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Title: The Hydrochemistry of Selected Coal Mine Drainage and Spoil-Tip Run-off Waters, Longyearbyen, Svalbard					
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<p>Summary:</p> <p>During July 1996, three sources of mine run-off were sampled from the mining complex around Longyearbyen, Svalbard: (i) Pumped discharge of minewater from Mine 3 to Bjørndalen, (ii) Run-off from a spoil tip at Mine 3 in Bjørndalen and (iii) Run-off from a spoil tip at Sverdrupbyen. One objective of the study was to obtain an indication whether the special climate of Svalbard influences the minewater hydrochemistry.</p> <p>The pumped mine water was found to be a highly alkaline, saline (Na-HCO₃-Cl) water with a low iron content. It is not known if this point sample is representative of pumped mine discharge at all times. Its alkaline nature may reflect the usage of large quantities of pulverised limestone in the mine to hinder explosion risk, but it is regarded as being more likely related to the natural hydrochemistry of the deep, sub-permafrost water entering the deepest levels of the mine.</p> <p>The two spoil tip leachates were found to be not atypical of coal spoil tip leachates from other more temperate climates. They are acidic (pH 3.7 and 2.7 respectively) and contain high concentrations of iron (179 mg/l at Sverdrupbyen), aluminium (27.5 mg/l), sulphate (1077 mg/l), zinc (1.3 mg/l) and several other metals including beryllium at 143 µg/l. The concentrations of barium and sulphate are negatively correlated, indicating a barite saturation control. Although the leachates contain high levels of heavy metals, the leachate discharge is very small and compared with that in the recipient watercourses, minimising the potential environmental impact.</p> <p>Preliminary Sr isotope work suggests a characteristic isotopic composition for the deep pumped minewater.</p>					
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CONTENTS

1. OBJECTIVE.....	4
2. INTRODUCTION.....	4
3. SAMPLING	5
4. SAMPLE SITES	5
4.1 Mine 3	5
4.2 Sverdrupbyen	6
5. RESULTS	7
5.1 Pumped Mine Water - Mine 3	7
5.2 Spoil Tips	8
6. ISOTOPIC ANALYSES	9
7. SPECIATION MODELLING.....	9
7.1 Pumped Mine Water - Mine 3	9
7.2 Spoil Tip Leachates	9
8. CONCLUSIONS.....	10
9. REFERENCES	12

TABLES

Table 1 Composition of the three sampled mine waters.	14
Table 2. Comparison of discharge water quality from selected British and Svalbardian pumping and abandoned mines and spoil tips (after Banks et al. <i>in press</i>)	15
Table 3. Strontium isotope ratios in the sampled waters.	16
Table 4. Ionic balances and saturation indices with respect to selected mineral phases estimated with the thermodynamic geochemical modelling code MINTEQA2.	17
Table 5. Speciation of dissolved Fe, Al and B as indicated by modelling using the code MINTEQA2.	18

FIGURES

Figure 1. Map of the area around Longyearbyen, showing the sample locations.	19
Figure 2. Schematic cross-sections of the sampling localities	20
Figure 3. Photographs of (a) Bjørndalen, (b) Bjørndalen, Mine 3 minewater discharge, (c) Mine 3 spoil leachate, (d) Sverdrupbyen site	21

1. OBJECTIVE

The objective of this report is to document the water quality of three samples of mine and spoil-tip run-off sampled during summer 1996 in the Longyearbyen area of Svalbard. The composition of these waters is investigated with speciation modelling and is compared with other coal mine discharge waters and spoil tip leachates internationally.

2. INTRODUCTION

Hjelle (1993) provides an excellent introduction to the geology of Svalbard. The mines which are the subject of this study are all worked in the Longyear Seam, the thickest (varying from 0.6 - 2 m) of several coal seams of the lower Tertiary sequence of the Longyearbyen area. Mining-related activity has occurred in the area since the early years of this century. Since the 1950s, production of coal on Svalbard has been between 250,000 and 500,000 tonnes per year. The coal has a relatively low sulphur content of some 1 % S. The Tertiary host rocks consist of series of sandstones, siltstones and shales. Mining conditions are further described by Amundsen (1994) and World Coal (1995).

The Longyear Seam dips gently southwards and mining takes place largely within the permafrost (which can reportedly exceed 300 m depth under the mountain areas) and partly in the unfrozen strata beneath it. The permafrost cap means that leakage of water from the surface into the deeper parts of the mine is low, although relatively small amounts of deep groundwater from saturated strata below the permafrost do enter the mine. The permafrost cap also permits the build-up of pockets of methane, necessitating the use of lime dust and water in the mine to bind coal dust and hinder explosions (Hjelle 1993, Amundsen 1995). The mine operators, Store Norsk Kullkompani, have observed that the quantities of water pumped, especially from Mine 7, do show a seasonal variation (Jon Utsi pers. comm.). It is thought that this may be indicative of fractures extending up through the permafrost layer to the zone of seasonal thaw.

Currently, only two mines actively produce coal in the Longyearbyen area: Mine 3 near the airport and Mine 7 at Foxdalen east of Longyearbyen. Mine 3 is currently winding down its activities and is planned to be closed in 1997. Production of coal is planned to be increased in the future in the so-called Central Field, near Svea (Utsi & Myrvang 1992).

