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Chemical and isotopic composition of groundwaters and their seasonal variability at the Osamu Utsumi mine and Morro do Ferro analogue study sites, Poços de Caldas, Brazil

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1990

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Poços de Caldas Report No. 6

Chemical and isotopic composition of groundwaters and their seasonal variability at the Osamu Utsumi mine and Morro do Ferro analogue study sites, Poços de Caldas, Brazil

An international project with the participation of Brazil, Sweden (SKB), Switzerland (NAGRA), United Kingdom (UK DOE) and USA (US DOE). The project is managed by SKB, Swedish Nuclear Fuel and Waste Management Co.

CHEMICAL AND ISOTOPIC COMPOSITION OF GROUNDWATERS AND THEIR SEASONAL VARIABILITY AT THE OSAMU UTSUMI MINE AND MORRO DO FERRO ANALOGUE STUDY SITES, POÇOS DE CALDAS, BRAZIL

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Chemical and isotopic composition of groundwaters and their seasonal variability at the Osamu Utsumi and Morro do Ferro analogue study sites, Poços de Caldas, Brazil.

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Abstract

Groundwaters and a few surface waters were collected over a period of 3 years from two natural analogue sites near Poços de Caldas, Brazil: the Osamu Utsumi uranium mine and the Morro do Ferro thorium/rare-earth deposit. These were analysed for major constituents, several trace elements, tritium, deuterium and ^{18}O*, to provide hydrochemical data for the modelling objectives as defined within the natural analogue study programme. The groundwaters are a K-Fe-*SO_4 *type, which classifies them as a highly unusual composition related to the weathering of a hydrothermally altered, mineralised complex of volcanic to sub-volcanic phonolites.*

A subset of selected constituents (Fe(II), Fe(total), SO_4*, pH, Eh, alkalinity, F and U) was monitored to gain detailed information on the seasonal variability. Seasonal patterns were only apparent from the very shallow groundwater data, but a trend of continuously increasing dissolved solids for the furthest down-gradient sampling point in deep groundwater indicates a growing plume of water affected by pyrite oxidation but without the residual acidity. Tritium and stable isotope measurements indicate that all groundwaters are of meteoric origin and are not affected significantly by evaporation or by water-rock interactions. Recharging groundwaters at both study sites demonstrate infiltration of water of less than about 35 years in age, whereas deep groundwaters are below 1 TU (tritium unit) but still contain detectable tritium in most cases. These deeper groundwaters may be interpreted as being 35-60 or more years in age, resulting mainly from an admixture of younger with older groundwaters and/or indicating the influence of subsurface-produced tritium.*

Zusammenfassung

Während drei Jahren wurden an den zwei Untersuchungsgeländen für natürliche Analoga, der Osamu Utsumi Uranmine und dem Morro do Ferro Thorium/Seltene Erden Lager von Poços de Caldas, Brasilien, Grundwasser- und teilweise auch Oberflächenwasserproben entnommen. Diese Proben wurden auf ihren Gehalt an Hauptbestandteilen, verschiedenen Spurenelementen, Tritium, Deuterium und ^{18}O *untersucht. Ziel dieser Untersuchungen war es, hydrochemische Daten für Modellierverfahren, wie sie im Rahmen natürlicher Analogstudien definiert werden, bereitzustellen. Die Grundwasserproben sind vom Typ K-Fe-*SO_4, *und damit von höchst ungewöhnlicher Zusammensetzung auf die Verwitterung eines hydrothermal veränderten, mineralisierten Komplexes von vulkanischen bis sub-vulkanischen Phonoliten.*

Eine Auswahl von Lösungsparametern wie (Fe[II], Fe[total], SO_4, *pH, Eh, Alkalinität, F und U) wurden verfolgt, um Aufschluss über ihr saisonal bedingtes Verhalten zu erlangen. Saisonale Verhaltensmuster waren nur aus den Daten von oberflächennahem Grundwasser ersichtlich; dagegen zeigt das Tiefengrundwasser aus der tiefstgelegenen Probenstelle eine kontinuierliche Zunahme an gelösten Feststoffen und deutet damit auf eine wachsende Ausbreitungszone von Grundwasser, das durch Pyritoxidation verändert aber membralisiert wurde. Tritium, Deuterium und* ^{18}O*-Messungen zeigen, dass alle Grundwässer meteorischen Ursprungs sind und unbedeutend beeinflusst werden durch Verdunstung oder durch Wasser/Gestein-Wechselwirkungen. Grundwässer an beiden Untersuchungsstellen lassen auf Infiltration vor weniger als ungefähr 35 Jahren schliessen, während Tiefengrundwässer unter 1 TU liegen aber in den meisten Fällen noch nachweisbare Spuren von Tritium enthalten. Diese Tiefengrundwässer sind wahrscheinlich 35 - 60 oder mehr Jahre alt und resultieren meist aus einer Mischung von jüngerem mit älterem Grundwasser und/oder weisen auf den Einfluss von unterirdisch produziertem Tritium hin.*

Résumé

Des échantillons d'eaux souterraines et de quelques eaux de surface ont été prélevés durant une période de 3 années sur deux sites d'étude d'analogies naturelles proches de Poços de Caldas au Brésil: la mine d'uranium d'Osamu Utsumi et le gisement de thorium/terres rares de Morro do Ferro. Ces eaux ont été analysées pour déterminer ses constituants principaux, divers éléments traces, le tritium, deuterium et ^{18}O, afin de fournir les données hydrochimiques nécessaires pour les objectifs de modélisation fixés par le programme d'étude des analogies naturelles. Les eaux souterraines sont du type K-Fe-SO_4. Ce type fort inhabituel est dû à l'érosion d'un massif de phonolites volcaniques et subvolcanique ayant subi une phase hydrothermale.

Un sous-ensemble d'une sélection de paramètres (Fe[II], Fe[total], SO_4, pH, Eh, alcalinité, F et U) a été suivi afin d'obtenir des informations quant aux variations saisonnières. Des effets saisonniers ne sont apparus que dans d'aquifères peu profonds. On note par contre une tendance à une augmentation régulière de la concentration en solides dissous dans les eaux souterraines les plus profondes, ce qui démontre l'existence d'un panache croissant d'eau affectée par l'oxydation de la pyrite, mais sans acidité résiduelle. Les mesures de tritium et d'isotopes stables montrent que toutes les eaux souterraines sont d'origine météorique et qu'elles ne sont pas affectées de façon significative par l'évaporation ou une interaction eau/roche. L'alimentation des eaux souterraines des deux sites révèle des eaux d'infiltration d'un âge inférieur à 35 ans environ, alors que les eaux souterraines profondes présentent moins de 1 TU (unité tritium) mais contiennent néanmoins dans la plupart des cas des quantités de tritium détectables. On peut interpréter ces eaux souterraines plus profondes comme ayant un âge de 35 à 60 ans ou plus, résultant principalement d'eaux jeunes mélange des eaux souterraines plus anciennes et/ou indiquant l'influence d'une production souterraine de tritium.

Preface

The Poços de Caldas Project was designed to study processes occurring in a natural environment which contains many features of relevance for the safety assessment of radioactive waste disposal. The study area, in the State of Minas Gerais, Brazil, is a region of high natural radioactivity associated with volcanic rocks, geothermal springs and uranium ore deposits. It contains two sites of particular interest on which the project work was focussed: the Osamu Utsumi uranium mine and the Morro do Ferro thorium/rare-earth ore body. The first site is notable in particular for the prominent redox fronts contained in the rock, while Morro do Ferro was already well-known as one of the most naturally radioactive locations on the surface of the Earth, owing to the high thorium ore grade and the shallow, localised nature of the deposit.

The features displayed by these two sites presented the opportunity to study a number of issues of concern in repository performance assessment. The four objectives set after the first-year feasibility study were:

1. Testing of equilibrium thermodynamic codes and their associated databases used to evaluate rock/water interactions and solubility/speciation of elements.
2. Determining interactions of natural groundwater colloids with radionuclides and mineral surfaces, with emphasis on their role in radionuclide transport processes.
3. Producing a model of the evolution and movement of redox fronts, with the additional aim of understanding long-term, large-scale movements of trace elements and rare-earths over the front (including, if possible, natural Pu and Tc).
4. Modelling migration of rare-earths (REE) and U-Th series radionuclides during hydrothermal activity similar to that anticipated in the very near-field of some spent-fuel repositories.

The project ran for three and a half years from June 1986 until December 1989 under the joint sponsorship of SKB (Sweden), NAGRA (Switzerland), the Department of the Environment (UK) and the Department of Energy (USA), with considerable support from a number of organisations in Brazil, notably Nuclebrás (now Urânio do Brasil). The first-year feasibility study was followed by two and a half years of data collection and interpretation, focussed on the four objectives above.

This report is one of a series of 15, summarising the technical aspects of the work and presenting the background data. A complete list of reports is given below. Those in series A present data and interpretations of the sites, while those in series B present the results of modelling the data with performance assessment objectives in mind. The main findings of the project are presented in a separate summary (no. 15).

The work presented in this report is a compilation of hydrochemical data to: a) characterise the groundwaters, b) appraise the seasonal influences of precipitation and c) provide representative datasets to assess geochemical models.

Poços de Caldas Project Report Series

Series A: Data, Descriptive, Interpretation

Report No.	Topic	Authors (Lead in Capitals)
1.	The regional geology, mineralogy and geochemistry of the Poços de Caldas alkaline caldera complex, Minas Gerais, Brazil.	SCHORSCHER, Shea.
2.	Mineralogy, petrology and geochemistry of the Poços de Caldas analogue study sites, Minas Gerais, Brazil. I: Osamu Utsumi uranium mine.	WABER, Schorscher, Peters.
3.	Mineralogy, petrology and geochemistry of the Poços de Caldas analogue study sites, Minas Gerais, Brazil. II: Morro do Ferro.	WABER.
4.	Isotopic geochemical characterization of selected nepheline syenites and phonolites from the Poços de Caldas alkaline complex, Minas Gerais, Brazil.	SHEA.
5.	Geomorphological and hydrogeological features of the Poços de Caldas caldera and the Osamu Utsumi mine and Morro do Ferro analogue study sites, Brazil.	HOLMES, Pitty, Noy.
6.	Chemical and isotopic composition of groundwaters and their seasonal variability at the Osamu Utsumi and Morro do Ferro analogue study sites, Poços de Caldas, Brazil.	NORDSTROM, Smellie, Wolf.
7.	Natural radionuclide and stable element studies of rock samples from the Osamu Utsumi mine and Morro do Ferro analogue study sites, Poços de Caldas, Brazil.	MacKENZIE, Scott, Linsalata, Miekeley, Osmond, Curtis.
8.	Natural series radionuclide and rare-earth element geochemistry of waters from the Osamu Utsumi mine and Morro do Ferro analogue study sites, Poços de Caldas, Brazil.	MIEKELEY, Coutinho de Jesus, Porto da Silveira, Linsalata, Morse, Osmond.

Report No.	Topic	Authors (Lead in Capitals)
9.	Chemical and physical characterisation of suspended particles and colloids in waters from the Osamu Utsumi mine and Morro do Ferro analogue study sites, Poços de Caldas, Brazil.	MIEKELEY, Coutinho de Jesus, Porto da Silveira, Degueldre.
10.	Microbiological analysis at the Osamu Utsumi mine and Morro do Ferro analogue study sites, Poços de Caldas, Brazil.	WEST, Vialta, McKinley.

Series B: Predictive Modelling and Performance Assessment

11.	Testing of geochemical models in the Poços de Caldas analogue study.	BRUNO, Cross, Eikenberg, McKinley, Read, Sandino, Sellin.
12.	Testing models of redox front migration and geochemistry at the Osamu Utsumi mine and Morro do Ferro analogue study sites, Poços de Caldas, Brazil.	Ed: McKINLEY, Cross, Haworth, Lichtner, MacKenzie, Moreno, Neretnieks, Nordstrom, Read, Romero, Scott, Sharland, Tweed.
13.	Near-field high-temperature transport: Evidence from the genesis of the Osamu Utsumi uranium mine, Poços de Caldas alkaline complex, Brazil.	CATHLES, Shea.
14.	Geochemical modelling of water-rock interactions at the Osamu Utsumi mine and Morro do Ferro analogue study sites, Poços de Caldas, Brazil.	NORDSTROM, Puigdomènech, McNutt.

Summary Report

15.	The Poços de Caldas Project: Summary and implications for radioactive waste management.	CHAPMAN, McKinley, Shea, Smellie.

Contents

1. Introduction

The Poços de Caldas Natural Analogue Project was initiated to determine and assess the hydrobiogeochemical processes that affect the mobility of naturally-occurring radionuclides in crystalline bedrock comprising both oxidised, weathered material and reduced unweathered material. A fundamental aspect of the investigations was to determine the chemical and isotopic composition of the groundwaters at the Osamu Utsumi mine and Morro do Ferro sites. The geology, mineralogy and petrology of these sites is described by Schorscher and Shea; Waber *et al.*; Waber and Shea (this report series; Reps. 1–4). Groundwaters were obtained from boreholes located near points of recharge and discharge so that changes in chemical composition could be assessed as a function of residence time along a flow-path.

The main objective of the hydrochemical investigations was to obtain representative chemical analyses of the groundwaters for (1) classifying the chemical types of groundwaters that characterise the sites, (2) appraising the influence of seasonal precipitation on groundwater chemistry and (3) providing basic chemical data that can be used to assess geochemical models.

This report contains the raw chemical analyses obtained from laboratories in Brazil, the United Kingdom and the United States, as well as the final selected values from inter-laboratory comparisons. Monitoring data on Fe(II), Fe(total), SO_4, pH, Eh, alkalinity, F, U and rainfall are provided in the form of time plots to show the seasonal trends. The discussion contains a description of how the samples were collected and analysed, how final values were selected, the types of groundwaters and the seasonal effects.

2. Field locations and borehole descriptions

The groundwater sampling locations are indicated in Figures 1-3. At the Osamu Utsumi mine (Figs. 1 and 2), boreholes F1, F2, F3 and F5 (mine locations respectively 9-1WC11, 9-1VC24, 9-1NH47 and MI55) were positioned at different depths along the general hydraulic gradient which approximates the old valley floor profile. Boreholes F1 at 125.71 m depth, F2 at 60 m depth, F3 at 77.6 m depth and F5 at 300 m depth were respectively positioned so as to intercept groundwaters of deep to intermediate origin. Some limited use was also made of the shaft (40 m depth) located adjacent to F3 and F5 and much further down-gradient from F1 and F2.

