +II and Al is assumed +III.

Sample	Cations	Anions	Ion balance error	Water type
	meq/l	meq/l	%	
TOM12	0.90	1.17	-13.40	Ca - HCO3 - (SO4)
TOM13	6.51	7.44	-6.69	Fe-Ca-(H, Mg) - SO4
TOM14	19.20	25.09	-13.31	Ca - SO4
TOM15	282.22	281.06	0.21	Fe-Al-(Mg,Ca)-SO4
TOM16	136.69	105.70	12.78	Fe-(Ca, H, Al)-SO4
TOM17	16.48	17.46	-2.89	Ca-(Al,Mg,H,Fe)-SO4
TOM18	47.16	42.90	4.73	Fe-Ca-(Al,Mg,H)-SO4
TOM21	237.49	238.94	-0.30	Fe-(Al,Mg,Ca)-SO4
TOM22	5.47	4.64	8.14	Ca-SO4

Iron assumed to be in the +II oxidation state for calculating ion balance errors and milli-equivalent concentrations. Similarly, Mn is assumed +II and Al is assumed +III.

4.6 Discussion of water chemistry - mine waters

Ion balance errors

The ion balance errors of the mine waters were rather variable, although broadly satisfactory. 4 of the 9 waters have IBEs of <5%, 2 of the 9 had IBEs of 5 - 10%, while the remaining three analyses had IBEs exceeding 10%, but less than 14%. High ion balance errors are not unexpected in mine waters containing high concentrations of a variety of metals and where metal speciation may be very complex. In addition it should be noted that all Fe was assumed to be in the +II state when calculating the IBE, where it can be seen in many of the waters (red-orange colour) that significant iron is likely to be in the +III state.

Water type

Only TOM12, the water draining from the Tsentral'nii adit, has a chemistry similar to 'normal' groundwater and a calcium-bicarbonate water type. No significant heavy metals were detected, and Fe, Mn and Al were all below detection limit. The chloride concentration was extremely low (<1 mg/L), reflecting the location distant from marine influence and the probable low Cl^- concentrations in rainfall. A sulphate concentration just over 11 mg/L may reflect a modest degree of sulphide oxidation.

All of the other mine waters have an anionic composition totally dominated by sulphate, whose concentrations range from 223 mg/L (Novii Berikul' tailings dam - TOM22) to over 13,000 mg/L (Komsomolskii Tailings 'Puddle of Blood - TOM15). There is a very clear inverse correlation between sulphate and pH in the samples (Figure 4.3). pH varies from 3.2 (in TOM22) to 1.68 in TOM16 (Komsomolskii 'Long Brown pool').

As for cations, the hydrochemistry is clearly dominated by calcium in only two samples, TOM22 (the water standing on the surface of Novii Berikul' tailings) and TOM14 (the water flowing over a black precipitate at the base of the Tsentral'nii spoil tip). In the other samples, Fe, Al, and H also become important components of the ion balance. In five of the samples, iron is the dominant cation (even if we assume iron is in the +II oxidation state !). Iron concentrations vary from 0.9 mg/L in the water standing above the Novii Berikul' tailings (TOM22) and 4.8 g/L in the Komsomolskii 'Puddle of Blood' (TOM15). Aluminium varies from 0.3 mg/L to almost 400 mg/L, with the same two analyses representing the extreme samples. The concentrations of most heavy metals and metalloids increase sharply with decreasing pH (Figures 4.3 and 4.4).

Magnesium is also an important component in the ion balance, especially in the lowest pH waters. Indeed, the Ma/Ca ratio appears to increase sharply as pH drops below 3 in these waters (Figure 4.5).

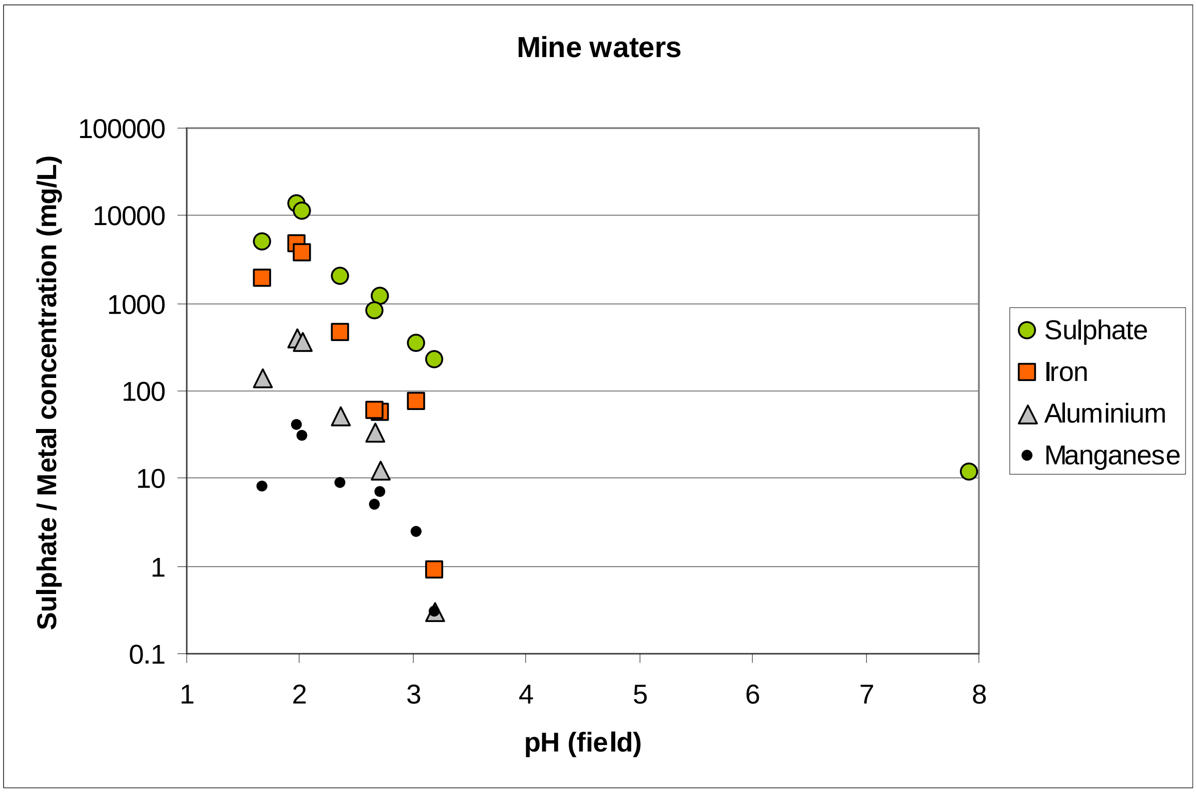


Figure 4.3. Concentrations of selected metals and sulphate (mg/L), plotted against field pH in mine waters (TOM12 - TOM22).