3. SAMPLING

The samples from Mine 3 were taken on the 20th July 1996; that from Sverdrupbyen on the 21st July 1996. The weather conditions during sampling were relatively good, with little precipitation. pH, Eh and temperature were determined in the field using a field-calibrated Yellow Springs International YSI 3500 meter. Alkalinity was determined in the field using an AquaMerck 11 109 field titration kit and pH 4.3 mixed indicator.

100 ml polyethene flasks were used for sampling. These were rinsed thoroughly prior to sampling with the mine/spoil water 3 times and with filtered mine/spoil water 2 times. The sampled water (100 ml) was filtered at 0.45 µm using a hand-held syringe and Millipore encapsulated filters (type SBHA 025 SB). In the case of the mine discharge water from Mine 3, a 500 ml sample of unfiltered water was taken in a polyethene flask, previously rinsed three times with mine water, for confirmatory analysis of pH and alkalinity in the laboratory. No field preservation was undertaken due to problems of transporting concentrated acid to Svalbard.

Following arrival at the Geological Survey of Norway laboratory on the 24th July, a limited quantity (c. 10 ml) of water was taken from each 100 ml flask for determination of anionic species by Ion Chromatography. The remaining c. 90 ml of each sample was acidified with 10 drops superpure concentrated HNO₃ to remobilise any precipitated or adsorbed metals and was analysed for a range of elements by ICP-AES. For the 500 ml sample, pH and alkalinity were determined in the laboratory both before and after laboratory filtration (it was suspected that the high measured alkalinity might be due to particles of lime dust in the water). Analytical techniques are further documented in Analytical Report NGU 1996.0123.

4. SAMPLE SITES

The location of the sampling sites is documented on Figure 1 and schematic cross-sections are indicated in Figure 2.

4.1 Mine 3

In the lower part of Bjørndalen are several areas of mine spoil derived from Mine 3. The surfaces of the shaley spoil fragments are frequently coated with a yellow mineral, possibly iron sulphate or jarosite derived from subaerial oxidation of pyrite.

The pumped mine discharge occurs from an 8" diameter pipe just below a double access / ventilation tunnel. A small area of ground below the discharge pipe is stained orange (Figure 3b), which probably indicates that the discharge of pumped water and the content of iron may at certain times be greater than that observed in the current study. The water pumped from the mine is believed largely to be derived from inflow of limited amounts of sub-permafrost groundwater leaking into the mine's deepest levels. It is possible however, that a component of the water may be derived from very shallow, supra-permafrost summer thaw water or from water introduced into the mine for dust damping. The water's chemistry may be influenced by chemicals introduced into the mine, e.g. lime dust.

On the 20th July 1996 at the start of sampling, the water flow was measured as a modest 0.056 l/s, but reduced during the course of sampling to 0.01 l/s. The pumping regime during sampling is not known; it is possible that sampling took place at the end of a pumping episode.

The ventilation and access tunnels emerge from the mountainside at the top of a spoil tip. The pumped water emerges at the top of the southern side of the tip. The sample of spoil leachate was taken from the northern side of this tip. It is possible that some of the leachate, particularly on the southern side of the tip, contains a component of infiltrated mine water, but but the leachate seep on the northern side (i.e. that sampled) is thought to largely consist of rainfall infiltrating the tip and thawing porewater within the tip. The sampled seepage of leachate was estimated as some 0.1 l/s, although other seepages emerged from other locations around the base of the tip. It was noted that the spoil appeared to contain a significant component of coal fragments in addition to the shaley and greenish sandstone fragments comprising the bulk of the spoil.

4.2 Sverdrupbyen

A major spoil tip, derived from the so-called Mine 1b, lies against the western mountainside of Longyeardalen, above the buildings and core store of Sverdrupbyen. The leachate from this tip runs down the hillside by a somewhat tortuous route and enters the Longyear River. The leachate emerges from a limited number of seeps from the tip, totalling possibly as much as a few l/s. That sampled appeared to be the most chemically aggressive (i.e. lowest pH) of the seeps, and had an estimated flow of some 0.25 l/s. At the point of sampling there was very little orange ferric oxyhydroxide precipitate, possibly due to the leachate being so acid. A few metres further down the channel (which the leachate forms in the spoil), on meeting another leachate stream, a classic orange ochre precipitate could be observed persisting in the bed of the leachate channel until the point of entry in the River.

The spoil itself consists of dominantly shale fragments, although with a significant component of coal. The shale fragments often have a yellow coating of presumed ferric sulphate or jarosite, while the coal fragments were observed more frequently to have a gelatinous orange ochreous coating.

5. RESULTS

The results of sampling are presented in Table 1 and are compared with a range of other mine and spoil-tip waters, derived from international literature, in Table 2.