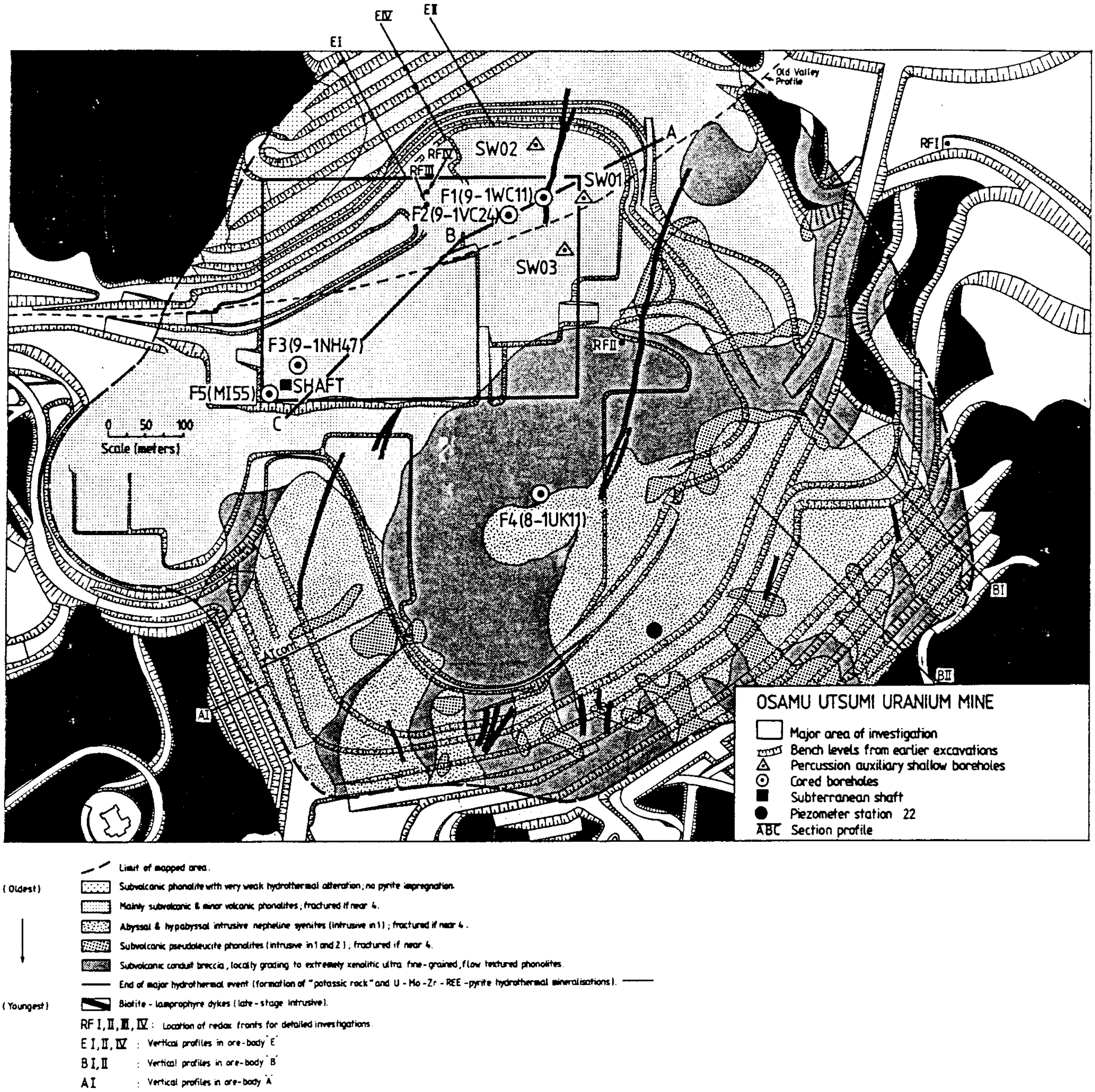

Figure 1. Osamu Utsumi mine showing the main geological subdivisions, the borehole locations, the groundwater sampling points and the surface exposure rock sampling profiles.

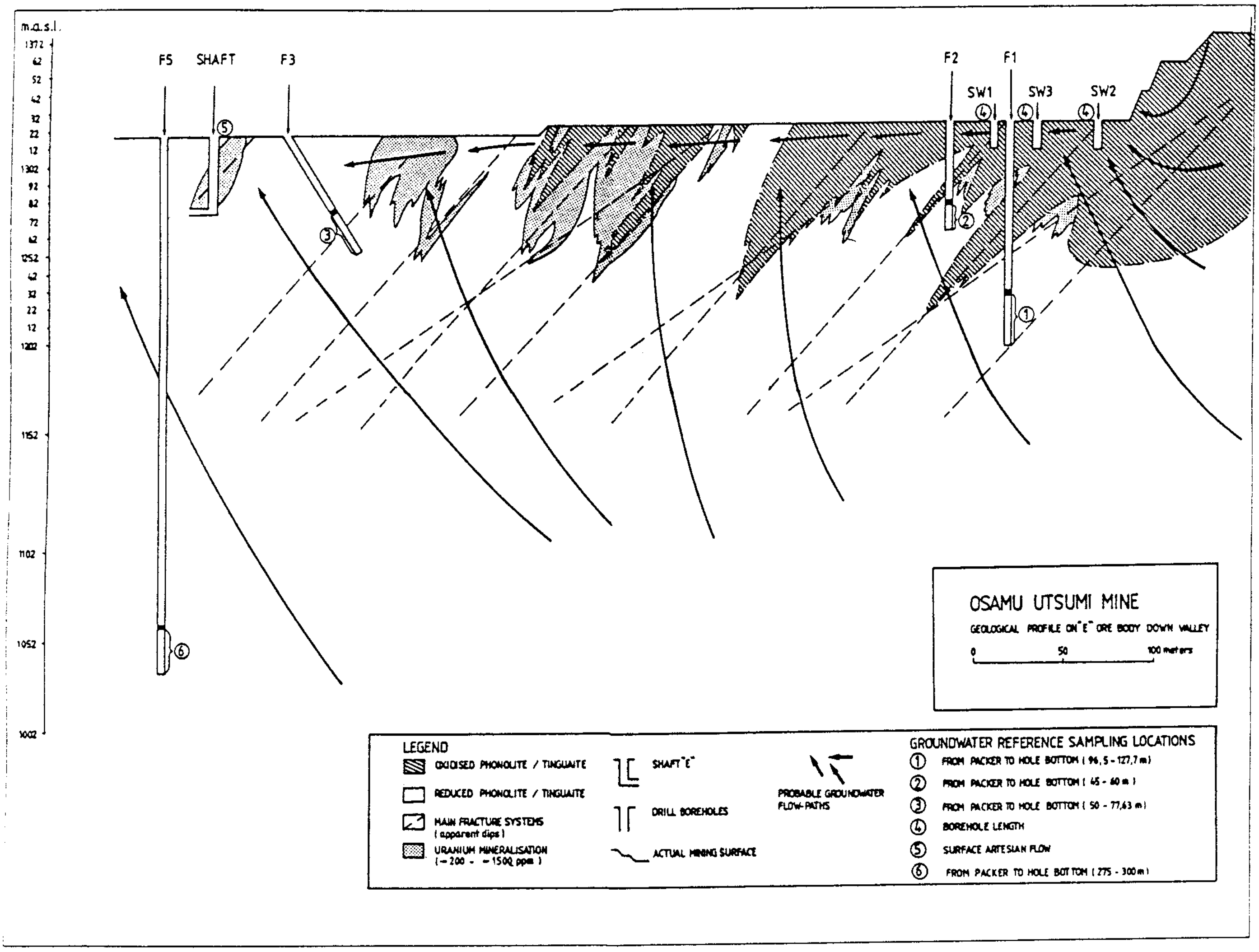

Figure 2. Cross-section of the Osamu Utsumi mine (section ABC; Fig. 1) showing borehole locations, redox fronts, mineralised zones, groundwater reference sampling points and general direction of groundwater flow.

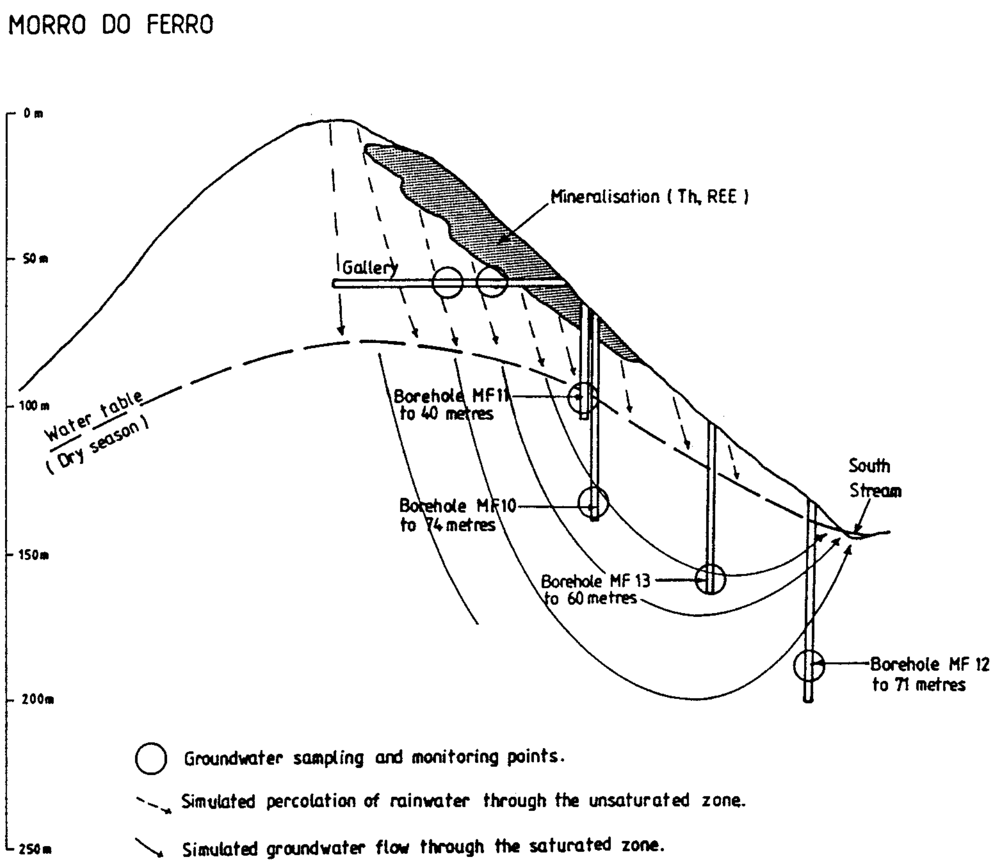

Figure 3. Cross-section of Morro do Ferro showing the borehole locations in relation to the mineralisation and the simulated groundwater flow gradients.

The nature of the near-surface, shallow groundwater was obtained from sampling three auxiliary boreholes (10–15 m in depth): SW01 and SW02 characterised by oxidised, non-mineralised bedrock and borehole SW03 located in a reduced, mineralised bedrock environment. Surface water was collected from a supply dam adjacent to the mine complex. Another reference sampling point, chosen to gauge the recharge groundwaters entering from the mine periphery, is represented by piezometer station 22 (Fig. 1) which is artesian in nature.

At Morro do Ferro (Fig. 3) four sampling points exist, all located within the same zone of magnetite breccia (contained by two massive magnetite dykes) which is considered to represent the most hydraulically conductive part of the mountain. This ensures that the same groundwater flow gradient is intercepted by all four sampling points.

Boreholes MF10 and MF11 are located at the entrance of the gallery; MF10 at 74 m collects groundwater at approx. 40 mbgl (metres below groundwater level) and MF11 at 40 m samples groundwater near the top of the water-table (approx. 10 mbgl). Down-gradient, near the south stream, borehole MF12 at 71 m collects groundwater at approx. 65 mbgl. MF13 was drilled up-gradient from MF12, but due to difficulties with borehole completion it is contaminated with recharge water.

Although emphasis is being placed on samples from the drilled boreholes, other localities within and outside Morro do Ferro and the Osamu Utsumi mine have also been sampled to achieve a wider perspective for groundwater interpretation. These localities include surface streams, lakes and seepage areas.

3. Sampling and analytical protocols

3.1. Sampling protocol

Two sampling programmes were initiated:

(1) approximately year-round weekly sampling for selected constituents (Fe(II), Fe(total), pH, Eh, SO_4, HCO_3, U, F). Later in the programme Na, K, DO and COD were added.

(2) seasonal sampling four times a year (wet and dry seasons and transitional periods) for complete major and trace element analyses. Additional samples for colloid and microbiological studies were collected in parallel.

During rotary-drilling operations there is always the possibility of groundwater contamination resulting from the flushing fluid and later, when the borehole is complete, from open-hole effects. Contamination and excess oxidation influencing an otherwise reducing groundwater were minimised by transporting artesian groundwater expected to be of a similarly reducing character by tanker from the old saturated subterranean gallery system in the mine (i.e. the shaft sampling location) and using it as a flushing medium during drilling. Initially the water was kept under nitrogen in the tanker, but subsequent periodic Eh measurements indicated that this was not necessary because of the very slow rate of oxidation. To keep any possible effects to a minimum, the tanker was emptied of residual water and refilled twice daily. To minimise open-hole effects, all boreholes (with the exception of the shallow boreholes SW01-SW03) were completed as soon as the geophysical logging and hydraulic testing had been successfully carried out.