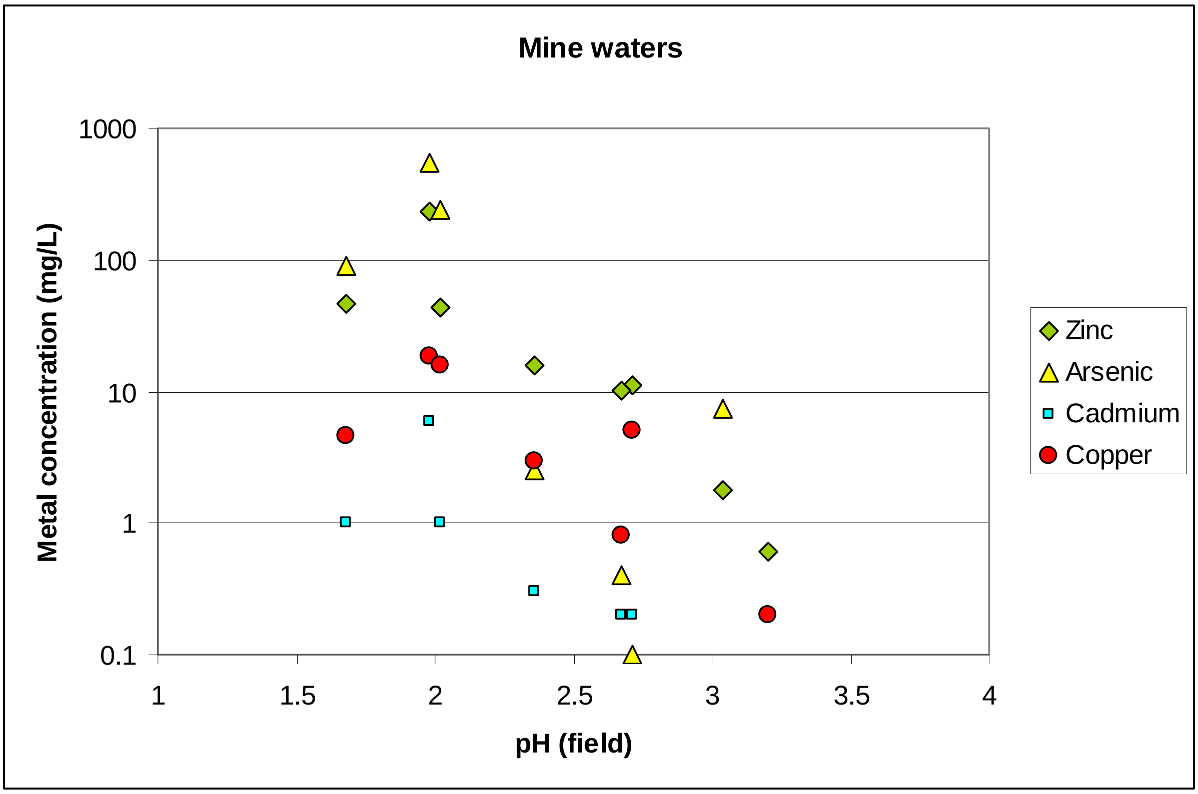


Figure 4.4. Concentrations of selected metals (mg/L) and arsenic, plotted against field pH in mine waters (TOM12 - TOM22).

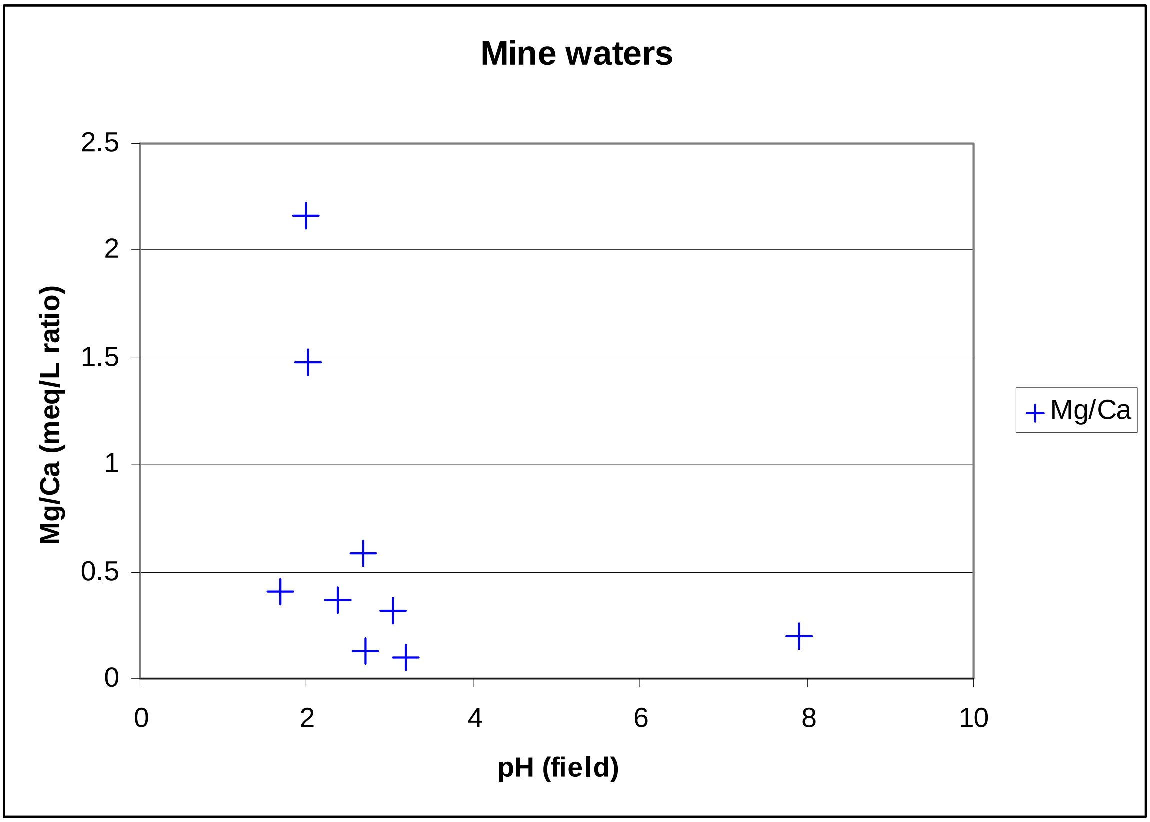


Figure 4.5. Milli-equivalent (molar) ratio of Mg/Ca, plotted against field pH in mine waters (TOM12 - TOM22).

Other hydrochemical features

Silicon concentrations in the mine waters often exceed 20 mg/L and range up to 42 mg/L, reflecting the enhanced and rapid hydrolysis of silica in the highly acid environment. As regards ranges of heavy metals in the waters, many of them are also pH related (Figures 4.3 and 4.4):

Arsenic: <0.1 to 556 mg/L (highest value in TOM15, the Komsomolskii 'Puddle of Blood')
Zinc: 0.6 to 232 mg/L (highest value in TOM15, the Komsomolskii 'Puddle of Blood')
Manganese: 0.3 to 40 mg/L (highest value in TOM15, the Komsomolskii 'Puddle of Blood')
Copper: <0.1 to 18.8 mg/L (highest value in TOM15, the Komsomolskii 'Puddle of Blood')
Nickel: <0.1 to 8.5 mg/L (highest value in TOM15, the Komsomolskii 'Puddle of Blood')
Cadmium: <0.1 to 5.9 mg/L (highest value in TOM15, the Komsomolskii 'Puddle of Blood')
Lead: <0.2 to 2.8 mg/L (highest value in TOM15, the Komsomolskii 'Puddle of Blood')
Cobalt: <0.1 to 2.5 mg/L (highest value in TOM15, the Komsomolskii 'Puddle of Blood')

5 DEEP OIL EXPLORATION WELLS - PARABEL' (ПАРАБЕЛЬ) AREA

Two former oil exploration boreholes were sampled in the Kolpashevo - Parabel' region towards the north of Tomsk oblast'. Both bores have been taken into use as spa facilities. Both boreholes are drilled into the Mesozoic sedimentary rocks of the West Siberian basin. All samples were taken in the period 17th to 19th August. The weather was generally good and dry.