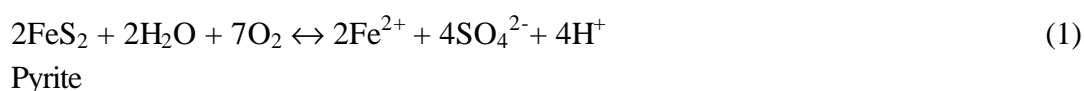
5.1 Pumped Mine Water - Mine 3

It is suspected that the sample taken may not be representative for the pumped mine water at all times. The sample has an extremely high alkalinity, which is confirmed both by field and laboratory analysis. This may be suspected to be due to the entrainment or dissolution of the lime dust used in the mine. The fact that the alkalinity was unchanged after filtration suggests, however, that the alkalinity is not due to dust particles in the water. Also, the fact that the calcium content is relatively low suggests that the alkalinity cannot totally be explained by the dissolution of lime dust. The other noteworthy feature of the water is its high content of chloride and even higher content of sodium. If this salinity were due to salt or seawater being introduced into the mine, one would expect that the chloride concentration would slightly exceed the sodium. It is thus suggested that the saline, alkaline Na-HCO₃-Cl water represents the natural quality of the deep sub-permafrost groundwater entering the deeper levels of the mine. In this respect it is not totally dissimilar to the deep groundwaters encountered in the Coal Measures of England (Downing and Howitt 1969). The water is low in sulphate, possibly indicating reducing conditions in the sub-permafrost aquifer. This is further confirmed by the high concentrations of barium. The low sulphate concentrations permit the accumulation of high concentrations of barium without the barite solubility control being exceeded. The Sr/Ca ratio (0.2) is also considerably higher than that observed in the spoil tip waters (0.017 and 0.022). This is likely to be due to the water, with its high alkalinity, reaching calcite saturation before achieving saturation with respect to strontianite or strontium sulphate, thus permitting the accumulation of strontium in the dissolved phase relative to calcium. Both the Sr and Ba phenomena have also been observed in the Coal Measures of the UK (Banks et al. 1996, Banks *in press*).

The concentrations of most trace elements are low, due to the unaggressive nature of the water, with the exception of boron (forms soluble borate anions in alkaline conditions), lithium and, as mentioned, barium and strontium.

5.2 Spoil Tips

The spoil tip at Mine 3 generates a run-off which falls in the same range for most parameters as other spoil tip leachates in Table 2, although is somewhat aggressive, with a pH of 3.73 and a concentration of aluminium of 1.8 mg/l. The concentration of Fe (1.6 mg/l) is rather low for such an aggressive water; in fact it is lower than Al. The Si concentration is also puzzlingly low (< 1 mg/l) and may be indicative of a relatively short residence time in the spoil (mine waters typically show a negative correlation of Si and many other elements with pH, indicating elevated weathering of silicate and carbonate phases at low pH - Banks et al. 1996). The sample contains elevated Zn (0.49 mg/l) and Cu (0.014 mg/l) concentrations. The chloride concentration (4.5 mg/l) can realistically be accounted for by marine salts in rainfall, although the sulphate concentration (76.6 mg/l) is clearly indicative of pyrite oxidation:



This equation implies a release of 2 moles sulphate for every mole iron. The observed molar ratio of 28:1 indicates that iron is being retained by precipitation, adsorption or ion exchange somewhere within the spoil.

The spoil tip at Sverdrupbyen again shows a chemistry which is typical for pyritiferous spoil and indicative of intense pyrite weathering, although the chemistry is more environmentally aggressive than the other waters detailed in Table 2. The pH of 2.7, iron content of 179 mg/l and sulphate concentration of 1077 mg/l indicate intense pyrite weathering. The acid conditions promote further weathering and dissolution of aluminosilicates and carbonates resulting in elevated concentrations of major cations, silica, aluminium and many "trace" components, including zinc at 1.3 mg/l, Cu at 0.17 mg/l and, interestingly, Be at 0.14 mg/l.

A sulphate : iron molar ratio of 3.5:1 again indicates that some of the iron generated by pyrite oxidation is being withheld in the spoil, though proportionately much less than at the spoil tip at Mine 3.

In both spoil tip waters, barium concentrations are relatively low (4 - 20 µg/l); in fact, one observes an inverse relationship of barium with sulphate indicating the existence of a barite solubility control. The Sr/Ca ratios are similar in both spoil waters (c. 0.02 - see 5.1) indicating congruent dissolution of minerals containing Sr and Ca in the absence of a calcite solubility control.

Both spoil tip waters exhibit high redox potentials of +420 and +481 mV

6. ISOTOPIC ANALYSES

The water samples were sent to the Norwegian Institutt for Energiforskning (IFE) as part of Göran Åberg's ongoing study of the isotopic composition of coals and mine drainage waters. They were analysed for $^{87}\text{Sr}/^{86}\text{Sr}$, yielding the results shown below in Table 3.

These results indicate that the strontium isotope composition of the deep mine water is significantly different from that of the spoil leachates. This reflects the differing evolutions of the Sr content of the waters (see above) and possibly also a foreign signature from strontium in the lime dust used in the mines. Further work is needed (including isotopic determinations of whole rock and/or mineral phases) to correctly interpret the results.