At Morro do Ferro, borehole MF10 was initially drilled to 60 m employing a simple dry-pushing method using a short barrel (50 cm in length); the final 14 m were water-flush-drilled. Boreholes MF11 and MF13 were drilled to 40 m and 60 m respectively without water-flushing. Borehole MF12 was initially rotary-drilled to 38.64 m using mud-flushing, and then to its maximum depth of 71 m using water-flushing. Unfortunately, because of flooding at the Osamu Utsumi mine during the drilling of these holes, access to the subterranean gallery system to pump the artesian water for flushing purposes at Morro do Ferro was not possible. Water was therefore collected from a surface-accumulated dam situated at the periphery of the mine and transported to the drilling site. This water was oxidising and some animal-derived nitrate contamination was also detected. However, it was felt that the groundwater flow through Morro do Ferro was sufficiently rapid to have flushed out the holes after some weeks.

With the exception of the shaft and piezometer station 22 (which are continuously artesian) and, to some extent, borehole F1 (which was artesian from November 1986 to June 1987), pumping was necessary to sample groundwaters. This may have been a source of problems because the borehole water remained static between sampling campaigns and changes in composition could have been expected. Controlled pumping experiments conducted at the two sites established an optimum time of 2 hours before the groundwater was considered to be representative, and thereby suitable for sampling (Table I). This was also confirmed by groundwater monitoring using the flow-through cell unit.

TABLE I

Variation in groundwater composition during pumping tests from boreholes F1 and F2, Osamu Utsumi mine, Poços de Caldas.

Time (mins)	HCO_3 (mg/L)	SO_4 (mg/L)	Fe^{2+} (mg/L)	Fe(tot) (mg/L)	pH
Borehole F1					
0	12.7	15.0	1.10	1.24	5.76
5	9.89	15.0	1.21	1.28	5.56
30	9.89	15.0	1.27	1.32	5.59
30	9.28	16.8	1.16	1.22	5.62
Borehole F2					
0	13.4	17.4	0.57	0.63	5.66
8	12.7	19.6	1.00	1.11	5.74
25	12.7	16.0	1.11	1.19	5.74
30	12.7	14.6	1.11	1.18	5.77
30	12.7	16.0	1.10	1.16	5.81
105	15.5	15.0	0.99	1.04	6.06

Analysis carried out at Urânio do Brasil, Poços de Caldas.

Routine sampling was carried out twice-weekly at the mine and weekly at Morro do Ferro. After ensuring a representative groundwater composition (2 hours pumping and pH and Eh monitoring using a portable unit) and on-site filtering (0.45 μm) and preservation (if necessary) with HCl, the samples were transported directly to the laboratory at the mine complex.

Monitoring of the groundwaters was carried out during a 3–5 day period, alternating between all boreholes. Using a flow-through cell unit, pH, Eh (platinum and carbon electrodes), dissolved oxygen, sulphide content, temperature and conductivity were measured. A groundwater flow-rate of 250–400 ml/min was maintained throughout the monitoring period and chemical stability of the water was usually achieved after 2–3 hours.

Although the duration of monitoring at each borehole was on average 4 days, extended monitoring was carried out if the groundwater chemistry showed any major perturbations that might be of importance, e.g. any response to heavy rainfall, etc.

In addition to the routine sampling and monitoring, large groundwater samples were collected from each location on a seasonal basis. These were filtered and/or preserved within 3–4 hours of collection. Depending on the requirements of the analysis, samples were distributed as unfiltered and unpreserved (i.e. for stable isotope and tritium determinations), filtered through 0.45 μm membranes and unpreserved (i.e. for major ions and cations), filtered and preserved with HCl (1%) conc. (i.e. for trace element determinations and Fe(II/III) determinations) and filtered, preserved and concentrated by evaporation (i.e. for the determination of uranium, its daughter decay products, thorium and rare-earth elements (REEs).

Filtering, concentration and general handling of the groundwater samples can influence the trace element contents. For filtering purposes a plastic (plexiglass) barrel filter unit was used.

The sampled groundwaters were collected, stored and transported in plastic containers. These were normally acid-washed and rinsed at least three times with deionised water. Care was taken to minimise the number of times waters were transferred from one container to another, which may have led to a steady depletion of those trace elements which are likely to adhere to the sides of the container, e.g. REEs.

For REEs, U, Th and some Cl, Br and Zr analyses, preconcentration of 40 litres of groundwater to 500 ml was needed. Due to the high Si content, especially in the mine waters, silica precipitation occurs on evaporation. Whether co-precipitation of other groundwater constituents also occurs is largely unknown; as a precaution Si was redissolved for the determination of REEs, U and Th.

3.2. Analytical protocol

The elements analysed, the responsible laboratory, the levels of detection and the sample preparation required are listed in Table II. A few samples were sent to a U.S.G.S. research laboratory in Menlo Park, California, for selected major and trace element determinations.

TABLE II

Analytical protocol for the Poços de Caldas groundwaters.

Element	Analytical Method	Detection Limit (mg/L)	Laboratory	Analytical Programme	Sample Preparation
Ca	ICP	0.05	BGS	Major	Filtered; unpreserved
	AA	0.05	CENA	Major	
Mg	ICP	0.14	BGS	Major	Filtered; unpreserved
	AA	0.05	CENA	Major	
Sr	ICP	0.001	BGS	Major	Filtered; preserved
	AA	0.003	CENA	Major	
Ba	ICP	0.001	BGS	Major	Filtered; preserved
	AA	0.05	CENA	Major	
Na	ICP	0.05	BGS	Major	Filtered; unpreserved
	FP	0.1	NUCL	Routine	
K	ICP	0.5	BGS	Major	Filtered; unpreserved
	FP	0.1	NUCL	Routine	
Li	ICP	0.015	BGS	Major	Filtered; unpreserved
Fe(II)	COLOR	0.1	NUCL	Routine	Filtered; preserved
Fe(tot)	ICP	0.02	BGS	Major	Filtered; preserved
	AA	0.01	CENA	Major	
	COLOR	0.1	NUCL	Routine	
Al	ICP	0.1	BGS	Major	Filtered: preserved
	AA	0.01	CENA	Major	
Mn	ICP	0.004	BGS	Major	Filtered; preserved
	AA	0.02	CENA	Major	
Zn	ICP	0.33	BGS	Major	Filtered; preserved
	AA	0.02	CENA	Major	
Cd	ICP	0.024	BGS	Major	Filtered; preserved
	AA	0.02	CENA	Major	
Cu	ICP	0.043	BGS	Major	Filtered; preserved
	AA	0.02	CENA	Major	
Cr	ICP	0.12	BGS	Major	Filtered; preserved
	AA	0.05	CENA	Major	
Co	ICP	0.035	BGS	Major	Filtered; preserved
Ni	ICP	0.085	BGS	Major	Filtered; preserved
	AA	0.02	CENA	Major	
Mo	ICP	0.6	BGS	Major	Filtered; preserved
Ag	AA	0.02	CENA	Major	Filtered; preserved
Pb	AA	0.10	CENA	Major	Filtered; preserved
SO_4	IC	0.5	BGS	Major	Filtered; preserved
	N	1.0	NUCL	Routine	
F	IC	0.1	BGS	Major	Filtered; preserved
	ISE	0.1	NUCL	Routine	
Cl	IC	0.1	BGS	Major	Filtered; unpreserved*
Br	IC	0.05	BGS	Major	Filtered; unpreserved*
NO_3	IC	0.1	BGS	Major	Filtered; unpreserved
HPO_4	IC	0.1	BGS	Major	Filtered; unpreserved
B	AA	0.01	CENA	Major	Filtered; preserved
SiO_2	ICP	0.18	BGS	Major	Filtered; unpreserved
	AA	0.2	CENA	Major	Filtered; unpreserved

(continued)

TABLE II (continuation)

Analytical protocol for the Poços de Caldas groundwaters.

Element	Analytical Method	Detection Limit (mg/L)	Laboratory	Analytical Programme	Sample Preparation
HCO_3	T	0.5	BGS	Major	Filtered; unpreserved
	T	0.5	NUCL	Routine	
Zr	ICP	0.045	BCS	Major	Filtered: preserved
La	ICP	0.032	BCS	Major	Filtered; preserved*
"	ICP	0.018	NYU	Major	Filtered; preserved*
"	ICP	0.018	PUC	Major	Filtered; preserved*
Ce	ICP	0.068	NYU	Major	Filtered; preserved*
"	ICP	0.068	PUC	Major	Filtered; preserved*
Pr	ICP	0.068	NYU	Major	Filtered; preserved*
"	ICP	0.068	PUC	Major	Filtered; preserved*
Nd	ICP	0.068	NYU	Major	Filtered; preserved*
"	ICP	0.068	PUC	Major	Filtered; preserved*
Sm	ICP	0.010	NYU	Major	Filtered; preserved*
"	ICP	0.010	PUC	Major	Filtered; preserved*
U	α-spec	0.008	NYU	Major	Filtered; preserved*
"	α-spec		PUC	Major	Filtered; preserved*
"	α-spec		FSU	Major	Filtered; preserved
"	F		NUCL	Routine	Filtered; preserved
Th	α-spec	0.0023	NYU	Major	Filtered; preserved*
"	α-spec	0.0023	PUC	Major	Filtered; preserved*
"	α-spec		FSU	Major	Filtered; preserved
^{18}O	mass spec		GSF	Major	Unfiltered; unpreserved
^{2}H	mass spec		GSF	Major	Unfiltered; unpreserved
^{3}H	LSC/E	0.7 TU	GSF	Major	Unfiltered; unpreserved
^{3}H	GC/E	0.1 TU	GSF	Major	Unfiltered; unpreserved

NOTE: Filtering was carried out using a pore diameter of 0.45 μm and HCl was used for sample preservation.
Samples preconcentrated for analysis are denoted by (*).

ICP – Inductively-Coupled Plasma Atomic Emission Spectroscopy
AA – Atomic Absorption
ISE – Ion Selective Electrode
N – Nephelometry
mass spec – Mass Spectrometry
α-spec – Alpha Spectrometry
LSC/E – Liquid Scintillation Counting with Electrolytic Enrichment
GC/E – Gas Counting with Electrolytic Enrichment
T – Titration
FP – Flame Photometry
COLOR – Colorimetry
F – Fluorimetry
IC – Ion Chromatography

BGS – British Geological Survey, Nottingham, U.K.
CENA – Centro de Energie Nuclear na Agricultura, Piracicaba, Brazil.
NUCL – Laboratory for Seepage and Groundwater Control, Urânio do Brasil, Poços de Caldas, Brazil.
NYU – University of New York, Institute of Environmental Medicine, New York, U.S.A.
PUC – Pontifical Catholic University of Rio de Janeiro, Department of Chemistry, Brazil.
FSU – University of Tallahassee, Department of Geology, Florida, U.S.A.
GSF – Gesellschaft für Strahlen- und Umweltforschung, Institut für Hydrologie, Neuherberg, Germany.

4. Evaluation of groundwater data

The following criteria have been used to evaluate the complete water analyses (those with all major ions) and to select the best values for chemical equilibrium computations:

1. Charge imbalances should be less than 30%. In all but one instance it was possible to reduce charge imbalances to less than 20% by careful evaluation of the data.
2. Inter-laboratory comparisons (between BGS, CENA, USGS and Uranio do Brasil). Sometimes numbers were averaged, sometimes one value was selected in preference to another, based on the reliability of the analytical method or other factors listed below.
3. Chemical behaviour of the elements. For example, conservative elements vary similarly to other conservative elements and redox-sensitive elements should behave in recognisable patterns, etc.
4. Geochemical consistency. Constituents that are known to produce patterns which reflect solubility controls should not be supersaturated by orders of magnitude without good cause. Likewise, rock composition and mineralogical occurrence and properties should have a recognisable relationship with water composition. Also, if a grossly anomalous value in a time series from a single borehole occurs, which cannot be explained by some anomalous hydrologic phenomenon, then it is likely to be in error.

Very often it is not the occurrence of any one of these criteria alone that suggests an error, but agreement between two or more criteria. These criteria have led to the selected values given in Appendix 3. The original analyses from all laboratories are tabulated in Appendix 2.

An example of an analytical inconsistency for a trace element is given by barium. BGS reported three values for barium that were a factor of 2 or 3 higher than all the other values and did not fit the trend in the data. Barite saturation indices for these three values were also higher. Consequently, the CENA values were chosen for barium for these three samples.

Another example was the highly discrepant charge balances seen in the initial sets of raw data. Only the major ions affect the charge balance and, in the Poços de Caldas waters, these are K^+, Fe^{2+}, SO_4^{2-}, HCO_3^- and F. The iron determinations were considered to have the least error because they were obtained by three different methods: colorimetry, AA and ICP. Furthermore the Fe(II) is nearly equal to the total Fe, which provides a further check on accuracy and precision. Potassium and SO_4 are well-known to have large uncertainties if proper precautions are not taken, so they may well be in error. The alkalinity was originally determined by simple end-point titration rather than from inflection points in an incremental titration curve or a Gran's plot. Later in the programme a modified Gran's plot was adopted, which greatly improved the results. Potassium, sulphate and alkalinity were sometimes varied within limits constrained by the overall consistency with other datasets to achieve an improved charge balance.

Five determinations of total dissolved sulphur have been made by ICP for comparison with the sulphate determinations. Dissolved sulphide is below about 10 μg/L so that total dissolved sulphur is equivalent to dissolved sulphate. Table III compares the results from ICP and IC for the determination of sulphate. The comparisons are rather good, except for the Morro do Ferro samples. The satisfactory comparison helps support the accuracy of the IC sulphate determinations.

TABLE III
Comparison of sulphate determinations in mg/L.

Sample		ICP	IC
PM-22	(PC-GW-27)	9.78	10.4
SHAFT	(PC-GW-28)	283	278
S. Stream	(PC-SW-04)	1.5	<0.2
N. Stream	(PC-SW-05)	1.5	0.36

Analytical determinations made by Urânio do Brasil for the monitoring data are described in Appendix 1. This account includes a section on changes in the procedure for alkalinity measurements and the sampling procedure for dissolved oxygen.

Isotopic measurements for tritium, deuterium and ^{18}O were also carried out and the results summarised in Table IV. Tritium results are expressed as TU (tritium units) where 1 TU corresponds to a $^{3}H/H$ ratio of 10^{-18}. Deuterium and ^{18}O isotope ratios are expressed as ‰ deviations from SMOW (Standard Mean Ocean Water).