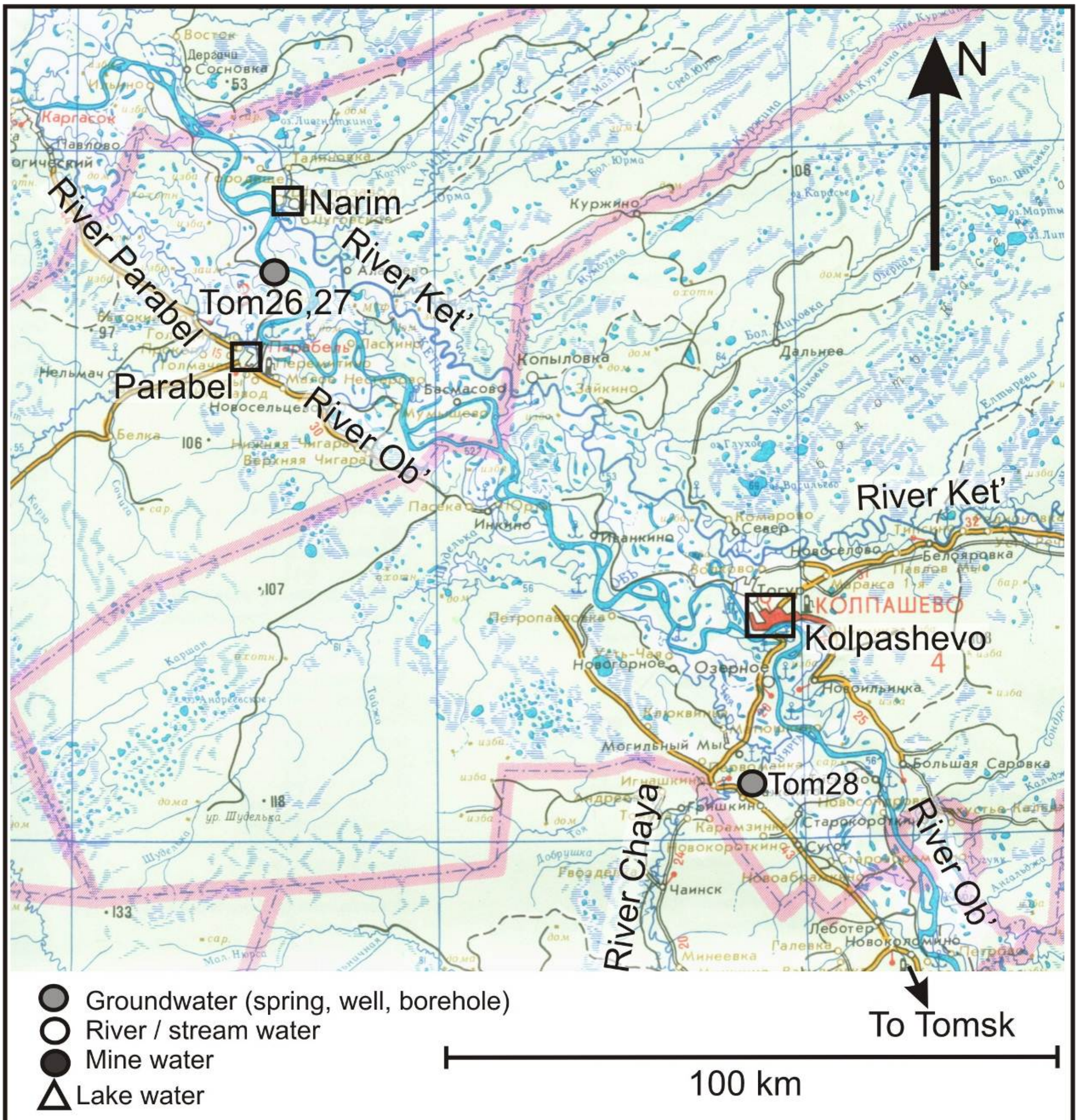
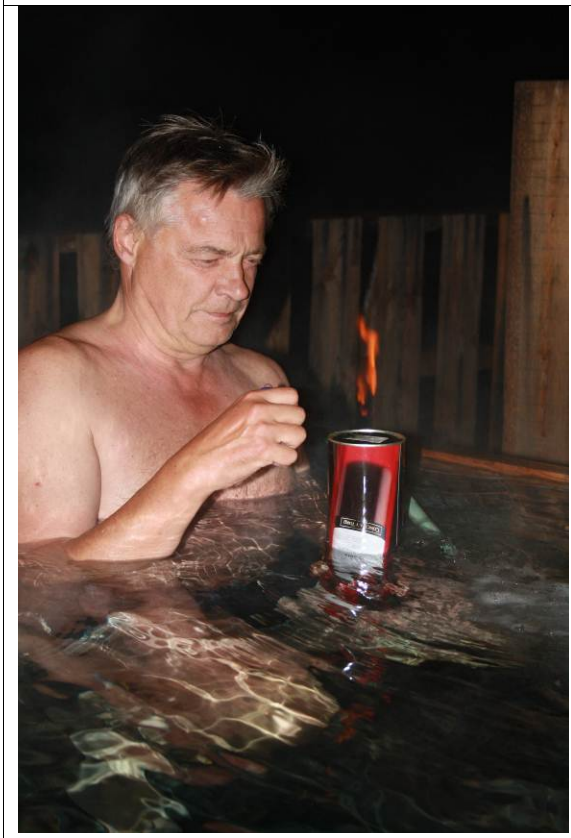


Figure 5.1. Sample locations around Parabel

Tom26/27 Borehole head at Goryachii Istochnik

Bath fed by borehole at Goryachii Istochnik



Professor Marc Solioz demonstrates that it is possible to light the methane content of the groundwater at Goryachii Istochnik. *Photo by Katya Komleva*

Tom28 Sampling point at Chazhemto spa

Figure 5.2. Photographs of sampling points for the deep oil exploration boreholes of the Kolpashevo - Parabel region (TOM26-28).

5.1 Sampling Sites

Sample Tom26 and Tom27: Deep borehole at Goryachii Istochnik (Горячий Источник).

The oil exploration well was reportedly drilled in around 1957, but no exploitable reserves were found. The well log, numbered "Borehole 3-R" reads as follows:

Ground surface = 57.74 m asl		
Age	**Description**	**Depth of base (m bgl)**
Quaternary	Sand with clay	30
Palaeogene Pg_3	Grey silts with interbedded clays	102
Palaeogene Pg_{2-3}	Dark green clay with interbedded sands	176
	Dark grey sand with interbedded pebbles	182
Cretaceous Cr_2	Grey silts	240
	Grey micaceous clay	360
	Iron-rich dark grey sandstone	376
	Grey-green sand	420
Cretaceous Cr_1	Grey micaceous clay	457
	Grey sand	600
	Grey clay with interbedded sand	674
	Coarse-grained micaceous sand	700
	Grey clay with interbedded sand	836
	Clay with sandstone	1020
	Grey clay with occasional interbedded sandstone	1120
	Grey calcareous sandstones	1362
	Dark green clay with interbedded sandstone	1486
	Clay / mudstone	1760
	Clay	2050
	Clay with interbedded sandstone	2140
	Clay/ mudstone with interbedded sandstone	2194
	Dark grey clay with interbedded sandstone	2250
Jurassic	Grey clay with interbedded sandstone	2330
	Alternating mudstones and sandstones	2600
Palaeozoic Pz	Monzonite and granite	2609

It is uncertain where the water is stratigraphically derived from, although a depth in excess of 2000 m must be suspected, given a water temperature of around 50°C.

The borehole is located on the west bank of the River Ob' midway between Parabel' (Парабель) and Narim (Нарым). The borehole overflows under artesian pressure. It overflows into baths at a small spa resort, which is not extensively developed, comprising wooden cabins. The surrounding area forms the boggy flood plain of the Ob'. The borehole's steel well casing protrudes from the ground and is highly corroded. The water has a strong smell of H_2S and the gas bubbles emerging from the water are flammable (methane - CH_4). The water flow rate is estimated at c. 0.2 to 0.3 L/s.

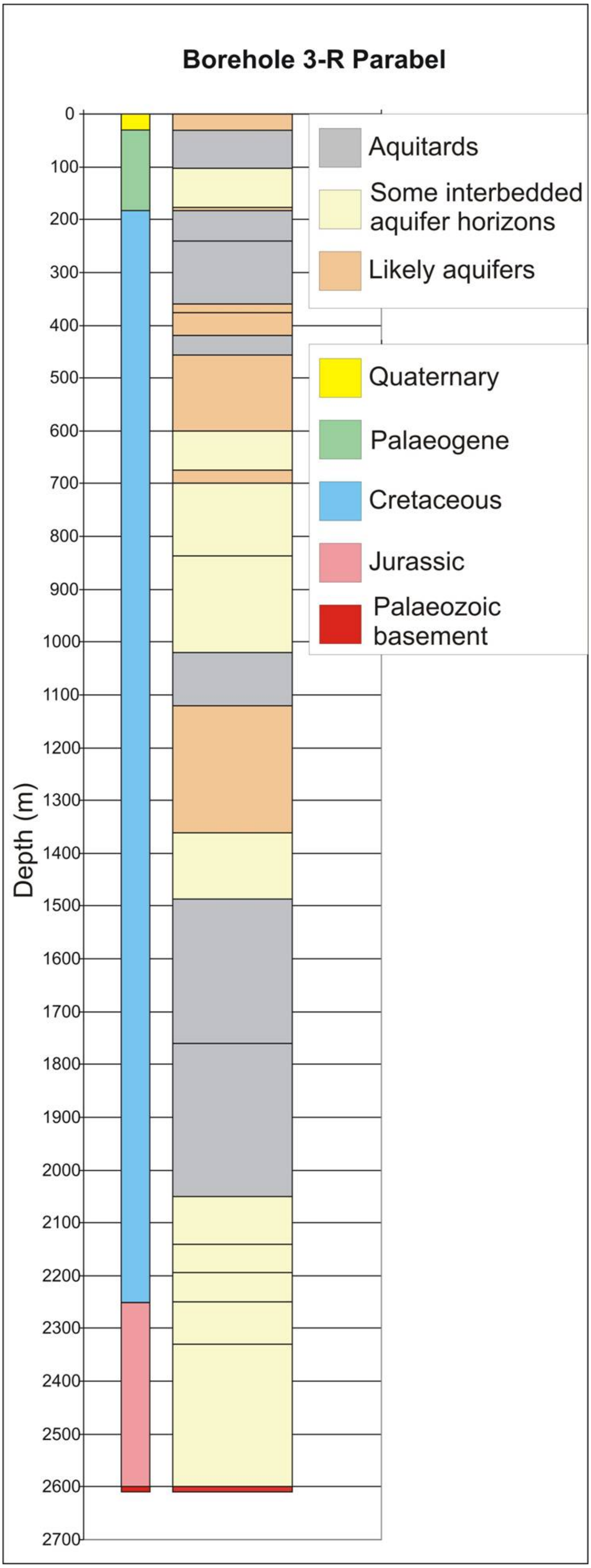


Figure 5.3. Graphical representation of borehole log from Borehole 3-R (Tom 26/27).