7. SPECIATION MODELLING

The code MINTEQA2 was used to carry out speciation modelling of the three waters. In the case of the spoil-tip waters, field measurements of Eh were employed to allow modelling of redox couples for the elements Fe, S, N and Mn. Both the Davies and extended Debye Huckel equations were used to estimate activity, but no significant differences were noted between the results of the two methods. The results of the modelling are shown in Tables 4 and 5 and are discussed below. They should, of course, be treated with extreme caution, bearing in mind the small size of the sample set.

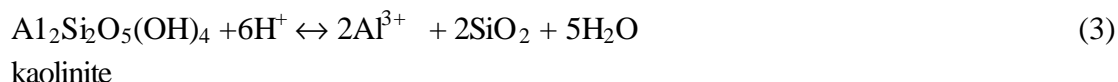
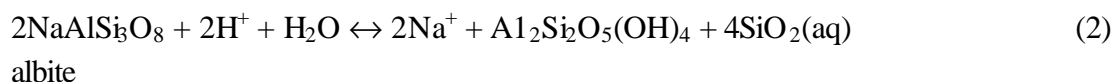
7.1 Pumped Mine Water - Mine 3

The pumped minewater from Mine 3 is relatively non-aggressive. It is oversaturated with respect to calcite and dolomite (and also strontianite), and to albite and microcline. It is, however, undersaturated with respect to siderite and with respect to anorthite. Lack of redox indicators does not permit an assessment of oxidation potential with respect to sulphide phases. The water is, as predicted, somewhat oversaturated with respect to barite.

7.2 Spoil Tip Leachates

Both the spoil tip waters are highly undersaturated with respect to pyrite, FeS and ZnS, confirming the intense sulphide oxidation occurring in these environments. They are also undersaturated, not only with respect to the feldspar phases but also with respect to the commonest clay minerals. This undersaturation suggests a mechanism for the release of the

high concentrations of major cations and aluminium observed in the spoil leachates, according to the following reactions:



The waters are undersaturated with respect to gibbsite but are only slightly undersaturated with respect to AlOH_2SO_4 . The existence of this latter phase has long been postulated in acidic, sulphate rich environments (Eriksson 1981). The modelling results, together with speciation studies of Al-rich minewaters from the UK coalfields (Banks et al. 1996), suggest that the phase may indeed be an important buffering mechanism for aluminium concentrations in mine waters.

The waters are slightly oversaturated with respect to barite, suggesting that the proposed explanation for the inverse barium / sulphate relationship (Section 5) is correct.

The leachates, especially that from Sverdrupbyen spoil tip, are undersaturated with respect to goethite, a possible explanation for why ochre deposits are not observed in the first stages of the leachate discharge (see section 4.2). The water is, however, saturated with respect to the possible phase $\text{Fe}^{\text{III}}(\text{OH})_{2.7}\text{Cl}_{0.3}$ offering a possible mechanism for iron removal from the dissolved phase in the spoil. Na-, K- and Hjarosite, phases which are often discussed in the context of an intermediate mineral reservoir for iron in mine drainage systems, are undersaturated for both spoil tip waters.

Interestingly, Table 5 indicates that the vast majority of iron in solution is in the +II rather than +III oxidation state, despite the low pH and high Eh of the waters. The table also suggests that a significant proportion of both Fe and Al may be complexed as sulphate or hydroxide complexes.

8. CONCLUSIONS

During July 1996, three sources of mine run-off were sampled from the mining complex around Longyearbyen, Svalbard: (i) Pumped discharge of minewater from Mine 3 to Bjørndalen, (ii) Run-off from a spoil tip at Mine 3 in Bjørndalen and (iii) Run-off from a spoil tip at Sverdrupbyen. One objective of the study was to obtain an indication whether the special climate of Svalbard influences the minewater hydrochemistry. The waters were in

many ways similar to waters found in coal fields of temperate regions (e.g. the UK). The pumped minewater has many features not dissimilar to deeper Coal Measures groundwaters in the UK. The spoil tip waters bear much resemblance to some of the more aggressive leachates generated by spoil tips in the UK. It is thus not possible to say that the Svalbard climate directly results in a minewater chemistry markedly differing from those observed in temperate climates.

The pumped mine water was found to be a highly alkaline, saline ($\text{Na-HCO}_3\text{-Cl}$) water with a low iron content. It is not known if this point sample is representative of pumped mine discharge at all times. Its alkaline nature may reflect the usage of large quantities of pulverised limestone in the mine to hinder explosion risk, but is regarded as being more likely related to the natural hydrochemistry of the deep, sub-permafrost water entering the deepest levels of the mine. The water contains low sulphate, high barium and high strontium, indicative of evolution in relatively reducing conditions with long residence times.

The two spoil tip leachates are acidic (pH values of 3.7 and 2.7). In particular, the Sverdrupbyen leachate contains high concentrations of iron (179 mg/l), aluminium (27.5 mg/l), sulphate (1077 mg/l), zinc (1.3 mg/l) and several other metals including beryllium at 143 $\mu\text{g/l}$. Barium shows an inverse relationship with sulphate, suggesting a barite saturation control. Although the leachates contain high levels of heavy metals, the water flux is small and recipient watercourses large, minimising the potential environmental conflict. In the UK, the main environmental problem relating to coal mine drainage is the smothering of benthic flora and fauna with iron oxyhydroxide precipitates. The recipients in the case of Svalbard are glacial meltwater rivers with extremely high and heavy bottom load transport. Such conditions are unlikely to permit the development of a benthic population of organisms.