Low tritium concentrations were expected in the study area and all groundwater samples were therefore electrolytically enriched before measurement. Liquid scintillation or gas counting was used, with detection limits of 0.7 and 0.1 TU (2σ) respectively, after electrolytic preconcentration (Eichinger *et al.*, 1981; Wolf *et al.*, 1981). Determinations of deuterium and ^{18}O in groundwater were made using standard procedures (e.g. Moser and Rauert, 1980) with an accuracy of about 1 and 0.15 ‰ respectively.

5. General hydrochemical characteristics

The groundwater compositions given in Appendix 2 are highly anomalous relative to most other groundwater compositions, reflecting the rather unusual bedrock mineralogy. The groundwaters at both the analogue study sites can be described as K-Fe-SO_4 type waters in which fluoride is a much more important anion than chloride. This groundwater type is not amenable to plotting on a standard Piper diagram because of the preponderance of iron and fluoride. Furthermore, it is an unusual composition because K always has a higher concentration than Na, sometimes by as much as an order of magnitude. Other cations such as Ca and Mg are commonly below 1 mg/L and of comparable concentrations to Sr and Ba. These results indicate an aquifer mineralogy highly enriched in potassium and strongly depleted in other cations due to long periods of weathering.

The combination of both high iron and sulphate concentrations is indicative of pyrite oxidation, a process that is clearly occurring in the shallow subsurface because of the acid mine water compositions appearing in the 'SW' series of samples. The F3 and shaft waters contain the highest concentrations of iron and sulphate (other than SW01-SW03), reflecting a significant contribution of acid mine waters. The fact that these two locations do not have any significant acidity associated with them suggests that other reactions have taken place to neutralise it. Neutralisation reactions could involve dissolution of aluminosilicates and carbonates.

Delineation of flow-paths by examining the water chemistry is rather difficult for two reasons: (a) although increases in dissolved solids often indicate longer residence times, the increases in dissolved solids at the Osamu Utsumi mine can also be caused by faster reaction rates in the presence of acid mine waters or by passage of the groundwater through a highly mineralised zone, and (b) many of the groundwater samples have very low dissolved solids contents with many constituents near or below detection limit, and differences in water chemistry between boreholes are often subtle. For these reasons, the determination of the isotopes of water (^3H, ^2H and ^{18}O) becomes very important in the estimation of flow direction and residence time.

At the Morro do Ferro site, both the MF10 and MF11 boreholes tapped shallow recharging groundwaters with such a low dissolved solids content that most constituents were below detection limit. These samples probably reflect the composition of rainwater with only small amounts of potassium, zinc, iron, manganese, fluoride and silica added from contact with the aquifer. The groundwaters collected at MF12 show increased concentrations for nearly every constituent, as would be expected for a discharging water with greater residence time. This conclusion is supported by the tritium concentrations which could suggest an age of around 40–50 years if no mixing of old and young groundwaters occurs. Measurements of hydraulic conductivity indicate values close to 10^{-7} m/s for MF10 and MF11, decreasing to 10^{-9} m/s for the lower portion of MF12 (below 58 m). If a flow-path length of 100–200 m is assumed between MF10 and MF12 then a hydraulic conductivity of 10^{-7} m/s gives an average residence time of 32–63 years, consistent with the tritium data. The sampling interval in MF12 is from 45–71 m, covering the range from high to low permeability zones in the bedrock. Although mixing of younger and older waters in MF12 cannot be ruled out, it would seem reasonable to assume that most of the groundwater sampled in MF12 is from the more permeable part of the aquifer and that a residence time of approximately 40–50 years is a good estimate for mass transport calculations. If average hydraulic conductivities of 10^{-8} or 10^{-9} m/s are assumed, the residence time then becomes several hundred to several thousand years and considerable mixing of younger water must be invoked to explain the tritium data. The reliability of the isotopic data is discussed in a later section.

At the Osamu Utsumi mine site the important borehole locations are F1-F3, F5 and SW01-SW03. The shallow boreholes SW01-SW03 contain typical examples of acid mine waters with low pH values and high sulphate concentrations. It is noteworthy that these groundwaters have very similar proportions of overall constituents to the 'F' borehole series and MF12, except for barium. This similarity illustrates that the same type of water composition can result from either longer residence times or faster reaction rates that occur with greater acidity.

The relationship of the sampling locations at the mine site to the directions of water flow, as reflected by the chemical analyses of groundwaters, is complex. A comparison of the F1 and F2 water compositions shows very little difference. The concentrations of calcium, aluminium, zinc and fluoride tend to be higher in F2 than in F1, yet the F1 borehole is sampling water at about twice the depth as in the F2 borehole. This relationship can arise in one of two ways. Either the water is flowing in an upward direction and the F2 samples have a longer residence time than the F1 samples (which must then be closer to the recharge area) or the groundwater flows through a highly mineralised zone before it arrives at F2. The upward flow of groundwater has been demonstrated by the distribution of head measurements in the boreholes. In addition, the water that flows from F1 to F2 probably does travel through a mineralised zone, based on analysis of the core logging and mapping in the open pit. As will be discussed below, the tritium data indicate that the F1 water may be younger than the F2 water, supporting the hydraulic data.

Groundwaters from F3 have the highest concentrations of constituents aside from the acid mine water samples. This borehole is located much farther down-gradient from F1 and F2 and it is near the shaft which contains a mixture of acid mine waters and deep groundwaters. This is probably also the case for the F3 groundwaters. This suggestion is also supported by the tritium data which are consistently greater than 1 TU for the F3 waters and only slightly lower than the tritium values in the 'SW' series.

The groundwaters that are perhaps most indicative of the deeper aquifer are those collected from the F5 borehole. These waters have higher calcium, iron, aluminium, manganese, zinc and fluoride concentrations than those from F1 and F2. The pH values and the alkalinities are also higher. The tritium concentrations, however, are also higher. These results may indicate subsurface production of tritium or, more likely, an admixture of younger water.

Several redox-sensitive species were determined to characterise the redox chemistry of the groundwaters. These species included Fe, Mn, SO_4, H_2S, As, Se, Cr and O_2. Unfortunately, the concentrations of As, Se, H_2S and Cr tended to be at or below detection limits. Dissolved iron concentrations were high and predominantly in the ferrous state. In rare instances some small concentrations of H_2S were detected, but they were so close to the detection limit and so inconsistent in appearance that they cannot be considered to be very reliable, with the possible exception of the F2 borehole which contained a few ppb of sulphide in all samples analysed. This observation would fit with the suggestion that F2 has seen a longer residence time than F1. However, it is surprising that no sulphide could be found in F5 groundwaters, unless only small amounts of sulphide were produced by sulphate reduction and were subsequently removed by secondary pyrite formation. The redox chemistry can be summarised by stating that the groundwaters are highly oxidising in recharge areas, with the consequent formation of acid mine waters at depths from 12 m to 50 m or more in the down-gradient locations. Deeper groundwaters have lost their oxygen content and nearly all the dissolved iron is in the reduced Fe(II) state, indicating mildly reducing conditions. Some older groundwaters show signs of sulphate reduction but only trace concentrations of sulphide are observed, which indicates that the rate of sulphate reduction is very slow and any sulphide may be quickly removed by secondary pyrite precipitation.

Most of the groundwaters, with the exception of the very young recharging groundwaters and the acid mine waters, have consistently high concentrations of dissolved silica (30–35 mg/L). In a mildly acidic environment with pH values of 5–6.5 and fairly high average rainfall, aluminosilicate minerals tend to weather rapidly, releasing high concentrations of silica.

Acid solutions tend to inhibit polymerisation and crystallisation of silica, so that either silica remains dissolved or tends to form metastable phases such as chalcedony or cristobalite.

6. Tritium, deuterium and ^{18}O results

Tritium, the radioactive isotope of hydrogen with a half-life of 12.4 a, is a tool commonly used in hydrology to distinguish between younger and older groundwater (recharged after or before 1952, respectively). Under special conditions, dating of groundwater is possible up to a time limit of 70 years.

The tritium concentrations in the sampled groundwaters vary between 0.04 and 9.2 TU (Table IV). These values are, as expected, relatively low and correspond, under simplifying assumptions (piston flow model, tritium input before 1952 about 4.5 TU), to "tritium model ages" up to more than 60 years. Some of the boreholes show temporal variations in the tritium concentration of the sampled groundwaters caused by admixture of recent groundwater (Fig. 4). In these cases "tritium model ages" are meaningless. Because the tritium data from IAEA network stations near Poços de Caldas are very incomplete (e.g. in the latest IAEA report (IAEA, 1990) no tritium data for the Brazilian network stations are recorded (W. Stichler, pers. comm., 1990)), measured tritium concentrations can only be interpreted very roughly. This rough interpretation is mainly based on the review paper by Gat (1980) and the IAEA reports (1981 and 1986).

Deuterium and ^{18}O in the groundwater can provide information on the recharge conditions or origin of the groundwater as a result of spatial and temporal variations of the stable isotopes in precipitation. These variations are due to fractionation effects during the evaporation and condensation of water.

The δ values of the stable isotopes ^{2}H and ^{18}O vary between -57.2 and -30.7 $\delta^{2}H$‰ SMOW and between -8.43 to -5.07 $\delta^{18}O$ ‰ SMOW respectively, and scatter perfectly around the meteoric waterline (Table IV; Fig. 5). This shows that all groundwaters are of meteoric origin and were not affected by isotope exchange with the rock matrix or evaporation. The relatively strong variation in the stable isotope values is mainly

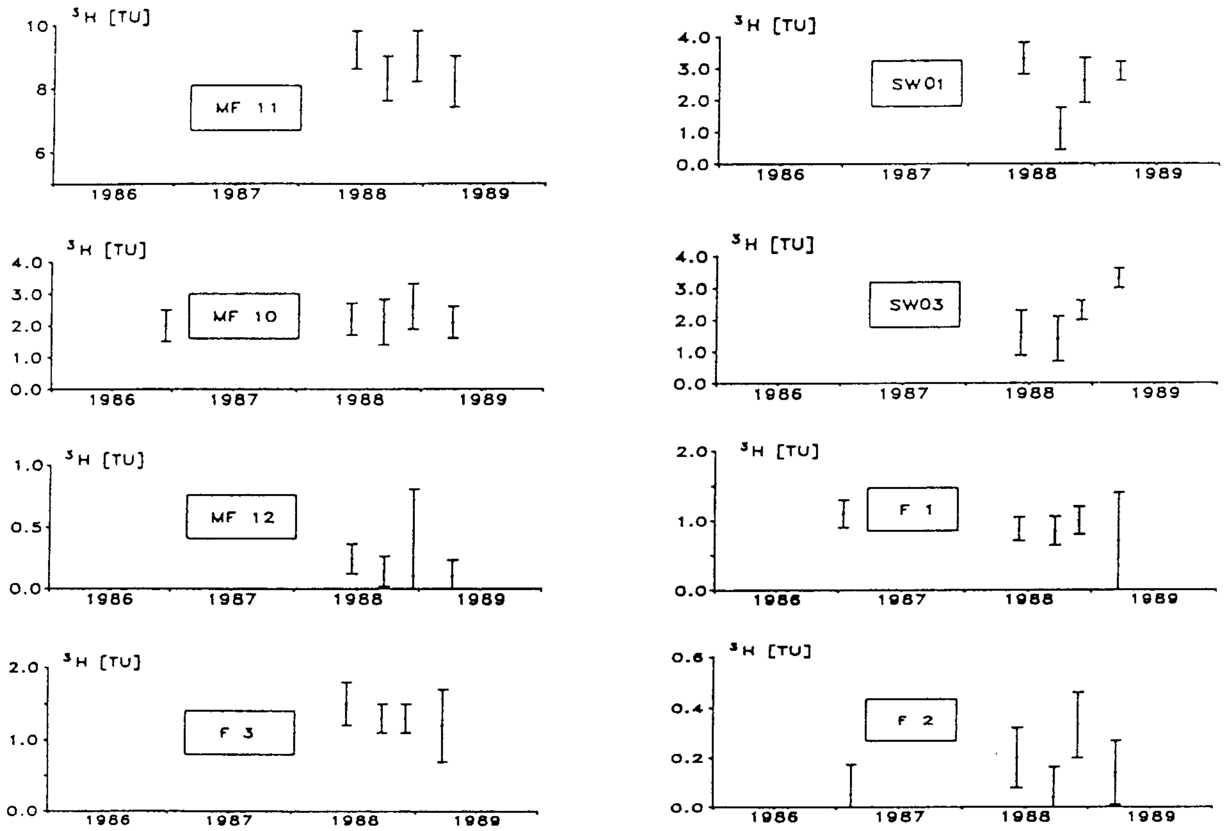

Figure 4. Tritium concentrations of groundwaters from different selected boreholes as a function of time.

TABLE IV

^3H, ^2H and ^{18}O contents of water samples (together with the two-fold standard deviation) from Morro do Ferro (MF), the Osamu Utsumi mine, and from collected rainfall near Poços de Caldas.