A number of analyses were made throughout the spring and summer of 1974 by the Tomsk Institute of Kurortology and the Tomsk Institute of Medicine. The analyses read as follows:

Parameter	Units	February 1974	April 1974	May 1974	September 1974
Iodine (I)	mg/L*	1.2	0.9	1.4	-
Bromine (Br)	mg/L*	-	3.0	6.0	3.0
H_2SiO_3	mg/L*	56.6	60.6	59.3	57.5
Si (calculated)	mg/L*	20.4	21.8	21.3	20.7
H_2S	mg/L*	-	5.3	3.4	6.8
Fluoride (F)	mg/L*	2.8	3.0	2.2	2.4
pH		7.55	7.5	7.6	7.25
Temp.	°C	53.0	53.0	53.0	53.0
Mineralization	g/L	13.4	14.3	13.0	13.5
Major ion content	meq/L %*	$\frac{Cl_{98}}{Na_{73}Ca_{25}}$	$\frac{Cl_{99}}{Na_{70}Ca_{25}}$	$\frac{Cl_{97}}{Na_{73}Ca_{26}}$	$\frac{Cl_{99}}{Na_{78}Ca_{20}}$

* = presumed units

Overall Kurlov formula $H_2S\ 0.00516\ M\ 13.5\ \frac{Cl_{98}}{Na_{74}Ca_{24}}\ pH\ 7.5\ T\ 53°C$

Another official analysis, dated 2006, was made by the Tomsk Scientific Research Institute for Kurortology and Physiotherapy (Томский Научно-исследовательский Институт Курортологии и Физиотерапии). The analysis found a total mineralization of 16.7 g/L. The temperature was reported as 68°C and the pH as 7.38. The major ion composition is given as a Kurlov Formula:

$$H_2SiO_3\ 0.169\ M\ 16.7\ \frac{Cl_{99}HCO3_1}{(Na+K)_{77}Ca_{21}Mg_2}\ pH\ 7.38\ T\ 68°C$$

In other words, the water is an NaCl brine with subsidiary Ca.

The samples and field measurements during 2010 were taken at the end of a c. 8 m sealed rubber sampling pipe connected to the wellhead. *In situ* measurements were made in an improvised throughflow cell to minimise atmospheric contact.

Two samples were taken, but other field measurements were made throughout the team's stay at the site. The alkalinity titration had a very slow end-point spanning the range 2.3 to 3.3 meq/L. Note that the recorded temperatures (around 45-46°C) are substantially less than previously recorded in the official analyses. There are thus some grounds to suspect that the temperature of the source is declining with time (although the temperature appears to have risen between 1974 and 2006, and the recorded temperature is likely to be rather susceptible to the means and location of measurement).

Note that the 2010 chloride determination made at the Geological Survey of Norway appears to be incorrect, resulting in an unacceptable ion balance error and not agreeing with parallel analyses made in Tomsk.

Field appearance of water: Clear / colourless water, with visible flammable gas bubbles. Odour of H_2S.
On filtration at 0.45µm: No colour or sediment observed on filter
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate

<u>Sample Tom28: Deep borehole at Chazhemto (Чажемто) Sanatorium.</u>

The sanatorium is located south of Kolpashevo (Колпашево), on the southern bank of the River Chaya (Река Чая), a tributary of the Ob'. The sanatorium is a well-established, relatively modern facility, with beds, treatment rooms, canteens etc. The sanatorium has several boreholes (some of which are used to produce a popular bottled water). The sampled borehole was, however, a deep, hot borehole, formerly used for oil exploration. The well head was not accessible, so the borehole's water was sampled as directly as possible via a bath tap in a treatment room. The borehole is called Borehole 1-4. An obvious H_2S smell could be observed.

Borehole 1-4 is reported to be 2205 m deep, according to a placard at the sanatorium, with the productive interval in the zone 2107 to 2154 m. The official analysis of 1988 is as follows:

$$H_2SiO_3\ 0.05\ M\ 6.1\ \frac{Cl_{97}HCO3_3}{(Na+K)_{88}Ca_{12}}\ pH\ 7.38\ T\ 48°C$$

Cl^- = 3479 mg/L HCO_3^- = 189.1 mg/L $SO_4^{=}$ = 13.9 mg/L
Na^++K^+ = 2042 mg/L Ca^{++} = 246 mg/L

In other words, this borehole's water is considerably less saline than that at Goryachii Istochnik (total mineralization 6.1 g/L), but it is also an Na-Cl water, with subsidiary Ca. The official analysis is generally in rather good agreement with the analysis carried out for this project.

The temperature recorded at the sampling point on 19/8/10 was 42.9°C. It is not known whether this reflects a genuine cooling of the water source since 1988 or heat losses in the pipework from the well head to the bath.

Field appearance of water: Clear / colourless water. Odour of H_2S.
On filtration at 0.45µm: No colour or sediment observed on filter
Water sample after filtration and storage to 1/9/10: Clear, colourless, no precipitate.

5.2 Field Analyses of Waters (pH, Temperature, Eh, Alkalinity)

Sample	Date / time	Location	Latitude	Longitude	Elevation	Type	Land use	Flow	TAlk1	TAlk2	TAlk3	T_alk	Temp	pH_{corr}	Eh
		Unit			m asl			L/s	meq/L	meq/L	meq/L	meq/L	°C		mV
	18/08/10 10:20	Goryachii Istochnik, Parabel	58°50.034	81°30.257		B	D/B						46.1	6.97	-292
	18/08/10 18:00	Goryachii Istochnik, Parabel	58°50.034	81°30.257		B	D/B						45.2		-284
TOM26	18/08/10 18:05	Goryachii Istochnik, Parabel	58°50.034	81°30.257		B	D/B	0.2 to 0.3	2.9	3.0		3.0	46.3	6.91	-297
TOM27	19/08/10 06:30	Goryachii Istochnik, Parabel	58°50.034	81°30.257		B	D/B		3.0	3.1		3.1	44.7	6.68	-270
TOM28	19/08/10 14:50	Chazhemto Sanatorium, borehole 1-4	58°4.405	82°50.197		B	U		3.0	2.9		3.0	42.9	7.40	-248

TAlk1 etc. represent individual determinations of total alkalinity. T_alk is the average. pH is corrected for daily drift.

Type

B = borehole water

Area Use

D = dachas

B = bog

U = urban (sanatorium complex)

5.3 Analyses of Anions by Ion Chromatography at Geological Survey of Norway

Sample		F^-	Cl^-	Br^-	NO_3^-	PO_4^{3}	SO_4^{2--}
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TOM26	Goryachii Istochnik, Parabel	3.1	3950	<1	<0.5	<2	<1
TOM27	Goryachii Istochnik, Parabel	3.1	4260	<1	<0.5	<2	<1
TOM28	Chazhemto Sanatorium, borehole 1-4	4.2	3260	<1	<0.5	<2	22

Cl^- analysed by TPU (table 5.8)
8857

All determinations on filtered samples at 0.45 µm

Note that concentrations of nitrite, nitrate, phosphate and sulphate are cited as mg/L NO_3^-, PO_4^{3-} and SO_4^{2-} and *not* mg/L N, P and S.

NOTE: the chloride concentrations determined by NGU for Goryachii Istochnik appear to be too low, in comparison with parallel analyses made at Tomsk Polytechnic University and in the context of the overall ion balance. See Table in 5.8.