Preliminary Sr isotope work performed at IFE is documented in this report, confirming the somewhat anomalous nature of the deep minewater. Further work is required to interpret the results meaningfully.

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Sample site	Mine water Mine 3	Spoil leachate Mine 3	Spoil leachate, <u>Sverdmphven</u>
Elements by ICP-AES (FA)			
Ca ppm	15.5	15.6	48.2
K	2.8	< 0.5	< 0.5
Na	925	3.4	18.0
Mg	3.5	4.5	48.6
Fe	< 0.01	1.6	179
Al	< 0.02	1.8	27.5
Mn	0.0043	0.402	3.2
Si	2.9	0.974	6.8
Ag ppb	< 10	< 10	< 10
B	516	< 10	46.7
Ba	3700	19.7	3.9
Be	< 1	1.6	143
Cd	< 5	< 5	< 5
Cc	< 50	< 50	73.5
CO	< 10	16.6	201
Cr	< 10	< 10	< 10
Cu	< 5	14.0	168
La	< 10	< 10	74.0
Li	600	< 5	82.4
Mo	< 10	< 10	< 10
Ni	< 20	37.4	393
P	< 100	< 100	172
Pb	< 50	< 50	< 50
Sc	< 1	< 1	27.1
Sr	3100	260	1100
Ti	< 5	< 5	< 5
V	< 5	< 5	46.6
Y	< 1	8.0	87.7
Zn	54.7	487	1300
Zr	< 5	< 5	5.1
Anions by IC (FU)			
Br ⁻ ppm	2.03	< 0.1	< 0.1
Cl ⁻	236	4.54	7.04
F ⁻	< 0.05	< 0.05	0.063
NO ₂ ⁻	< 0.05	< 0.05	< 0.05
NO ₃ ⁻	1.43	0.569	2.43
PO ₄ ³⁻	< 0.2	< 0.2	< 0.2
SO ₄ ²⁻	7.43	76.6	1077
Lab. measurements			
pH (unfiltered)	8.37		
pH (lab. Filtered)	8.39		
Alkalinity (unfiltered) meq/l	32.64		
Alkalinity (lab.filtered) meq/l	32.82		
Elec. Conductivity (unfiltered) mS/m	338		
Field Measurements (all unfiltered)			
Flow l/s	ca. 0.056	ca. 0.1	ca. 0.25
pH	8.12 - 8.20	3.73	2.70
Alkalinity meq/l	(duplicate i) 35.3 (duplicate ii) 36.9 (average) 36.1	0	0
Eh (mV)		+ 420	+ 481
Temp. °C	4.7	0.0	1.9

Table 1 Composition of the three sampled mine waters. FA implies a filtered (0.45 µm) sample, acidified in the lab. with conc. HNO₃. FU implies a filtered, unacidified sample.

Table 2. Comparison of discharge water quality from selected British and Svalbardian pumping and abandoned mines and spoil tips (after Banks et al. *in press*) – (sources; Younger 19193, Madawee 1994, Fuge et al. 1991, Lemon 1991, Bucha, 1962, Banks et al. 1996 and this report).

* The alkaline nature of this water may be partially explained by the use of limestone dust to hinder explosion in the mine, but may also be related to the potentially somewhat unusual chemistry of the deep, cold sub permafrost water entering the mine.

** The saline water derived from this spoil tip probably represents leaching of saline pore water from the spoil derived from this deep mine. Wiggering (1993) reports a similar phenomenon from the Ruhr area of Gennny.

	Discharge	pH	TDS	Fe	Al	Mn	Zn	Cu	Cl-	SO4=
	l/s		mg/l	mg/l	Mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Pumping coal mines										
Pumping coal mines										
Kibblesworth (Durham)	740	7.1	3185	3.63			.0056			690
Nicholson (Durham)	90	7.1	3100	5.8			0.034			1170
Kimbleworth (Durham)	105	7.3	1800	5.0			0.030			380
Tilmanstone (Kent)		7.7	2107	25					795	404
Moorgreen Piper (E.Midlands)										
Longyearbyen Mine 3 (Svalbard)*	c. 0.06	8.2		<0.01	<0.02	0.004	0.055	<0.005	236	7.4
Abandoned coal mines										
Stony Heap (Durham)		6.3	630	2.2						148
Dunston (Chesterfield)	c. 20	6.3		10.6	<0.045	1.26	<0.007	<0.007	26	210
R. Hipper Discharge (Chesterfield)	c. 0.75	3.6		101.3	17.3	4.02	0.221	0.007	29	1044
Duke's Level, Buxton (Derbyshire)	c. 20	6.3		4.9	0.078	0.36	0.048	0.005	18	83
Ynysarwed (South Wales)	c. 35	4.2		180	<0.5	6.1	0.061		32	1554
Hapton (Lancashire)	c. 9	7.9		0.097	<0.01	0.138	<0.005	0.0007	21	176
Coal spoil tips										
Crook (Durham)		3.5	1000	70						810
Quaking Housees (Durham)		4.1	2314	15						1358
Oatlands (Cumbria)		5.5		287	0.97	5.2	0.05	<0.007		146
Thurcroft (S. Yorkshire)**		6.8		18.6	<0.045	2.0	<0.007		511	1327
Longyearbyen Mine 3 (Svalbard)	c. 0.1	3.7		1.6	1.8	0.40	0.49	0.014	4.5	77
Sverdrupbyen Mine 1 (Svalbard)	c. 0.25	2.7		179	27.3	3.2	1.3	0.168	7.0	1077
Metal Mines										
Cae Coch (Wales, pyrite)		2.5		1460	84.21	3.05	0.94	0.16		51110
Cwm Rheidol (Wales – Pb, Cu, Zn)		2.8-3.0			13.9-20.1		38 - 72	0.03-0.068		441-846
Allen Hill Spaw (Matlock, Derbyshire)	c. 0.15 l/s	6.5		14.9	0.132	2.10	0.029		82.6	124
Metal Mine spoil tips										
Cwm Rheidol (Wales – Pb, Cu, Zn)		2.6-2.7			104-128		577-978	1.2-9.35		791
E.C. limits for drinking water		6.2-8.5 ¹		0.05 ¹ 0.2 ²			0.10 ³			25 ¹ 250 ²