Code	Borehole	Sampling date	^3H (TU) ± 2σ		δ^2H (°/oo) ±1.0	$\delta^{18}O$ (°/oo) ±0.15
PC-GW-08	MF 10	86 10 16	–		-50.2	-7.73
PC-GW-12	MF 10	86 12 12	2.0	±0.5	-54.9	-8.11
PC-GW-33	MF 10	88 01 27	–		-55.1	-8.43
PC-GW-48	MF 10	88 06 08	2.2	±0.5	-55.1	-8.31
PC-GW-52	MF 10	88 09 12	2.1	±0.7	-55.7	-8.37
PC-GW-69	MF 10	88 12 06	2.6	±0.7	-55.8	-8.26
PC-GW-83	MF 10	89 04 05	2.1	±0.5	-57.2	-8.36
PC-GW-35	MF 11	88 01 28	–		-49.0	-7.47
PC-GW-49	MF 11	88 06 13	9.2	±0.6	-50.3	-7.65
PC-GW-53	MF 11	88 09 13	8.3	±0.7	-52.5	-7.78
PC-GW-70	MF 11	88 12 12	9.0	±0.8	-51.7	-7.84
PC-GW-82	MF 11	89 04 04	8.2	±0.8	-49.8	-7.66
PC-GW-34	MF 12	88 01 28	–		-53.6	-8.19
PC-GW-50	MF 12	88 06 14	0.24	±0.12	-53.2	-8.01
PC-GW-56	MF 12	88 09 19	0.14	±0.12	-55.0	-8.02
PC-GW-71	MF 12	88 12 14	0.1	±0.7	-54.3	-7.96
PC-GW-85	MF 12	89 04 11	0.10	±0.13	-53.3	-7.96
PC-GW-73	MF 13	88 12 20	7.2	±0.5	-50.8	-7.62
PC-GW-84	MF 13	89 04 07	5.9	±0.5	-53.0	-7.82
PC-GW-14	F1	87 01 06	1.1	±0.2	-50.1	-7.62
PC-GW-15	F1	87 02 11	–		-50.8	-7.72
PC-GW-17	F1	87 05 06	–		-50.7	-7.66
PC-GW-40	F1	88 02 08	–		-51.3	-7.80
PC-GW-42	F1	88 06 01	0.87	±0.18	-49.3	-7.62
PC-GW-54	F1	88 09 15	0.84	±0.20	-52.5	-7.77
PC-GW-63	F1	88 11 29	1.0	±0.2	-51.9	-7.74
PC-GW-77	F1	89 03 20	0.7	±0.7	-52.4	-7.79
PC-GW-16	F2	87 02 12	0.05	±0.12	-49.7	-7.58
PC-GW-41	F2	88 02 09	–		-48.2	-7.47
PC-GW-43	F2	88 06 02	0.20	±0.12	-49.9	-7.60
PC-GW-60	F2	88 09 23	0.04	±0.12	-53.1	-7.77
PC-GW-64	F2	88 11 29	0.34	±0.13	-52.3	-7.79
PC-GW-78	F2	89 03 20	0.14	±0.13	-49.2	-7.55

(continued)

TABLE IV (continuation)

^3H, ^2H and ^{18}O contents of water samples (together with the two-fold standard deviation) from Morro do Ferro (MF), the Osamu Utsumi mine, and from collected rainfall near Poços de Caldas.

Code	Borehole	Sampling date	^3H (TU) $\pm 2\sigma$	δ^2H (‰) ± 1	$\delta^{18}O$ (‰) ± 0.15
PC-GW-36	F3	88 02 01	-	-50.7	-7.79
PC-GW-42	F3	88 02 24	-	-48.8	-7.55
PC-GW-45	F3	88 06 06	1.5 ±0.3	-49.0	-7.30
PC-GW-55	F3	88 09 16	1.3 ±0.2	-52.4	-7.68
PC-GW-65	F3	88 11 30	1.3 ±0.2	-47.1	-7.09
PC-GW-79	F3	89 03 21	1.2 ±0.5	-48.4	-7.46
PC-GW-44	F4	88 06 03	0.49 ±0.15	-50.8	-7.59
PC-GW-59	F4	88 09 22	0.1 ±0.5	-50.8	-7.71
PC-GW-67	F4	88 11 30	0.23 ±0.13	-51.2	-7.75
PC-GW-62	F5	88 11 28	0.42 ±0.12	-48.4	-7.49
PC-GW-72	F5	88 12 20	2.1 ±0.2	-53.7	-7.97
PC-GW-80	F5	89 04 13	0.52 ±0.14	-49.7	-7.61
PC-GW-37	SW01	88 02 02	-	-34.8	-5.70
PC-GW-46	SW01	88 06 07	3.3 ±0.5	-43.6	-6.76
PC-GW-57	SW01	88 09 21	1.1 ±0.7	-47.7	-7.00
PC-GW-68	SW01	88 12 02	2.6 ±0.7	-35.8	-5.71
PC-GW-75	SW01	89 03 16	2.9 ±0.3	-53.5	-7.93
PC-GW-38	SW02	88 02 03	-	-40.2	-6.22
PC-GW-39	SW03	88 02 03	-	-40.6	-6.27
PC-GW-47	SW03	88 06 07	1.6 ±0.7	-43.6	-6.76
PC-GW-58	SW03	88 09 22	1.4 ±0.7	-47.8	-7.29
PC-GW-66	SW03	88 11 30	2.3 ±0.3	-30.7	-5.07
PC-GW-76	SW03	89 03 16	3.3 ±0.3	-52.6	-7.84
PC-GW-87	LGS	89 05 03	5.5 ±0.4	-42.1	-6.58
	Rain	89 01 02/3	4.5 ±1.5	-54.8	-8.10

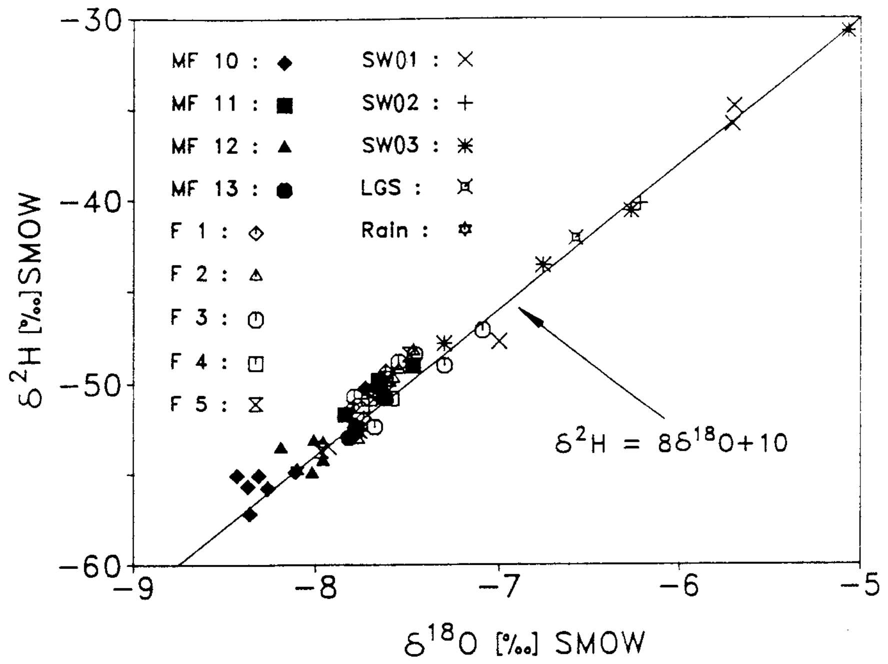

Figure 5. Deuterium contents vs ^{18}O contents of groundwaters with the global meteoric waterline: $\delta^2H = 8\delta^{18}O + 10$.

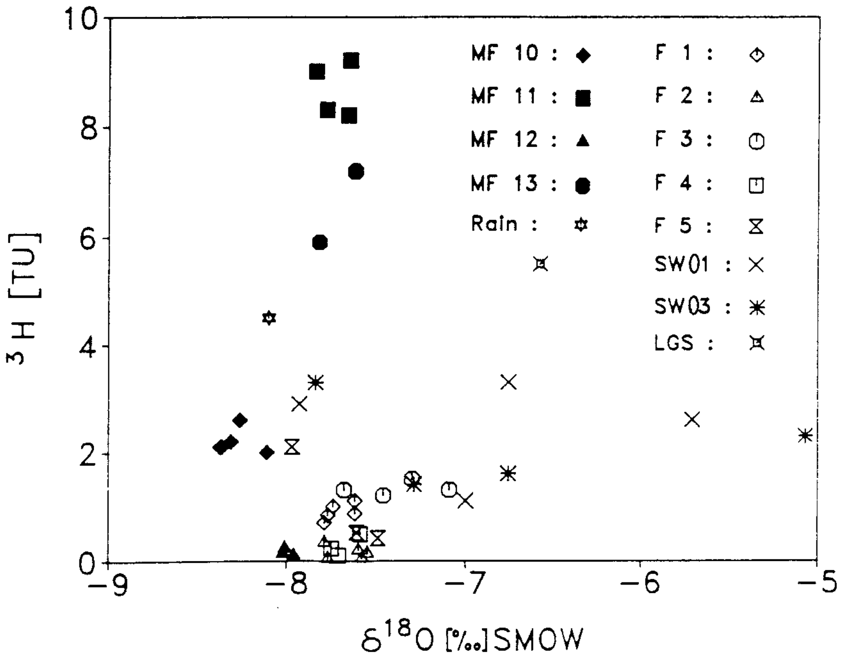

Figure 6. Tritium concentrations plotted against ^{18}O contents of the groundwaters.

determined by seasonal variations in precipitation and, to a lesser extent, by altitude effects.

Modern tritium input may be represented by the tritium content of rainwater near Poços de Caldas (4.5 ± 1.5 TU). This value is in good agreement with estimated tritium concentrations derived from tritium results for the IAEA network stations Cuiaba and Porto Alegre, Brazil (IAEA, 1986) extrapolated to the sampling date.

Comparable or only slightly higher tritium concentrations were measured in groundwaters from boreholes LGS and MF13, corresponding to "tritium model ages" of either only a few years or about 25 to 30 years. Because LGS represents recharge conditions, the lower age for LGS is more probable. Groundwater from borehole MF11 shows the highest tritium concentration (about 9 TU) and could be about 20 to 25 years old, although this groundwater should represent recharge conditions. This could be explained by the relatively long percolation time of rainwater through the extensively altered (by hydrothermal activity and weathering processes) unsaturated zone, damping out seasonal variations of the stable isotopes.

Lower tritium concentrations than measured in modern precipitation were found in groundwater from all other boreholes. In the range of about 1 to 3 TU (corresponding to "tritium model ages" of about 30 to 35 years), two groups of groundwaters can be distinguished (Fig. 6). Whereas the stable isotope concentrations of groundwaters from deeper boreholes MF10, F1 and F3 are relatively constant, those of the shallow boreholes SW01 and SW02 vary very strongly, indicating admixture of seasonal precipitation. In this case we have mixtures of very young groundwater with much older groundwater (with tritium concentrations around 1 TU or even lower).

Groundwaters with such low tritium concentrations were found in the boreholes MF12 (0.1 to 0.24 TU), F1 (about 0.9 TU), F4 (about 0.3 TU), F2 (0.04 to 0.34 TU) and (with the exception of the 2.1 TU value for Dec. 20, 1988) in F5 (about 0.5 TU). Analytical errors can be excluded in the case of the 2.1 TU value because this sample was prepared and measured twice using two different methods (liquid scintillation and gas counting). In both cases the same tritium concentration was found and is thought to be a result of near-surface water contamination.

The "tritium model ages" of groundwaters with tritium concentrations between about 0.04 and 1 TU can be estimated to be between about 35 and more than about 60 years. Such low tritium concentrations were also found in deep STRIPA groundwaters (Moser *et al.*, 1989). It is important to note that these estimated "tritium model ages" are only minimum ages because contamination problems (e.g. by admixture of tritium-containing drilling fluid) become more dominant at these low tritium levels.

It may be worth considering that the subsurface production of tritium via the reaction $^6Li(n, \alpha)^3H$ might be significant in cases of high U and/or Th and Li concentrations in the rock matrix (Andrews *et al.*, 1989). In the investigated area there are, in principle, very high U and/or Th concentrations and, if the Li concentrations are not too low, tritium could be produced in significant concentrations. However, Li concentrations are low (mean value of 90 ppm for the F1 drillcore; MacKenzie *et al.*, this report series; Rep. 7) and, furthermore, porosities of the rock matrix in comparison to STRIPA granite are much higher and "compensate" partly for the very high U and Th concentrations found in the study area. Finally, the transfer of tritium produced in the rock matrix to the groundwater may be below 1% (Forster *et al.*, 1989), resulting in additional reduction of subsurface-produced tritium to the groundwater.

7. Long-term monitoring results and seasonal patterns

The long-term monitoring results are shown in Appendix 4. Some of the apparent variations are related to perturbations in the borehole or improper sampling techniques during the early part of the programme. After these effects settled down, there were improvements in the measurements of pH and alkalinity, resulting in lower and more reliable values than before.

After accounting for these effects and normal scatter in the data, only two trends are apparent. One is the seasonal patterns that are demonstrated in the shallow boreholes SW01-SW03 (Fig. 7). These show pattern changes in SW01 during the transition from dry to wet seasons, i.e. marked increases in Fe(II) and Fe(tot), SO_4, F and U; pH showed a corresponding decrease of about 1 unit. Other increases in dissolved constituents occurred in the March-April period early in 1988, but there is no obvious explanation for this that can be related to precipitation trends. The other trend is that of increasing concentrations of all constituents in the F3 borehole, indicting a plume of acid mine water moving down-gradient in the flow system and being neutralised along the way (Fig. 8).