There is also a strong suspicion that the NGU determinations for bromide may be too low, in the context of analyses performed in Tomsk, see Tables 5.7 and 5.8.

5.4 Analyses of 32 Elements by ICP-AES at Geological Survey of Norway

Sample		Ca	Mg	Na	K	Fe	Mn	Al	Si	Ba	Sr	B	P
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TOM26	Goryachii Istochnik, Parabel	1160	3.98	4100	35.9	0.0606	0.268	<0.02	16.1	13.8	92.2	7.82	0.100
TOM27	Goryachii Istochnik, Parabel	1170	3.99	4140	36.1	0.0618	0.267	<0.02	16.1	13.8	93.5	7.89	0.132
TOM28	Chazhemto Sanatorium, borehole 1-4	234	0.884	1880	17.3	0.0218	0.0737	<0.02	15.5	1.75	19.1	8.79	0.151

Sample	Ti	Cu	Zn	Pb	Ni	Co	V	Mo	Cd	Cr	Zr	Ag	Be	Li	Sc	Ce	La	Y	As	Sb
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
TOM26	0.0034	<0.005	0.0309	<0.005	0.0170	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	0.769	<0.001	<0.02	<0.005	<0.001	0.117	<0.005
TOM27	0.0034	<0.005	0.0313	<0.005	0.0161	<0.001	<0.005	0.0056	<0.0005	<0.002	<0.002	<0.005	<0.001	0.765	<0.001	<0.02	<0.005	<0.001	0.120	<0.005
TOM28	0.0014	<0.005	0.0200	<0.005	0.0123	<0.001	<0.005	<0.005	<0.0005	<0.002	<0.002	<0.005	<0.001	0.382	<0.001	<0.02	<0.005	<0.001	<0.01	<0.005

All determinations on water samples were on samples filtered at 0.45 µm. Laboratory-acidified, in original flask.

5.5 Ion Balance Error and Water Type calculated from NGU analyses

ID	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Sr^{++}	Ba^{++}	Al^{+++}	Fe^{++}	Mn^{++}	Cl^{-} NGU	Cl^{-} Tomsk	NO_3^{-}	$SO_4^{=}$	Alk	Br^{-}	F^{-}	H^{+}
	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L
TOM26	57.88	0.33	178.338	0.918	2.1045	0.2010		0.0022	0.0098	111.425	249.84			2.95		0.1632	0.0001
TOM27	58.38	0.33	180.078	0.923	2.1342	0.2010		0.0022	0.0097	120.169	249.84			3.05		0.1632	0.0002
TOM28	11.68	0.07	81.775	0.442	0.4360	0.0255		0.0008	0.0027	91.961			0.458	2.95		0.2211	0.0000

ID		Cations	Anions	Anions (using Tomsk value for Cl)	Ion balance error IBE (%)	IBE (using Tomsk value for Cl)	Water Type
		meq/L	meq/L	meq/L	%	%	
TOM26		239.79	114.54	252.96	35.3	-2.7	Na - (Ca) - Cl
TOM27		242.06	123.38	253.06	32.5	-2.2	Na - (Ca) - Cl
TOM28		94.43	95.59		-0.6		Na - (Ca) - Cl

5.6 Field analyses carried out by staff of Tomsk State University (Na = not analysed)

	25-August-2009, morning	16-February-2010, morning	18-August-2010, morning	18-August-2010, evening	19-August-2010, morning
T, °C	46.9	50.2	46.1	45.2	44.7
Eh, mV	-248	-299	-292	-284	-270
H_2S, mg l^{-1}	2.46 ± 0.48	3.27 ± 0.49	Na	7.42 ± 0.51	5.68 ± 1.38

5.7 Analyses of metals and trace elements by Laboratories in Tomsk (ICP-MS)

Results are compared with Tom 26 and Tom 27 analysed at NGU, and with previous sampling rounds (August 2009 and February 2010) carried out by Tomsk organisations.

	Concentrations (mg/L)				
	Aug-09	Feb-10	Aug-10 TOM26	Aug-10	Aug-10 TOM 27
Element	ICP (Tomsk)	ICP (Tomsk)	18-August-2010, evening (ICP Norway)	18-August-2010, evening (ICP Tomsk)	19-August-2010, morning (ICP Norway)
Si	24.17	29.5	16.1	20.09	16.1
Al	0.214	0.205	<0.02	0.0134	<0.02
Fe	6.24	5.79	0.0606	8.38	0.0618
Ti	0.00288	0.04	0.0034	0.00504	0.0034
Mg	5.64	5.47	3.98	4.71	3.99
Ca	1376	1303	1160	895	1170
Na	4281	4950	4100	3649	4140
K	30.2	33.2	35.9	28.8	36.1
Mn	0.347	0.355	0.268	0.394	0.267
P	0.534	0.469	0.100	0.12	0.132
Cu	0.00441	0.00587	<0.005	0.00352	<0.005
Zn	0.00346	0.146	0.0309	0.00469	0.0313
Pb	<0.0002	0.00086	<0.005	0.00038	<0.005
Ni	0.00222	0.0381	0.0170	0.00224	0.0161
Co	0.00227	0.00227	<0.001	0.00229	<0.001
V	0.0607	0.0476	<0.005	0.107	<0.005
Mo	0.00057	0.00048	<0.005	0.00039	0.0056
Cd	<0.0001	<0.0001	<0.0005	<0.0001	<0.0005
Cr	0.0069	0.0069	<0.002	0.0054	<0.002
Ba	16.14	16.71	13.8	16.8	13.8
Sr	79.1	89.13	92.2	81.03	93.5
Zr	0.00018	0.00104	<0.002	<0.0002	<0.002
Ag	<0.0001	<0.0001	<0.005	<0.0001	<0.005
B	7.81	6.5	7.82	6.65	7.89
Be	<0.0001	<0.0001	<0.001	<0.0001	<0.001
Li	0.674	0.873	0.769	0.701	0.765
Sc	<0.002	0.00378	<0.001	0.00391	<0.001
Ce	<0.00005	<0.00005	<0.02	<0.00005	<0.02
La	9.1E-05	0.0002	<0.005	0.00012	<0.005
Y	0.00043	0.00053	<0.001	0.00038	<0.001
As	0.156	0.145	0.117	0.165	0.120
Sb	0.00038	0.00044	<0.005	0.00032	<0.005
Ga	0.00016	0.00035	Na	<0.0002	Na
Ge	0.011	0.0114	Na	0.0112	Na
Se	0.118	0.151	Na	0.14	Na
Br	29.92	32.14	Na	31.11	Na

Analyses of metals and trace elements by Laboratories in Tomsk (ICP-MS) (continued)

	Aug-09	Feb-10	Aug-10 TOM26	Aug-10	Aug-10 TOM 27
Element	ICP (Tomsk)	ICP (Tomsk)	18-August-2010, evening (ICP Norway)	18-August-2010, evening (ICP Tomsk)	19-August-2010, morning (ICP Norway)
Rb	0.0676	0.0615	Na	0.0648	Na
Nb	0.00025	0.00032	Na	<0.0001	Na
Ru	<0.00005	<0.00005	Na	<0.00005	Na
Rh	<0.00005	<0.00005	Na	<0.00005	Na
Pd	<0.0001	<0.0001	Na	<0.0001	Na
In	<0.00005	<0.00005	Na	<0.00005	Na
Sn	<0.0002	<0.0002	Na	<0.0002	Na
Te	<0.002	<0.002	Na	<0.002	Na
I	1.00	0.19	Na	0.42	Na
Cs	0.02	0.0179	Na	0.0195	Na
Pr	<0.00005	<0.00005	Na	<0.00005	Na
Nd	<0.00005	<0.00005	Na	<0.00005	Na
Sm	<0.00005	0.00007	Na	0.00009	Na
Eu	<0.00005	0.00021	Na	0.00021	Na
Gd	<0.00005	<0.00005	Na	<0.00005	Na
Tb	<0.00005	<0.00005	Na	<0.00005	Na
Dy	<0.00005	<0.00005	Na	<0.00005	Na
Ho	<0.00005	<0.00005	Na	<0.00005	Na
Er	<0.00005	<0.00005	Na	<0.00005	Na
Tm	<0.00005	<0.00005	Na	<0.00005	Na
Yb	<0.00005	<0.00005	Na	<0.00005	Na
Lu	<0.00005	0.00011	Na	<0.00005	Na
Hf	<0.00005	<0.00005	Na	<0.00005	Na
Ta	<0.00005	<0.00005	Na	<0.00005	Na
W	0.00111	0.00119	Na	0.00114	Na
Re	<0.00005	<0.00005	Na	<0.00005	Na
Os	<0.00005	<0.00005	Na	<0.00005	Na
Ir	<0.00005	<0.00005	Na	<0.00005	Na
Pt	<0.00005	<0.00005	Na	<0.00005	Na
Au	<0.00005	<0.00005	Na	<0.00005	Na
Hg	<0.00004	<0.00004	Na	<0.00004	Na
Tl	0.00014	0.00032	Na	0.00037	Na
Bi	6.3E-05	<0.00005	Na	7.8E-05	Na
Th	<0.00005	<0.00005	Na	<0.00005	Na
U	<0.00005	<0.00005	Na	<0.00005	Na

Na = Not analysed;

Yellow cells highlight minor discrepancies between NGU's ICP-AES results and the ICP-MS results from Tomsk.