¹ Guide Level

² Minimum Allowable Concentration

³ At discharge from pump or treatment plant

Sample	$^{87}\text{Sr}/^{86}\text{Sr}$
Pumped minewater - Mine 3 (FA)	0.711285 (filtered and acidified in lab = FA)
Pumped minewater - Mine 3	0.711272 (not filtered or acidified)
Spoil tip leachate - Mine 3 (FA)	0.709913
Spoil tip leachate - Sverdrupbyen (FA)	0.710746

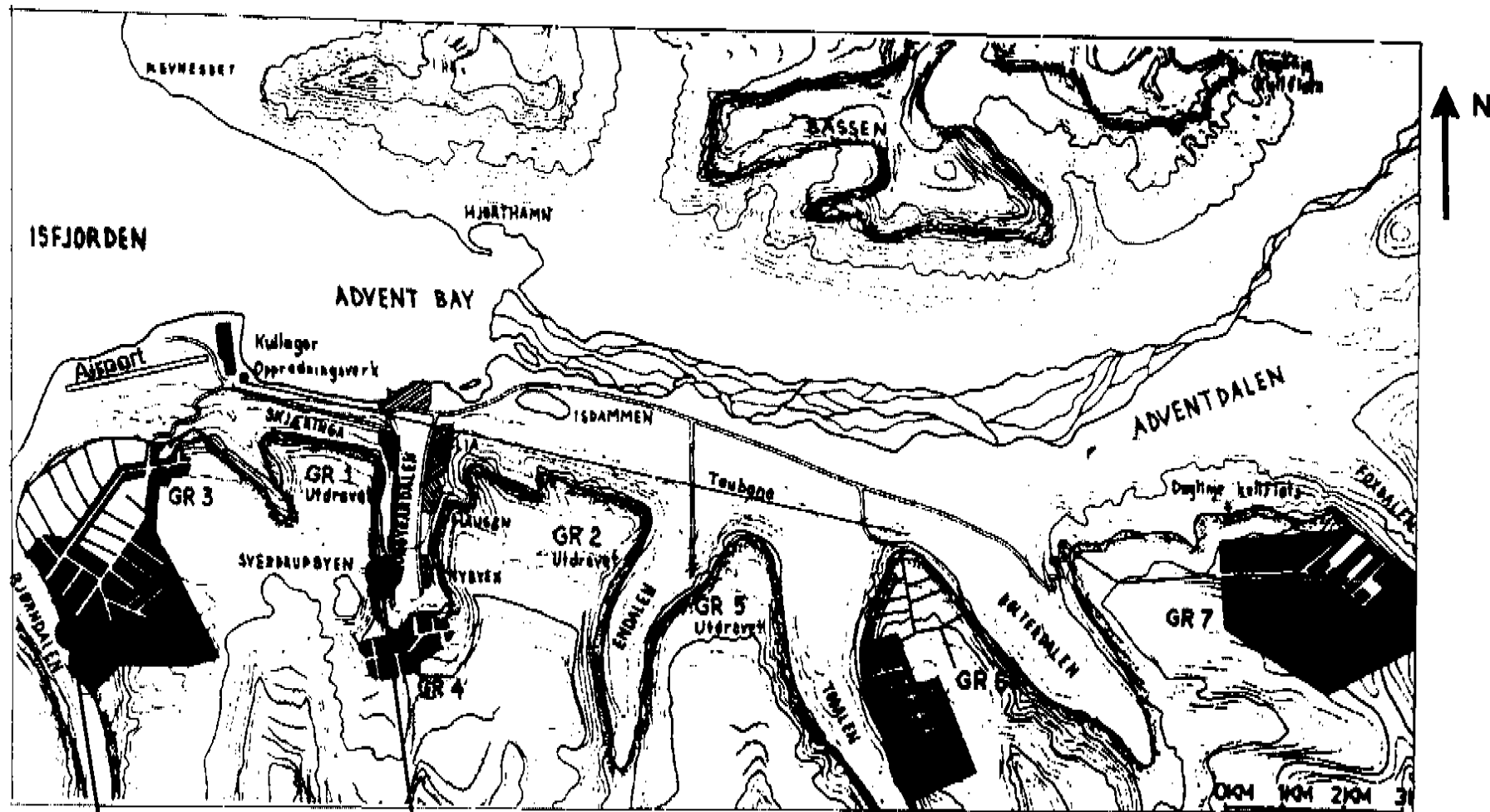
Table 3. Strontium isotope ratios measured on the mine waters by IFE. FA = field-filtered and laboratory acidified sample.