8. Conclusions

Chemical analyses of groundwaters at two natural analogue study sites in Brazil show unusual compositions dominated by a K-Fe-SO_4 type water high in fluoride and silica. In

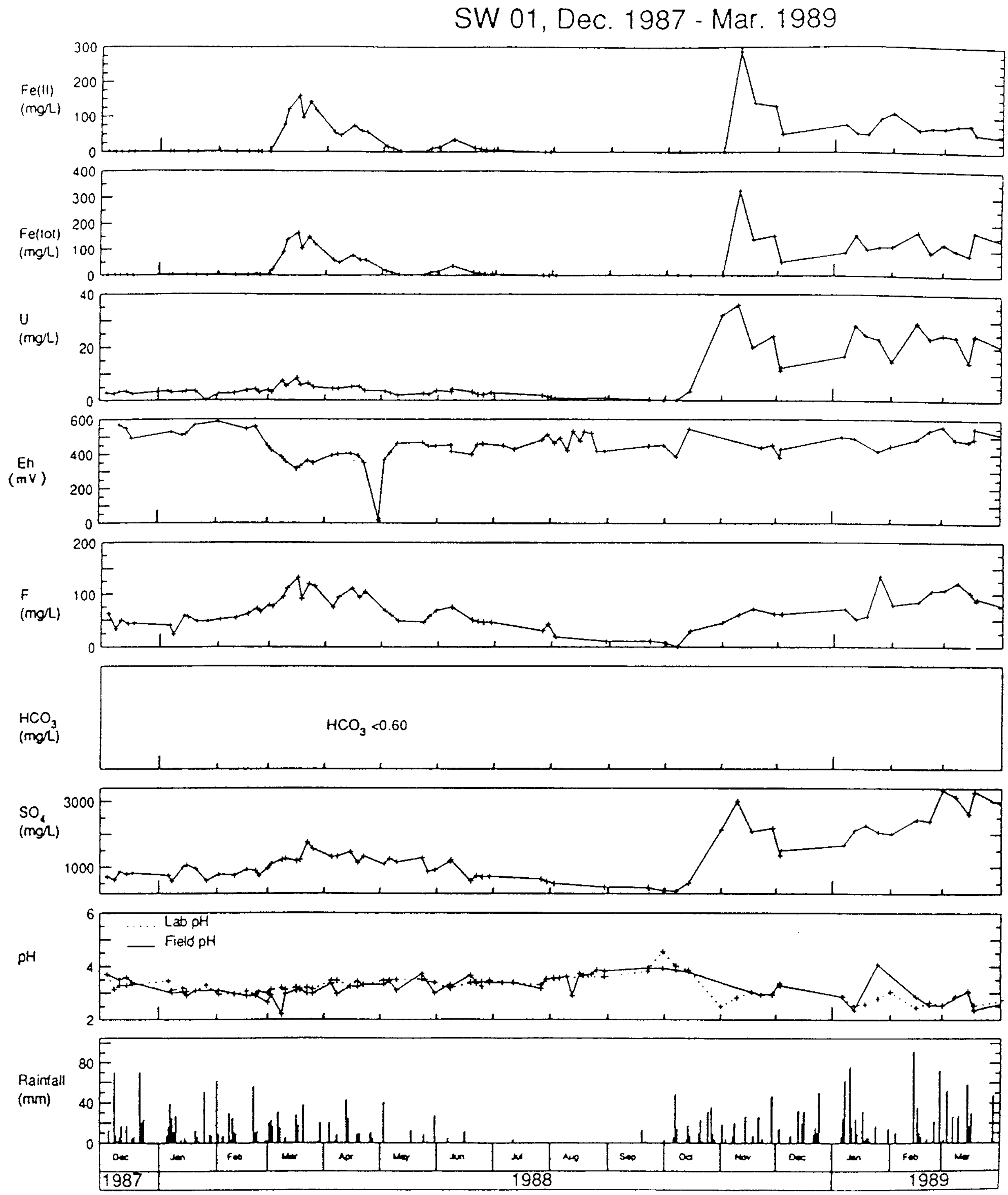

Figure 7. Seasonal variability of monitored parameters with precipitation for the acid mine waters from the SW01 borehole.

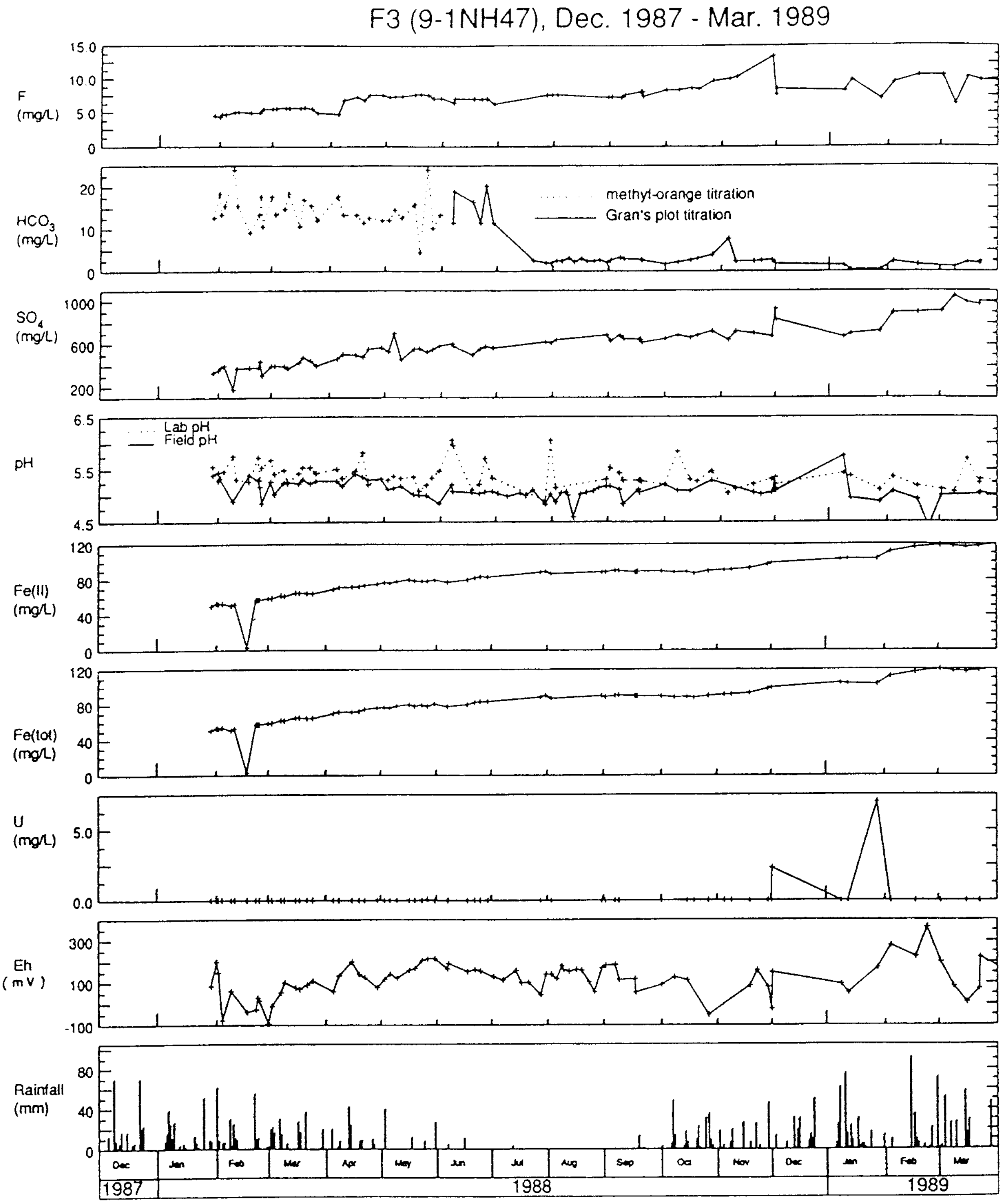

Figure 8. Time series trends of monitored parameters with precipitation for the F3 borehole showing the continuously increasing iron concentrations with time.

the near-surface environment there is a considerable amount of acid mine water production. Some of the intermediate-depth waters reflect a mixing of acid mine waters with normal, deeper groundwaters. The highly depleted concentrations of Na and divalent cations indicate advanced stages of weathering, and the high concentrations of iron and sulphate suggest pyrite oxidation is one of the dominant processes. The high dissolved silica concentrations reflect the ultimate breakdown of primary and secondary aluminosilicate minerals in an acidic environment.

Tritium and stable isotope measurements make it possible to classify groundwaters with regard to approximate residence times and positions along the flow-path. Shallow groundwaters have tritium concentrations above 1 TU, indicating that a significant proportion has recharged after 1952. Groundwater from the deeper boreholes shows tritium concentrations mostly below 1 TU and can be interpreted as groundwater with ages of about 35–60 years, although the groundwater may be influenced by subsurface-produced tritium.

The stable isotopes clearly reflect recharge conditions and demonstrate that all the groundwaters are of meteoric origin and not affected by evaporation or water-rock interactions.

9. Acknowledgements

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10. References

Andrews, J.N., Davis, S.N., Fabryka-Martin, J., Fontes, J-Ch., Lehmann, B.E., Loosli, H.H., Michelot, J-L., Moser, H., Smith, B. and Wolf, M., 1989. The in situ production of radioisotopes in rock matrices with particular reference to the Stripa granite. *Geochim. Cosmochim. Acta*, 53, 1803-1815.

Eichinger, L., Forster, M., Rast, H., Rauert, W. and Wolf, M., 1981. Experience gathered in low-level measurement of tritium in water. In: Low-Level Tritium Measurement. *IAEA TECDOC-246*, Vienna, 43-64.

Gat, J.R., 1980. The isotopes of hydrogen and oxygen in precipitation. In: P. Fritz and J-Ch. Fontes (Editors), Handbook of Environmental Isotope Geochemistry. *Elsevier*, Amsterdam, 21-47.

Forster, M., Moser, H., Ramm, K. and Hietel, B., 1989. Investigating the neutron-induced subsurface production of environmental isotopes ^{37}Ar, ^{39}Ar, ^{3}H and ^{36}Cl with neutron irradiation of aquifer material. *Chem. Geol. (Isot. Geosci. Sect.)*, 79, 325-332.

IAEA (International Atomic Energy Agency), 1981. Statistical Treatment of Environmental Isotope Data in Precipitation. *IAEA Tech. Rep. Ser., 206*, Vienna, 256 pp.

IAEA (International Atomic Energy Agency), 1986. Environmental Isotope Data No. 8: World Survey of Isotope Concentration in Precipitation (1980–1983). *IAEA Tech. Rep. Ser., 264*, Vienna, 184 pp.

IAEA (International Atomic Energy Agency), 1990. Environmental Isotope Data No. 9: World Survey of Isotope Concentration in Precipitation (1984–1987). *IAEA Tech. Rep. Ser.*, Vienna (In press).

Moser, H. and Rauert, W., 1980. In: G. Matthess (Editor), Isotopenmethoden in der Hydrologie; Lehrbuch der Hydrogeologie, Bd. 8. *Gebr. Borntraeger*, Stuttgart-Berlin, 400 pp.

Moser, H., Wolf, M., Fritz, P., Fontes, J-Ch., Florkowski, T. and Payne, B.R., 1989. Deuterium, oxygen-18, and tritium in Stripa groundwater. *Geochim. Cosmochim. Acta*, 53, 1757-1763.

Wolf, M., Rauert, W. and Weigel, F., 1981. Low-level measurement of tritium by hydrogenation of propadiene and gas counting of propane. *Intl. J. Appl. Radiat. Isot.*, 32, 919-928.

Appendix 1

Groundwater analysis conducted by the CIPC/Urânio do Brasil Control Laboratory, Osamu Utsumi mine complex, Poços de Caldas, Minas Gerais, Brazil.

Appendix 1

Groundwater analysis conducted by the CIPC/Urânio do Brasil Control Laboratory, Osamu Utsumi mine complex, Poços de Caldas, Minas Gerais, Brazil.

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1. Introduction

The CIPC/URÂNIO DO BRASIL Process Control Laboratory carried out the following on-site determinations in near-surface water and groundwater samples: iron (II), total iron, sulphide, sulphate, uranium, alkalinity, potassium, sodium, fluoride and dissolved oxygen.

2. Sampling procedure

Routine sampling was carried out at the Osamu Utsumi mine and Morro do Ferro sites. After ensuring: a) a representative groundwater composition (2 hours pumping and pH and Eh monitoring using a portable unit), b) on-site filtering (0.45 μm) and c) preservation when necessary (with HCl for iron (II) and total iron analysis only), the samples were transported directly to the Process Control Laboratory at the mine complex where they were immediately analysed. Sampling for dissolved oxygen analysis was performed in a special arrangement as shown in Figure 1-1.

3. Analytical procedure

- *Fe(II) and Fe (total)*, were carried out by the Ferrozine method, as described by Nordstrom (pers. comm. 1988). Repetitive determinations were carried out.
- *Sulphide* was determined using a specific-ion electrode after a preconcentration step. The sulphide was separated as ZnS, co-precipitated with $Zn(OH)_2$ and subsequently dissolved in alkaline EDTA-ascorbic acid solution for potentiometric measurement with the sulphide-selective electrode. (Baumann, 1974; Vivit *et al.*, 1984).

- *Uranium* was determined by the fluorimetric method as described in the "Manual de Métodos de Análise Química do Laboratório de Processos Minerais de Poços de Caldas", method nr. M-92.
- *Potassium and sodium* were determined by the flame photometric method, as described in "Standard Methods for the Examination of Water and Wastewater", 14th Edition, 1975, APHA-AWWA-WPCF, 234-235 and 250-253.
- *Sulphate* was determined by the nephelometric method (see above uranium reference, 496-498).
- *Fluoride* was determined by the specific-ion electrode procedure (see above uranium reference, 391-393).
- *Dissolved Oxygen* was determined by the Winkler (or Iodometric and its azide modification) method (see above uranium reference, 440-447).
- *Alkalinity* was determined firstly by the methyl orange endpoint titration, but the results were not satisfactory. Two alternative procedures were tested; see Butter (1982) and Thomas and Linch (1960). Table I summarises the results obtained by these two procedures. As the results were in agreement, the modified Gran's plots titrations were adopted because this was easier and less time consuming than the Gran's plots titration method.

TABLE 1-I
Alkalinity determination by the Gran's plots and Modified Gran's plots Methods (mg/L).

Sample Identification	Sampled Date	Gran's plots	Modified Gran's plots
F1	17-06-88	2.59	2.47
F2	17-06 88	9.09	8.95
F4	28-06-88	5.96	4.26
SHAFT	28 06 88	12.3	12.9
F3	28-06-88	2.45	2.48
MF10	28-06-28	2.81	2.44
PM22	28-06-88	22.3	20.9
F2	28-06-88	11.3	10.3
F1	28-06-88	2.90	2.92
MF12	30-06-88	23.4	23.0
MF10	30-06-88	2.40	2.39
MF11	30-06-88	0.20	0.19
HCO_3^-	1,99 mg/L	1.75	1.74
HCO_3^-	9,95 mg/L	9.58	9.42

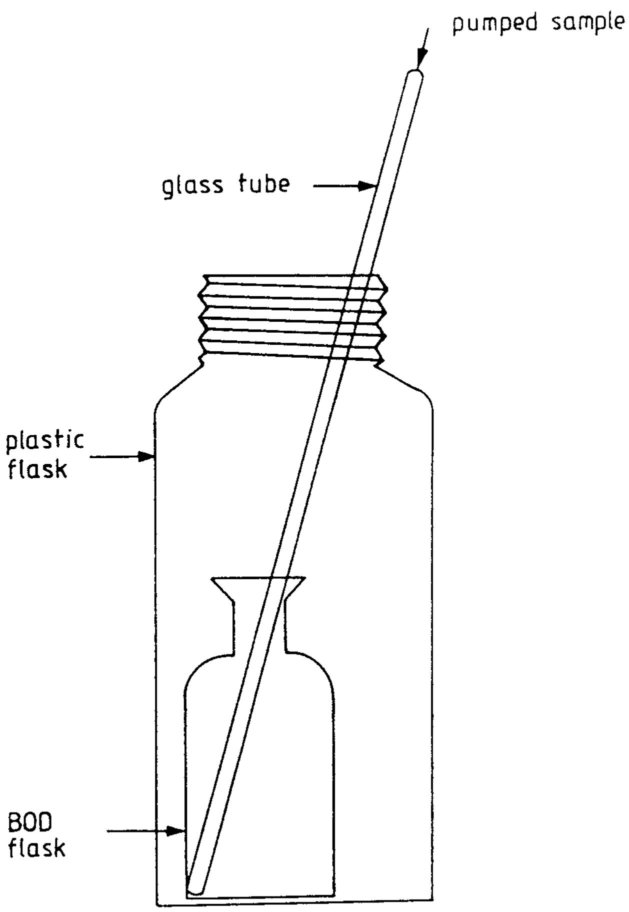


Figure 1-1. Sampling device used for dissolved oxygen analysis.