For Si, Ca and Na, the NGU results agree quite well with the conventional chemical analyses carried out in Tomsk in Table 5.8, suggesting the Tomsk ICP-MS results may be in error.

For Zn, Ni and Co, the discrepancies are unexplained.

For Sc, there is a well known interference with Si in ICP-MS and the Tomsk results are suspected to be in error.

Pink cells highlight major discrepancies between NGU's ICP-AES results and the ICP-MS results from Tomsk.

For V and Cr there are possible interferences with ICP-MS techniques with chloride, and the Tomsk results are suspected to be in error.

The cause of the rather high iron concentrations observed in the analyses of the Tomsk team may be due to either interferences (possibly with Cl^-) in the ICP-MS method, or possibly the filtration approaches used, although no obvious precipitation of iron was observed on filters. More credence should possibly be given to the NGU results, given the robustness of the ICP-AES method for Fe and the reproducibility of the results.

5.8 Analyses of ionic substances by Laboratories in Tomsk

Results are compared with Tom 26 and Tom 27 analysed at NGU, and with previous sampling rounds (August 2009 and February 2010) carried out by Tomsk organisations. TPU = Tomsk Polytechnic University. Oblkompriroda = Regional Committee for Environment. Na = not analysed, Nd = not detected

		Aug-09	Feb-10	Mar-10	Aug-10		
Time of sampling		25-Aug-2009, morning	17-Feb-10		18-Aug-2010, evening	18-Aug-2010, evening	19-Aug-2010, morning
Laboratory		TPU	TPU	Oblkom-priroda	NGU TOM 26	TPU	NGU TOM 27
F^-	mg l^{-1}	Na	Na	Na	3.1	3.8	3.1
Cl^-	mg l^{-1}	8875	8650	9198	3950	8857.3	4260
NO_2^-	mg l^{-1}	<0.003	<0.01	Na		<0.03	
Br^-	mg l^{-1}	Na	Na	Na	<1	29	<1
NO_3^-	mg l^{-1}	114.6	4.5	<0.1	<0.5	2	<0.5
PO_4^{3-}	mg l^{-1}	0.57	0.09	0.06	<2	0.15	<2
SO_4^{2-}	mg l^{-1}	4.23	<2.0	<10.0	<1	<2.0	<1
I^-	mg l^{-1}	1.4	2	Na	Na	0.38	Na
HCO_3^-	mg l^{-1}	183	140.3	Na	Na	135	Na
CO_3^{2-}	mg l^{-1}	Nd	Nd	Na	Na	Nd	Na
CO_2	mg l^{-1}	7.04	19.8	Na	Na	13.2	Na
NH_4^+	mg l^{-1}	12.9	6.6	2.14	Na	5.67	Na
Ca^{2+}	mg l^{-1}	1240	1075	1242	Na	1125	Na
Mg^{2+}	mg l^{-1}	18	106.25	<1.2	Na	83.9	Na
Na^+	mg l^{-1}	4320	4200	Na	Na	4313	Na
K^+	mg l^{-1}	31.2	20.0	Na	Na	54	Na
Si	mg l^{-1}	15.64	20.38	20.76	Na	15.64	Na
Fe	mg l^{-1}	0.15	Na	Na	Na	0.18	Na
Petroleum hydrocarbons	mg l^{-1}	1.56	0.053	0.038	Na	Na	Na
Chemical oxygen demand	mgO_2 l^{-1}	4400	201.5	1400	Na	177	Na
Permanganate oxidability	mgO_2 l^{-1}	29.4	4.8	Na	Na	5.2	Na
C organic	mg l^{-1}	1650	75.55	Na	Na	66.22	Na
Density	g cm^{-3}	1.01	1.0096	Na	Na	1.009	Na
Salinity (by density)	mg l^{-1}	15000	15000	Na	Na	13500	Na
Salinity (by salts)	mg l^{-1}	Na	14191	TDS 15728	Na	14514	Na
Electrical conductivity	mS cm^{-1}	Na	23.2	Na	Na	24.3	Na
Total hardness	°	63.5	62.5	62	Na	63.13	Na
pH		7.42	7.67	Na	Na	7.64	Na

Yellow cells highlight minor discrepancies between NGU's IC results and the ion analysis results from Tomsk.

The presence of nitrate (TPU) in the water seems unlikely, given the strongly sulphate-reducing nature of the water and, in this case, the NGU result is preferred.

Pink cells highlight major discrepancies between NGU's IC results and the ion analysis results from Tomsk.

For Cl^-, the Tomsk results seem to be correct, on the basis of reproducibility and on ion balance considerations.

Given the high Cl^- concentrations, there seems a strong probability that the Tomsk results for bromide are to be preferred to those of NGU. Moreover, the Tomsk bromide results agree very well with the ICP results for bromine (Table in 5.7)

The Tomsk results for Mg^{++} and K^+ seem to be grossly overestimated, compared with the ICP results, both from Tomsk and NGU.

5.9 Analyses of trace organic compounds, carried out at Laboratories in Tomsk

Compound	Concentration in August 2009, $\mu g/l^{-1}$	Concentration in February 2010, $\mu g/l^{-1}$	Concentration in August 2010, $\mu g/l^{-1}$
Decane	Nd	Nd	2.185
Undecane	Nd	Nd	2.692
Dodecane	Nd	Nd	2.355
Tridecane	0.053	0.113	1.868
Tetradecane	0.194	0.277	1.458
Pentadecan	0.378	0.297	0.889
Hexadecane	0.603	0.338	0.512
Heptadecane	1.042	0.406	0.347
Octadecane	0.495	0.316	0.194
Nonadecane	0.875	0.319	0.116
Icosane	1.375	0.409	0.098
Total alkanes C10:C20	**5.015**	**2.475**	**12.714**
Henicosane	1.198	0.516	0.078
Docosane	0.699	0.603	0.086
Tricosane	0.321	0.749	0.112
Tetracosane	0.182	0.774	0.116
Pentacosane	0.162	0.773	0.128
Hexacosane	0.11	0.618	0.127
Heptacosane	0.122	0.535	0.111
Octacosane	0.109	0.464	0.073
Nonacosane	0.128	0.401	0.04
Triacontane	0.061	0.321	0.022
Hentriacontane	0.036	0.209	0.011
Dotriacontane	Nd	0.145	0.007
Tritriacontane	Nd	0.18	0.004
Tetratriacontane	Nd	0.122	Nd
Total alkanes C21:C35	**3.128**	**6.41**	**0.915**
Hexanoic acid	4.326	Nd	0.884
Enanthic acid	0.636	Nd	0.249
Caprylic acid	0.767	0.002	0.445
Pelargonic acid	0.686	0.036	0.513
Capric acid	0.148	0.01	0.122
Undecanoic acid	0.03	Nd	0.04
Lauric acid	0.088	0.014	0.159
Tridecanoic acid	0.033	Nd	0.036
Myristic acid	0.086	0.039	0.236
Pentadecanoic acid	0.053	0.017	0.094
Palmitic acid	0.645	0.312	0.988
Stearic acid	Nd	0.014	Nd
Total carboxylic acids	**7.498**	**0.444**	**3.766**

Compound	Concentration in August 2009, $\mu g/l^{-1}$	Concentration in February 2010, $\mu g/l^{-1}$	Concentration in August 2010, $\mu g/l^{-1}$
Naphthalene	0.015	Nd	0.262
2-Methylnaphthalene	0.024	Nd	0.351
1-Methylnaphthalene	0.042	Nd	0.255
C2-naphthalenes	0.036	0.009	0.605
C3- naphthalenes	0.062	0.01	0.291
C4- naphthalenes	Nd	Nd	0.124
Fluorene	Nd	Nd	0.011
Methylfluorene	Nd	Nd	0.008
Phenanthren	0.06	0.015	0.019
Methyl (phenanthren + anthracene)	0.037	Nd	Nd
C2 (phenanthren + anthracene)	0.063	Nd	Nd
Propyl undecanoate	0.177	0.008	Nd
Propyl tridecanoate	Nd	0.006	0.005
Total propyl ethers	**0.177**	**0.014**	**0.005**
Pristane	Na	0.089	Nd
Phytane	0.604	0.085	Nd

Nd, not detected

5.10 General Comments on Analyses of Abandoned Oil Exploration Wells

Correspondence between the Tomsk and NGU laboratories for TOM26 and TOM27

The correspondence between the analyses carried out by NGU and the Tomsk team was generally rather good, with the exception of several parameters.