Phase	Pumped mine water Mine 3	Spoil tip leachate Mine 3	Spoil tip leachate Mine 1b
Ion balance error			
Before speciation	1.6%	1.4%	9.1%
After speciation	1.6%	2.6%	8.6%
SATURATION INDICES			
Barite	+0.95	+0.21	+0.18
Calcite	+0.67		
Dolomite	+0.66		
Gypsum	-3.40	-1.91	-0.83
Magnesite	-0.48		
Rhodochrosite	-1.14		
Siderite	-1.04		
Strontianite	+0.51		
Witherite	-0.21		
Chalcedony	-0.21	-0.63	+0.20
Quartz	+0.36	-0.04	+0.78
Albite	+0.75	-10.59	-10.86
Anorthite	-5.57	-21.81	-26.69
Microcline	+0.25	-9.64	-10.66
Kaolinite	+3.50	-3.6j	-6.87
Halloysite	-0.01	-7.22	-10.41
Gibbsite	-0.45	-3.62	-6.05
Al(OH) ₃	-8.02	-0.79	-0.40
Alunite	-7.47	-1.26	-4.12
Pyrite FeS ₂		-84.69	-80.28
FeS		-58.13	-56.06
Sphalerite		-50.47	-50.13
Ferrihydrite		-4.32	-4.50
Fe(OH) _{2.7} Cl _{0.3}		+1.32	+1.49
Goethite		-0.90	-1.00
Haematite		+3.09	+2.89
Na-Jarosite		-11.02	-5.85
K-Jarosite		-8.46	-4.03
H-Jarosite		-11.27	-5.63

Table 4. Ion balances and saturation indices with respect to selected mineral phases estimated with the thermodynamic geochemical modelling code MINTQA2. For modelling the Davies algorithm was used for calculating activity (a check revealed that use of the extended DebyeHuckel equation does not yield significantly different results). For the pumped mine water, no redox couple was activated and all Fe and Mn were assigned to states Fe²⁺ and Mn²⁺. For parameters below the detection limit (particularly Al and K), the concentration was set to half the detection limit: mineral phases affected by this assumption are shown in *italics*.

	Pumped mine water Mine 3	Spoil tip leachate Mine 3	Spoil tip leachate Mine 1b
Oxidation state of Fe Fe ^{II} Fe ^{III}	Assumed 100 %	99.993 % 0.007 %	99.98 % 0.02 %
Conc. Fe ^{II} (mole/l) Speciation of Fe ^{II}	8.97 E-8 <i>99.3 % as Fe²⁺</i>	2.87 E-5 95.3 % as Fe ²⁺ 4.7 % as FeSO ₄ (aq)	3.21 E-3 79.5 % as Fe ²⁺ 20.5 % as FeSO ₄ (aq)
Conc. Fe ^{III} (mole/l) Speciation of Fe ^{III}		1.89 E-9 2.2 % as Fe ³⁺ 11.3 % as FeOH ²⁺ 3.6 % as FeSO ₄ ⁺ 83.0 % as Fe(OH) ₂ ⁺	6.72 E-7 12.5 % as Fe ³⁺ 4.1 % as FeOH ²⁺ 72.3 % as FeSO ₄ ⁺ 1.8 % as Fe(OH) ₂ ⁺ 9.2 % as Fe(SO ₄) ₂ ⁻
Speciation of Al ^{III}	7.1 % as Al(OH) ₄ ⁻ 92.3 % as Al(OH) ₃ (aq)	77.4 % as Al ³⁺ 21.1 % as AlSO ₄ ⁺	44.6 % as Al ³⁺ 41.7 % as AlSO ₄ ⁺ 13.3 % as Al(SO ₄) ₂ ⁻
Speciation of B	93.6 % as H ₃ BO ₃ 6.4 % as H ₂ BO ₃ ⁻		100 % as H ₃ BO ₃

Table 5. Speciation of dissolved Fe, Al and B as indicated by modelling using the code MINTEQA2. For modelling the Davies algorithm was used for calculating activity (a check revealed that use of the extended Debye-Huckel equation does not yield significantly different results). For the pumped mine water, no redox couple was activated and all Fe and Mn were assigned to states Fe^{II} and Mn^{II}. For parameters below the detection limit (particularly Al and K), the concentration was set to half the detection limit: species affected by this assumption are shown in *italics*.