4. References

Baumann, E.W., 1974. Determination of parts per billion sulphide in water with the sulphide-selective electrode. *Anal. Chem.*, 46 (9), 1345-1347.

Butter, J.N., 1982. The Gran's Plots Titration. In: Addison-Wesley (Editor), Carbon dioxide equilibria and their applications.

Thomas, J.F.J., and Linch, J.J., 1960. The modified Gran's plots titration. In: Determination of carbonate alkalinity in natural waters. *Jour. AWWA*, 259-268.

Vivit, D.F., Ball, W. and Jenne, E.A., 1984. Specific-ion electrode determination of sulphide pre-concentrated from San Francisco Bay waters. *Environ. Geol. Water. Sci.*, 6 (2), 79-90.

Appendix 2

Chemical analyses of groundwater samples from the Osamu Utsumi mine and Morro do Ferro study sites.

Selected analytical results of groundwater samples from the Osamu Utsumi Mine

F1 (9-1WC11) Reference water sample for determination of accuracy and precision.

Borehole	F1 (9-1WC11)	F1 (9-1WC11)	F1 (9-1WC11)	F1 (9-1WC11)	F1
Sample Code No.	PC-GW-51	PC-GW-61	PC-GW-74	PC-GW-86	Selected[†]
Sampling Int (m)	96.5-125.7	96.5-125.7	96.5-125.7	96.5-125.7	
Date Collected	880707	880707	880707	880707	
Temperature(°C)	22	22	22	22	22
pH (field/lab)	4.87/4.06	4.87/3.63	4.87/3.71	4.87/3.59	4.87
Cond.(mS/m)	----	----	----	----	---
Eh(mV)	338	----	----	----	338
Alkalinity (mg/L HCO_3)	<5.0	<5.0	<5.0	<5.0	2.0
Sum Cations (meq/L)					0.4367
Sum Anions (meq/L)					0.4730
Charge Balance %					-8.0%

Element	mg/L				
Ca	0.45 (0.46/0.48)	0.45	0.593	0.385	0.47 ±0.07
Mg	0.07 (0.12/0.07)	<0.07	<0.070	<0.070	0.07
Sr	0.044 (0.045/0.046)	0.042	0.043	0.043	0.043 ±0.0015
Ba	0.124 (0.135/0.137)	0.125	0.126	0.124	0.125 ±0.0055
Na	0.19 (<0.20/<0.20)	0.21	0.224	0.165	0.20 ±0.02
K	12.0 (13.1/12.7)	12.1	13.4	12.9	12.7 ±0.6
Li	<0.010	<0.010	<0.01	<0.010	<0.010
Fe(II)	----	----	----	----	1.30
Fe(tot)	1.32 (0.28/0.20)	1.35	1.36	1.30	1.33 ±0.03
Al	<0.050 (<0.5)	<0.050	0.10	<0.05	<0.05
Mn	0.104 (0.19/0.20)	0.187	0.187	0.18	0.19 ±0.03
Zn	0.081 (0.093/0.115)	0.083	0.085	0.080	0.083 ±0.013
Cd	<0.005 (<0.005)	<0.005	<0.005	<0.005	<0.005
Cu	<0.005 (<0.05)	<0.005	<0.005	<0.005	<0.005
Cr	<0.02 (<0.01)	<0.02	<0.02	<0.02	<0.010
Co	---- (<0.002)	----	<0.020	<0.020	<0.002
Ni	<0.025 (<0.003)	<0.025	<0.025	<0.025	<0.003
Mo	<0.035	<0.035	<0.035	<0.035	<0.035
Pb	<0.090 (<0.2)	<0.090	<0.09	<0.09	<0.09
Zr	<0.015	<0.015	<0.0015	<0.015	<0.0015
V	----	----	<0.015	----	<0.015
Be	(<0.001/0.0014)	----	----	----	<0.001
SO_4	15.5	15.7	16.2	16.5	16 ±0.5
F	0.30	0.36	0.52	0.48	0.41 ±0.102
Cl	1.38	6.20	<2.0	3.8	3 ±2.4
Br	<0.005	<0.005	<0.05	<0.05	<0.005
NO_3	0.02	0.06	<0.10	<0.10	0.04
HPO_4	<0.10	<0.10	<0.1	<0.1	<0.1
B	<0.015	<0.015	<0.015	<0.015	<0.015
SiO_2	33(37.0/37.2)	----	33	34	35 ±2.1
Ti	(<0.010)	----	----	----	<0.010

( ) U.S.G.S. data, J.W.Ball, number before slash is on filtered sample, after slash is on unfiltered sample.

† These represent "best" values based on a comparison of 5 independent analyses, known trends (i.e.. consistency in time), charge balance and results from Gran's titrations for alkalinity from similar samples. Error range is one standard deviation based on all positive determinations. "Best" values sometimes represent the mode instead of the mean.

Selected analytical results of groundwater samples from the Osamu Utsumi Mine

Borehole	F1 (9-1WC11)	F1 (9-1WC11)	F1 (9-1WC11)	F1 (9-1WC11)
Sample Code No.	PC-GW-09	PC-GW-14	PC-GW-15	PC-GW-17
Sampling Int (m)	96.5-125.7	96.5-125.7	96.5-125.7	96.5-125.7
Date Collected	861113	870106	870210	870506
Temperature(° C)	20.5	21.0	20.0	22.5
pH (lab)	5.8	5.4	5.5	5.5
Cond.(mS/m)	6.2	6.0	---	6.2
Eh(mV)	325	---	---	203
Alkalinity (mg/L HCO_3)	11	10	11	10
Sum Cations (meq/L)	0.46	0.47	0.47	0.49
Sum Anions (meq/L)	0.53	0.50	0.53	0.58
Charge Balance %	-13.7	-7.4	-10.9	-16.6
Element		mg/L		
Ca	0.50	0.61	0.68	0.70
Mg	0.11	0.05	0.10	<0.14
Sr	0.09	0.10	0.05	0.064
Ba	0.15	0.14	0.15	0.17
Na	1.29	0.57	0.23	0.38
K	10.0	12.0	13.3	13.4
Li	---	---	---	<0.02
Fe(II)	1.60	1.53	1.62	2.03
Fe(tot)	1.70	1.62	1.67	2.06
Al	0.31	0.155	<0.06	0.03
Mn	0.27	0.28	0.27	0.34
Zn	0.15	0.12	0.11	0.12
Cd	<0.02	<0.02	---	<0.02
Cu	<0.02	<0.02	<0.01	<0.02
Cr	<0.05	<0.05	<0.02	<0.05
Co	---	---	<0.035	<0.035
Ni	<0.02	<0.02	<0.085	<0.02
Mo	---	---	<0.60	<0.60
Ag	<0.02	<0.02	<0.02	<0.05
Pb	<0.10	<0.10	<0.10	<0.10
Zr	---	---	---	<0.01
SO_4	15	15	15.4	18.8
F	0.74	0.47	0.50	0.55
Cl	---	---	<0.10	<0.10
Br	---	---	<0.005	<0.05
NO_3	---	---	<0.05	<0.02
HPO_4	---	---	<0.10	<0.05
B	<0.01	<0.02	<0.02	<0.02
SiO_2	34.0	34.5	35.5	32.6

Selected analytical results of groundwater samples from the Osamu Utsumi Mine

Borehole	F1 (9-1WC11)	F1 (9-1WC11)	F1 (9-1WC11)	F1 (9-1WC11)
Sample Code No.	PC-GW-22	PC-GW-23	PC-GW-40	PC-GW-42
Sampling Int (m)	96.5-125.7	96.5-125.7	96.5-125.7	96.5-127.7
Date Collected	870820	870917	880208	880601
Temperature (°C)	20.5	20.4	23	21.3
pH [field/lab] lab	6.1	5.7	[5.40/5.67]2.35	[5.25/5.53]5.51
D.O (mg/L)	----	---	0.19	0.72
Eh(mV)	220	---	461	146
Alkalinity (mg/L HCO_3)	8	8	3.0	4.3
Sum Cations (meq/L)	0.40	0.41	0.382	0.435
Sum Anions (meq/L)	0.45	0.45	0.439	0.424
Charge Balance %	-11.9	-10.6	-13.97	2.78

Element	mg/L			
Ca	0.51	0.518	0.52	0.45
Mg	0.043	0.042	0.032	0.08
Sr	0.034	0.035	0.042	0.0424
Ba	0.107	0.108	0.111	0.126
Na	0.16	0.196	0.19	0.22
K	12.0	12.0	10.9	13.0
Li	<0.02	<0.02	0.0005	<0.015
Fe(II)	1.12	1.24	1.2	1.26
Fe(tot)	1.18	1.33	1.23	1.29
Al	0.04	0.04	0.07	<0.06
Mn	0.145	0.140	0.17	0.185
Zn	0.045	0.036	0.08	0.08
Cd	<0.1	<0.01	<0.005	<0.005
Cu	<0.015	<0.015	<0.015	<0.015
Cr	<0.12	<0.05	<0.12	0.011
Co	<0.035	<0.035	<0.002	<0.002
Ni	<0.020	<0.020	0.003	<0.003
Mo	<0.030	<0.030	0.003	<0.050
Pb	<0.10	---	<0.100	<0.050
Zr	<0.01	<0.01	<0.045	<0.045
V	----	----	----	<0.2
U	----	----	0.0014	[0.0003]0.0045
Th	----	----	----	<0.00005
SO_4	14.5	14.8	15.8	15.8
F	0.34	0.29	0.42	0.36
Cl	<0.20	<0.20	52.5	0.18
Br	---	---	<0.050	<0.050
NO_3	<0.02	---	<0.10	<0.01
HPO_4	<0.05	<0.02	0.18	<0.05
B	<0.01	<0.02	<0.020	---
SiO_2	34.3	32.31	31	33
S^{2-}	----	----	0.005	0.004

Selected analytical results of groundwater samples from the Osamu Utsumi Mine

Borehole	F1 (9-1WC11)	F1 (9-1WC11)	F1 (9-1WC11)	F1 (9-1WC11)
Sample Code No.	PC-GW-51	PC-GW-54	PC-GW-63	PC-GW-77
Sampling Int (m)	96.5-125.7	96.5-125.7	96.5-125.7	96.5-125.7
Date Collected	880707	880915	881129	890320
Temperature(°C)	22	21	21	22
pH [field/lab] lab	4.87	[5.35/5.64] 6.08	[5.37/5.47] 6.08	[5.27/6.45] 5.27
D.O. (mg/L)	----	<0.008	<0.008	<0.008
Eh(mV)	338	308	239/207	259
Alkalinity (mg/L HCO_3)	<5.0	3.0	12	3.38
Sum Cations (meq/L)	0.437	0.435	0.442	0.465
Sum Anions (meq/L)	0.472	0.523	0.552	0.456
Charge Balance %	-8.0	-18.2	-22.3	2.0
Element		mg/L		
Ca	0.47	0.70	0.622	0.43
Mg	0.07	<0.07	0.077	0.14
Sr	0.043	0.060	0.039	0.038
Ba	0.125	0.156	0.115	0.119
Na	0.20	0.19	0.229	0.174
K	12.7	12	12.7	14
Li	<0.010	<0.010	<0.01	0.002
Fe(II)	1.30	1.76	1.50	1.14
Fe(tot)	1.33	1.77	1.52	1.17
Al	<0.05	<0.050	<0.05	0.071
Mn	0.19	0.28	0.161	0.145
Zn	0.083	0.11	0.067	0.073
Cd	<0.005	<0.005	<0.005	<0.0005
Cu	<0.005	<0.005	<0.005	<0.005
Cr	<0.010	<0.02	<0.02	<0.02
Co	<0.002	<0.020	<0.020	<0.0005
Ni	<0.003	<0.025	<0.025	<0.025
Mo	<0.035	<0.035	<0.035	0.011
Rb	----	----	----	0.026
Cs	----	----	----	<0.0005
Pb	<0.09	<0.09	<0.09	0.001
Zr	0.0015	<0.0015	<0.0015	<0.0005
V	<0.015	<0.2	<0.015	<0.2
U	<0.001	0.005	0.005	0.005
Th	----	----	----	0.000015
SO_4	16	20	16.4	18
F	0.41	0.5	0.27	0.49
Cl	3	1.09	<2.0	<2.0
Br	<0.005	<0.020	<0.05	<0.05
NO_3	0.04	<0.02	<0.10	<0.10
HPO_4	<0.1	<0.10	<0.1	<0.1
B	<0.015	<0.015	<0.015	<0.015
SiO_2	35	32	36	31
S^{2-}	<0.010	0.0038	0.0056	0.0040