In general, several of the discrepancies noted between the ICP-MS results of the Tomsk laboratories and the ICP-AES results of the NGU laboratory (Table 5.7) can be ascribed to either:

(i) interferences in the ICP-MS method, either with Cl^- or Si.
(ii) possible lack of accuracy at the upper end of the determination range for major ions by ICP-MS (and the NGU ICP-AES results for the major elements generally agree rather well with the Tomsk laboratories' more conventional analyses (Table 5.8).

In general, therefore, it would appear that generally more credence should be given to the robust ICP-AES methodology, in the case of discrepancies, than the Tomsk ICP-MS results.

For anions, there are two serious discrepancies between the Tomsk (TPU) and Norwegian (NGU) results, namely for chloride and bromide. The NGU result for chloride yields a very large ion balance deficit for anions, whereas the TPU result leads to a very low ion balance error. In this case, therefore, the NGU result appears to be in error and the TPU result is preferred. As regards bromide, the very low NGU result is surprising given the extremely high chloride concentrations and, in this case too, the TPU result is preferred. The TPU ion analysis (Table 5.8) for bromide also agrees very well with the ICP-MS result (Table 5.7).

Ion balance errors

Provided that the TPU values for chloride concentrations are used in calculating the ion balance errors of TOM26 and 27, the errors are all very small (-2 to -3% for TOM26 and TOM27 and only -0.6% for TOM28) - rather impressive for such saline waters.

Water type - Goryachii Istochnik

The Goryachii Istochnik water (TOM 26 and TOM27) is a sodium-(calcium)-chloride saline water with a salinity around 40% of seawater. The water is strongly reducing, with sulphate reducing (presence of around 5 mg/L of H_2S, sulphate absent) and methanogenic conditions prevailing and an observed Eh of around -270 to -300 mV. The water is circum-neutral and the alkalinity is around 3 meq/L.

There is no clear evidence of very high concentrations of dissolved iron or manganese, concentrations of these and other metals being suppressed by the elevated sulphide concentrations.

Rather high silicon concentrations of around 16.1 mg/L (=34.4 mg SiO_2/L) were recorded by NGU, which are ascribable to the elevated solubility of silica at high temperatures.

Water type - Chazhemto

The Chazhemto water (TOM 28) is also a sodium-(calcium)-chloride saline water, but with a less extreme character than Goryachii Istochnik. The salinity is only around 17-18% of seawater. The water is strongly reducing, with sulphate reducing (presence of H_2S, sulphate absent) conditions prevailing and an observed Eh of around -250 mV. The water is circum-neutral and the alkalinity is around 3 meq/L.

There is no clear evidence of very high concentrations of dissolved iron or manganese, concentrations of these and other metals being suppressed by the elevated sulphide concentrations.

A rather high silicon concentration of around 15.5 mg/L was recorded by NGU, which is ascribable to the elevated solubility of silica at high temperatures.

Other hydrochemical features

The waters from Goryachii Istochnik are also characterised by extremely low Mg/Ca rations (around 0.006 molar ratio, compared with a ratio of 5.2 in sea water) and very high Sr/Ca ratios (around 0.037 molar ratio, compared with 0.015 in sea water). The Na/Cl ratios are close to sea water (molar ratio 0.86), although the Goryachii Istochnik ratio is slightly lower than sea water.

Otherwise the waters contain relatively high concentrations of Silicon (Si, 16 mg/L), nickel (Ni, 12 - 17 μg/L, according to NGU), fluoride (F^-, 3 - 4 mg/L), barium (Ba, a key indicator of sulphate removal by sulphate reduction), boron (B, c. 8 mg/L), lithium (Li, 380 - 770 μg/L). and slightly elevated concentrations of Ti, Zn, ***Furthermore, the Goryachii Istochnik water appears to contain around 120 μg/L of arsenic. The owners of the spa should be made aware of this result and it should be emphasised that this water should not be used as a potable supply.***

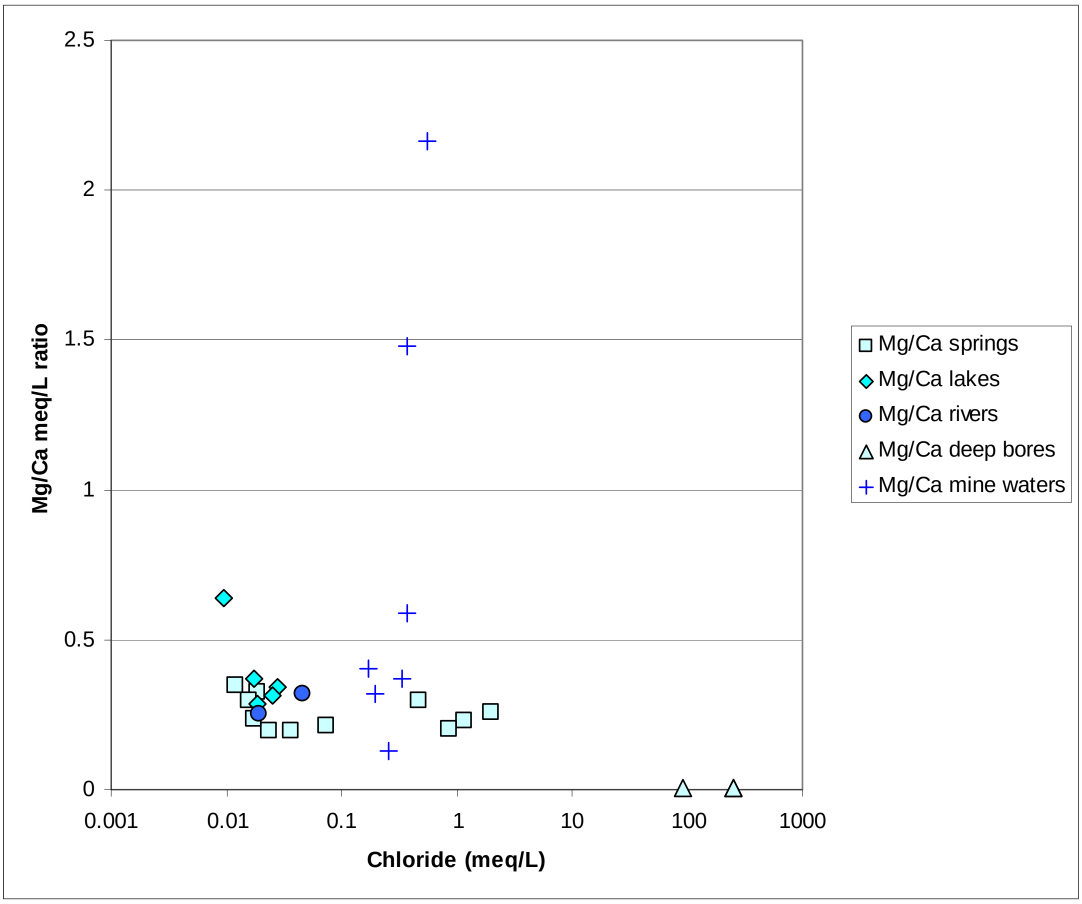


Figure 5.4. All sampled waters (this report) plotted as Mg/Ca molar ratio versus chloride (in meq/L). For TOM26 and 27, Tomsk results for Cl^- used.