Mine 1b, Sverdrupbyen, spoil tip

Mine 3, Bjørndalen, pumped minewater discharge and spoil tip

Oversikt over gruvene til Store Norske Spitsbergen Kulkompani A/S. De sorte feltene markerer kull som står igjen. Mektigheten er som regel så lav at kulla ikke er driververdig.

Fra boka «Store Norske 75 år»

Figure 1. Map of the area around Longyearbyen, showing the sample locations, modified after Amundsen (1994)

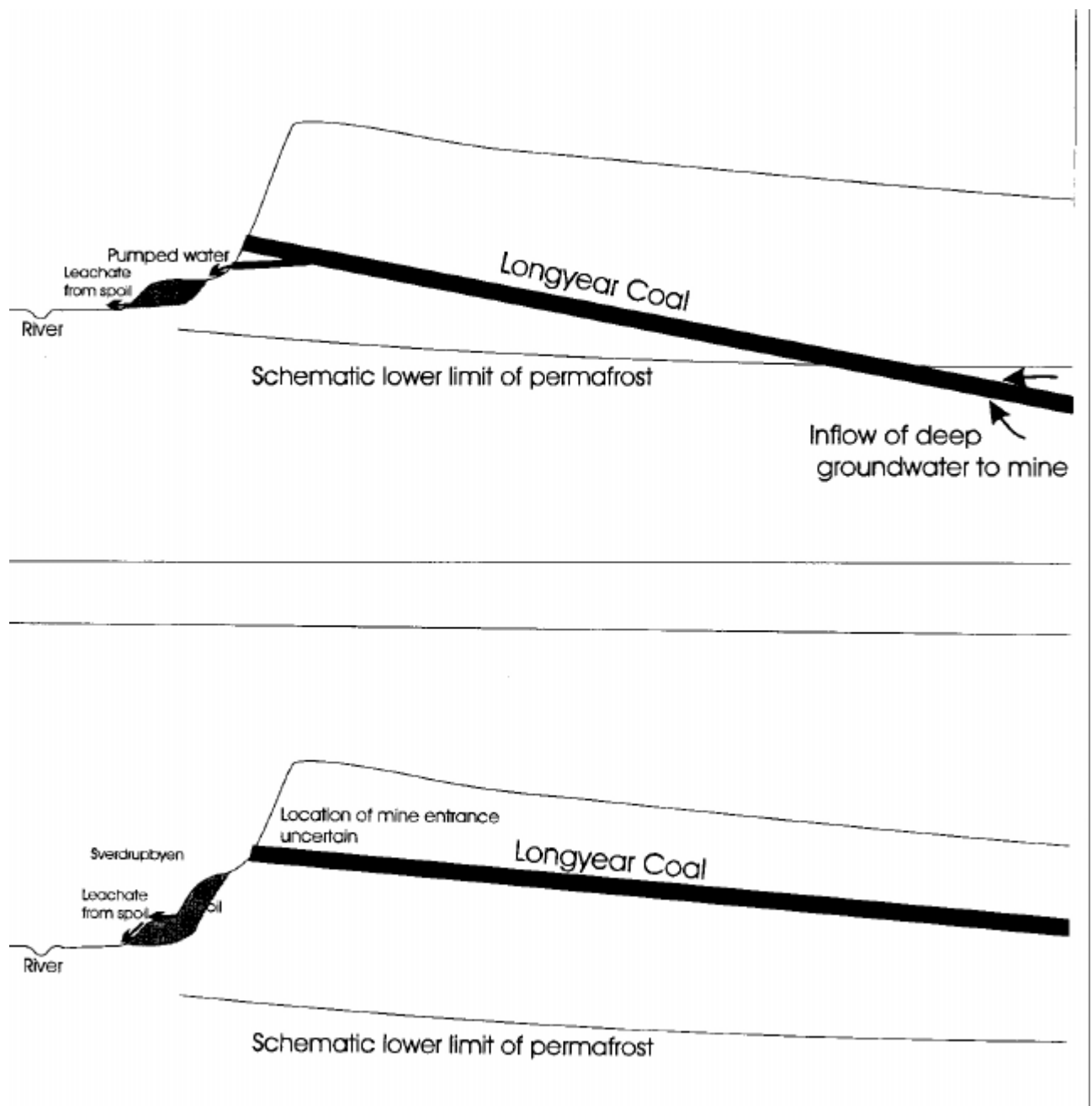


Figure 2. Highly schematic cross-sections of likely hydrogeological situation at (a) Mine 3, where deep mine water leakages are pumped out in the vicinity of the spoil tip and (b) Sverdrupbyen, where the mine is not pumped. The mine structure shown is based on the most likely interpretation of information available to the author



Figure 3a. Bjørndalen, looking south. The flat-topped spoil heap where samples were taken from Mine 3 is seen in the background.

Figure 3b. The minewater discharge point from Mine 3 in Bjørndalen.



Figure 3c. Leachate from the spoil tip at Mine 3 in Bjørndalen. The sample point was at the head of the seep on the left of the picture.



Figure 3d. The old mining area at Sverdrupbyen. The leachate sampled is derived from the spoil tip to the left of the yellow building.