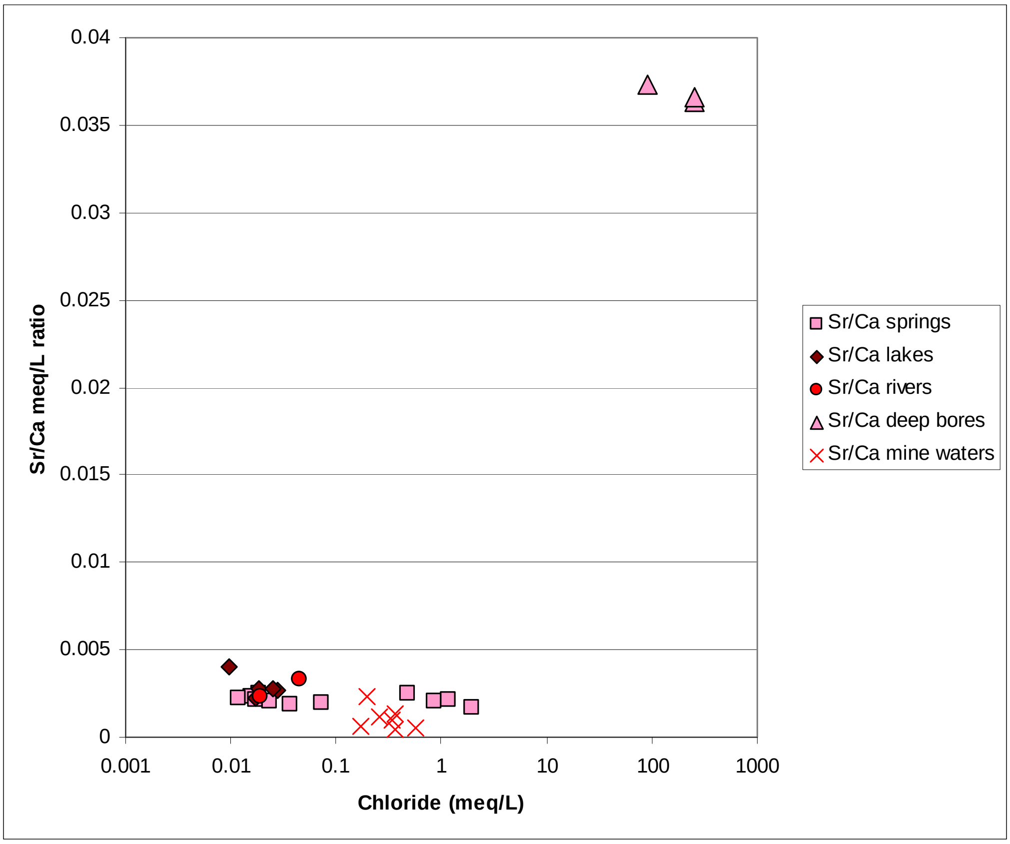


Figure 5.5. All sampled waters (this report) plotted as Sr/Ca molar ratio versus chloride (in meq/L). For TOM26 and 27, Tomsk results for Cl^- used.

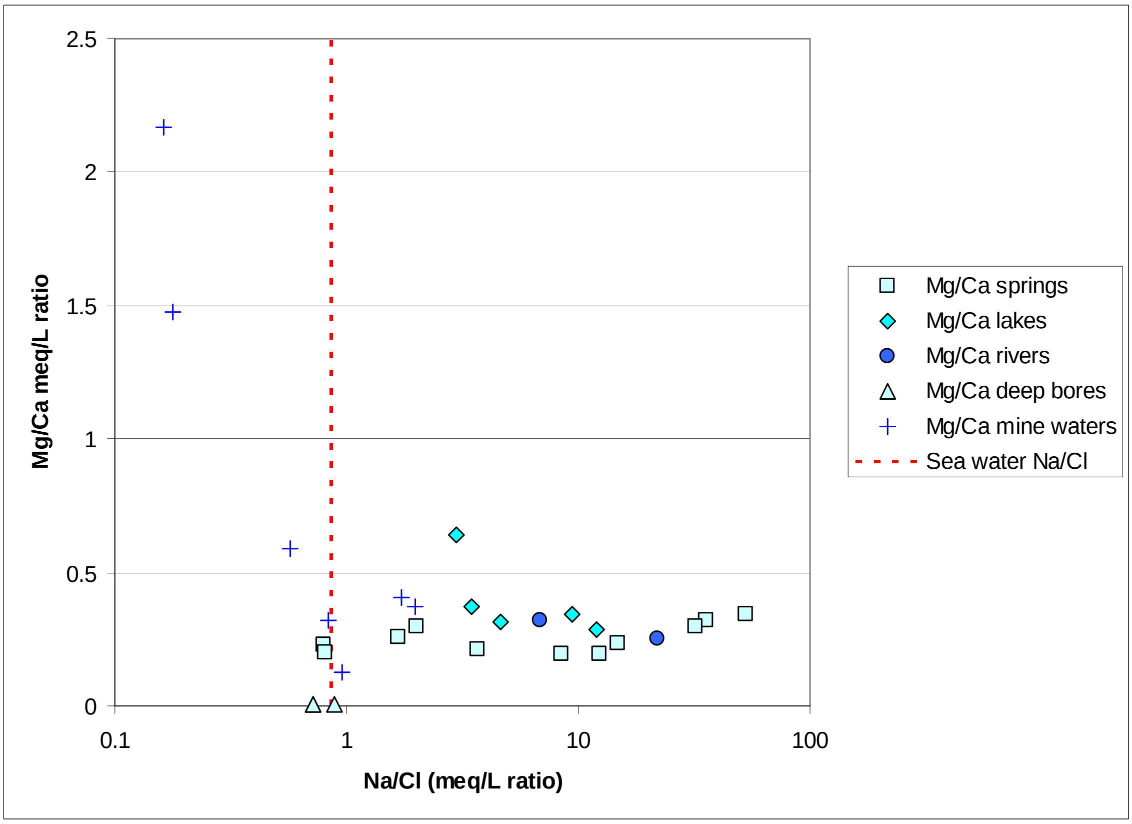


Figure 5.6. All sampled waters (this report) plotted as Mg/Ca molar ratio versus Na/Cl molar ratios. For TOM26 and 27, Tomsk results for Cl^- used.

6 CONCLUSIONS

This report documents the hydrochemical analyses performed on water samples collected during a field expedition during the summer of 2010 to the Martaiga gold mining province (Kemerovo Oblast'), the Goryachii Istochnik and Chazhemto spas (based on deep oil exploration wells) in the north of Tomsk Oblast' and various sites in and around the city of Tomsk – all in south-western Siberia. Data have been obtained from groundwater (wells, boreholes and springs), rivers, lakes and discharges from abandoned mines and mine wastes. Of particular interest are the following observations:

(i) The shallow groundwaters of the Tomsk region are typically dominated by relatively high concentrations of Ca^{++} and bicarbonate alkalinity, and slightly alkaline pH. The high concentrations may reflect high partial pressures of CO_2 in recharge water. They also result in the degassing of CO_2 at spring discharges, the formation of travertine in some springs and high pH (> 8) in spring-fed streams.

(ii) The urban springs in Tomsk are characterised by elevated concentrations of nitrate, sulphate, potassium, chloride and sodium. In one spring (Voskresenskii spring), chloride reaches 70 mg/L (compared with a background of <2 mg/L in uncontaminated waters) and nitrate is recorded as 160 mg/L, rendering it potentially unsafe to drink, especially for infants.

(iii) Especially aggressive mine tailings leachate was found at the tailings ponds in Komsomolsk, Martaiga, with concentrations ranging up to 13.5 g/L sulphate, 4.8 g/L iron, 399 mg/L Al, 556 mg/L As, 232 mg/L Zn, 18.8 mg/L Cu, 5.9 mg/L Cd and pH values as low as 1.68.

(iv) The > 2 km deep abandoned oil exploration boreholes at Goryachii Istochnik (near Parabel') and at Chazhemto Spa (near Kolpashevo) yield saline Na-(Ca)-Cl waters with salinities around 40% and 18% of seawater, respectively. The waters were characterised by sulphate reduction and, at least in the case of Goryachii Istochnik, by methanogenesis. Temperatures are broadly consistent with a normal geothermal gradient. The waters exhibit very low Mg/Ca ratios, elevated Sr/Ca ratios, and elevated concentrations of, e.g. Si, Zn, B, Li and Ba. At Goryachii Istochnik, arsenic concentrations of around 120 μg/L were recorded and it is recommended that the spa be informed that the water is not suitable for potable use.

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