Selected analytical results of groundwater samples from the Osamu Utsumi Mine

Borehole	F2 (9-1VC24)	F2 (9-1VC24)	F2 (9-1VC24)	F2 (9-1VC24)
Sample Code No.	PC-GW-13	PC-GW-16	PC-GW-20	PC-GW-25
Sampling Int (m)	45-60	45-60	45-60	45-60
Date Collected	861215	870212	870724	870928
Temperature (°C)	21.5	21.0	21.0	21.0
pH (lab)	5.8	5.8	5.6	5.66
Cond.(mS/m)	5.7	---	6.0	6.3
Eh(mV)	311	---	190	---
Alkalinity (mg/L HCO_3)	10	13	10	11
Sum Cations (meq/L)	0.49	0.48	0.49	0.48
Sum Anions (meq/L)	0.53	0.54	0.53	0.54
Charge Balance %	-7.2	-12.8	-9.0	-12.5
Element		**mg/L**		
Ca	1.7	1.5	2.00	2.10
Mg	0.07	<0.10	<0.10	0.044
Sr	0.10	0.048	0.064	0.064
Ba	0.11	0.095	0.113	0.100
Na	0.52	0.19	0.14	0.109
K	11	12	12	11.4
Li	---	---	<0.02	<0.02
Fe(II)	0.58	0.89	0.56	0.61
Fe(tot)	0.79	0.95	0.58	0.73
Al	0.395	0.35	0.28	0.259
Mn	0.185	0.120	0.210	0.174
Zn	0.230	0.205	0.300	0.167
Cd	<0.02	---	<0.02	<0.01
Cu	<0.02	<0.01	<0.02	<0.01
Cr	<0.05	<0.02	<0.05	<0.05
Co	---	<0.035	<0.035	<0.035
Ni	<0.02	<0.01	<0.02	<0.02
Mo	---	<0.060	<0.030	<0.030
Ag	<0.02	<0.02	---	---
Pb	<0.10	<0.01	0.10	<0.10
SO_4	13	11.8	13	12.9
F	1.74	1.62	1.9	1.72
Cl	---	<0.10	<0.10	<0.20
Br	---	<0.005	<0.05	<0.02
NO_3	---	<0.01	<0.10	0.03
HPO_4	---	<0.01	<0.10	0.06
B	<0.01	<0.02	<0.02	---
SiO_2	33.0	34.5	30.8	32.1

Selected analytical results of groundwater samples from the Osamu Utsumi Mine

Borehole	F2 (9-1VC24)	F2 (9-1VC24)	F2 (9-1VC24)	F2 (9-1VC24)	F2 (9-1VC24)
Sample Code No.	PC-GW-41	PC-GW-43	PC-GW-60	PC-GW-64	PC-GW-78
Sampling Int (m)	45 - 60	45 - 60	45 - 60	45 - 60	45 - 60
Date Collected	880209	880602	880923	881129	890320
Temperature(°C)	22	21.0	22	21	21
pH [field/lab] lab	[5.6/6.05]6.11	[5.72/6.08]5.98	[5.73/5.81]6.06	[5.88/5.84]5.75	[5.90/6.42]5.73
D.O. (mg/L)	0.57	0.72	0.21	<0.008	<0.008
Eh(mV)	339	323	262	270	191
Alkalinity (mg/L HCO_3)	6.0	8.0	6.50	12	10
Sum Cations (meq/L)	0.500	0.511	0.450	0.564	0.610
Sum Anions (meq/L)	0.497	0.503	0.520	0.592	0.595
Charge Balance %	0.716	1.65	-14.6	-4.81	2.56

Element	mg/L				
Ca	2.28	2.2	2.0	2.66	2.65
Mg	0.17	0.07	<0.007	0.070	0.070
Sr	0.063	0.064	0.061	0.079	0.009
Ba	0.110	0.11	0.104	0.126	0.131
Na	0.14	0.13	0.18	0.142	0.2
K	11	12	10.85	12.8	13.5
Li	0.0010	<0.015	<0.010	<0.01	<0.010
Fe(II)	0.98	1.05	0.92	1.16	1.67
Fe(tot)	1.01	1.11	0.935	1.18	1.70
Al	0.28	0.23	0.220	0.27	0.319
Mn	0.20	0.20	0.169	0.241	0.318
Zn	0.15	0.15	0.169	0.173	0.211
Cd	<0.005	<0.005	<0.005	<0.005	<0.005
Cu	<0.015	<0.015	<0.005	<0.005	<0.005
Cr	<0.12	<0.12	<0.02	<0.02	<0.02
Co	<0.002	<0.002	<0.020	<0.020	<0.020
Ni	<0.003	<0.003	<0.025	<0.025	<0.025
Mo	<0.0065	<0.050	<0.035	<0.035	<0.035
Pb	<0.100	<0.050	<0.090	<0.09	<0.09
Zr	<0.045	<0.045	<0.015	<0.0015	<0.015
V	----	<0.2	<0.2	<0.2	<0.2
U	0.0015	[0.0014]0.0056	<0.005	0.013	0.009
Th	----	<0.00005	----	----	----
SO_4	12.6	12.8	15	13.3	14.2
F	2.50	2.00	1.78	2.24	2.57
Cl	<1.0	<0.10	0.20	<2.0	<2.0
Br	<0.050	<0.050	<0.005	<0.05	<0.05
NO_3	<0.10	<0.01	0.04	<0.10	<0.10
HPO_4	0.15	<0.05	<0.010	<0.1	<0.1
B	0.078	----	<0.015	<0.015	<0.015
SiO_2	32	32	30	31	29
S^{2-}	0.004	0.004	0.0015	0.0021	0.019

Selected analytical results of groundwater samples from the Osamu Utsumi Mine

Borehole	F3 (9-1NH47)	F3 (9-1NH47)	F3 (9-1NH47)	F3 (9-1NH47)	F3 (9-1NH4
Sample Code No.	PC-GW-36	PC-GW-45	PC-GW-55	PC-GW-65	PC-GW-79
Sampling Int (m)	50 - 77.6	50 - 77.6	50 - 77.6	50 - 77.6	50 - 77.6
Date Collected	880201	880606	880916	881130	890321
Temperature(°C)	22	22.2	22	22	23
pH [field/lab] lab	[5.45/5.29]3.56	[5.21/6.06]3.99	[5.10/5.18]2.99	[5.35/5.14]3.49	[5.03/5.24]3.
D.O. (mg/L)	<0.008	<0.008	<0.008	<0.008	<0.008
Eh(mV)	448	414	338	225	319
Alkalinity (mg/L HCO_3)	3.0	3.0	2.65	1.78	2.06
Sum Cations (meq/L)	7.58	10.2	11.6	12.8	14.0
Sum Anions (meq/L)	8.75	11.0	11.7	15.0	16.0
Charge Balance %	-14.3	-7.70	-1.03	-15.4	-13.6

Element		mg/L			
Ca	74	100	111	122	131
Mg	3.00	4.0	4.00	4.16	4.0
Sr	1.5	2.0	2.1	2.35	2.7
Ba	0.050	0.050	0.051	0.049	0.046
Na	1.1	1.1	1.28	1.0	1.00
K	33.5	39.7	42.5	44.5	46.3
Li	0.0034	<0.015	<0.010	<0.01	0.015
Fe(II)	53.4	----	88.7	98.9	117.5
Fe(tot)	53.5	74	88.9	99.4	118.5
Al	2.5	3.2	4.420	5.14	6.2
Mn	12	18	19	20.0	20.7
Zn	2.02	3.0	3.27	8.77	3.8
Cd	0.0008	<0.005	<0.005	<0.005	<0.0005
Cu	0.0014	<0.015	<0.005	<0.005	<0.0005
Cr	<0.010	<0.010	<0.02	<0.02	0.092
Co	0.007	0.008	<0.020	<0.020	<0.005
Ni	0.004	0.009	<0.025	<0.025	<0.025
Mo	<0.050	<0.050	<0.035	<0.035	0.002
Pb	<0.100	<0.050	<0.090	<0.09	0.0008
Zr	<0.045	<0.045	<0.015	<0.015	<0.0005
V	----	<0.2	<0.2	<0.2	<0.2
U	0.0045	[0.008] 0.0017	<0.001	0.019	0.001
Th	---	0.0002	----	----	0.0003
SO_4	400	510	540	700	745
F	5.4	6.14	7.05	6.57	9.24
Cl	2.9	0.44	<0.20	<2.0	<2.0
Br	<0.050	0.084	<0.010	<0.05	<0.05
NO_3	<0.10	0.02	0.18	<0.10	0.44
HPO_4	<1.0	<0.05	<0.10	<0.1	<0.1
B	0.065	----	0.145	0.204	0.235
SiO_2	34	34	36	34	35
S^{2-}	----	<0.0001	<0.001	0.0018	0.0028

Selected analytical results of groundwater samples from the Osamu Utsumi Mine

Borehole	F5 (MI-55)	F5 (MI-55)	F5 (MI-55)
Sample Code No.	PC-GW-62	PC-GW-72	PC-GW-80
Sampling Int (m)	275-300	275-300	275-300
Date Collected	881128	881220	890413
Temperature(°C)	24	-----	24
pH [field/lab] lab	[6.25/6.39] 5.56	[6.00] 5.98	[5.83/6.38] 6.02
D.O. (mg/L)	<0.008	<0.008	<0.008
Eh(mV)	255	----	462
Alkalinity (mg/L HCO_3)	26.5	31.4	23.5
Sum Cations (meq/L)	1.87	1.42	1.10
Sum Anions (meq/L)	1.89	1.46	0.70
Charge Balance %	-1.23	3.24	44.2

Element		mg/L	
Ca	15.6	10.8	7.88
Mg	0.145	0.3	0.46
Sr	0.366	0.26	0.20
Ba	0.105	0.110	0.12
Na	0.612	0.80	0.63
K	13	12.5	11.8
Li	<0.01	<0.01	0.002
Fe(II)	9.25	—	6.13
Fe(tot)	9.35	8.68	6.27
Al	1.05	0.6	0.183
Mn	6.86	2.95	2.17
Zn	0.490	0.17	0.13
Cd	<0.005	<0.005	<0.0005
Cu	<0.005	<0.005	<0.0005
Cr	<0.02	<0.02	<0.02
Co	<0.020	<0.020	<0.0005
Ni	<0.025	<0.025	<0.025
Mo	<0.035	<0.035	0.014
Pb	<0.09	<0.09	≤0.0005
Zr	<0.0015	<0.0015	<0.0005
V	<0.015	<0.015	<0.2
U	0.008	0.011	0.002
SO_4	53	30	28
F	6.7	6.16	6.0
Cl	<2.0	<2.0	<2.0
Br	<0.05	<0.05	<0.05
NO_3	<0.10	<0.10	<0.10
HPO_4	<0.1	<0.1	<0.1
B	0.230	0.020	<0.015
SiO_2	37	37.3	34
S^{2-}	<0.001	<0.001	----

. Selected analytical results of surface and groundwater samples from locations within the Osamu Utsumi Mine study site

Borehole	9-1UC16	SHAFT	SUPPLY DAM
Sample Code No.	PC-GW-21	PC-GW-28	PC-SW-03
Sampling Int (m)	--	0-40	---
Date Collected	870729	871007	870709
Temperature (°C)	21.02	20.05	17.5
pH (lab)	5.5	5.7	6.5
Cond.(mS/m)	6.0	6.4	6.0
Eh(mV)	--	---	---
Alkalinity (mg/L HCO_3)	10	20	9
Sum Cations (meq/L)	0.53	6.77	0.16
Sum Anions (meq/L)	0.62	6.66	0.18
Charge Balance %	-15.8	1.6	-9.3
Element		**mg/L**	
Ca	2.40	59.8	0.14
Mg	0.134	2.28	<0.10
Sr	0.108	1.61	0.01
Ba	0.129	0.059	0.014
Na	0.22	1.35	0.19
K	12.2	21.8	5.3
Li	<0.02	<0.02	<0.02
Fe(II)	--	44.5	0.012
Fe(tot)	0.03	44.7	0.14
Al	0.55	7.68	<0.02
Mn	0.19	13.1	0.088
Zn	0.12	0.184	<0.02
Cd	<0.02	<0.02	<0.01
Cu	0.018	<0.015	<0.02
Cr	<0.05	<0.05	<0.05
Co	<0.035	<0.035	<0.035
Ni	<0.02	<0.02	<0.02
Mo	<0.03	<0.03	<0.03
Ag	<0.05	<0.05	<0.05
Pb	<0.10	<0.10	<0.10
Zr	<0.01	<0.01	<0.01
SO_4	20	278	0.98
F	0.75	10.3	0.13
Cl	<0.20	<0.20	<0.20
Br	<0.01	---	---
NO_3	0.29	<0.02	0.19
HPO_4	<0.05	<0.02	<0.05
B	<0.02	<0.02	<0.02
SiO_2	32.0	38.6	8.0

Selected analytical results of groundwater samples from the Osamu Utsumi Mine study site

	Piezometer Station	Piezometer Station
Borehole	PM 22	PM 22
Sample Code No.	PC-GW-19	PC-GW-27
Sampling Int (m)	0 - 20	0 - 20
Date Collected	870707	871002
Temperature (C)	21.5	20.0
pH (lab)	6.7	6.2
Cond.(mS/m)	6.0	6.3
Eh(mV)	---	---
Alkalinity (mg/L HCO_3)	28	30
Sum Cations (meq/L)	0.79	0.84
Sum Anions (meq/L)	0.90	0.93
Charge Balance %	-12.7	-10.2

Element	mg/L	
Ca	4.90	5.0
Mg	0.37	0.749
Sr	0.156	0.154
Ba	0.04	0.043
Na	0.45	0.417
K	13.4	13.9
Li	<0.02	<0.02
Fe(II)	2.04	2.08
Fe(tot)	2.23	2.13
Al	0.034	0.048
Mn	1.77	1.80
Zn	<0.02	0.74
Cd	<0.02	<0.01
Cu	<0.02	<0.015
Cr	<0.05	<0.05
Co	<0.035	<0.035
Ni	<0.02	<0.02
Mo	<0.03	<0.03
Ag	<0.05	<0.05
Pb	<0.10	<0.10
Zr	<0.01	<0.01
V	---	---
U	---	---
SO_4	9.97	10.4
F	4.45	4.15
Cl	<0.20	<0.20
Br	---	---
NO_3	---	0.04
HPO_4	<0.05	<0.02
B	<0.02	<0.02
SiO_2	42.0	44.6

Selected analytical results of groundwater samples from the Osamu Utsumi Mine

Borehole	SW-01	SW-01	SW-01	SW-01	SW-01
Sample Code No.	PC-GW-37	PC-GW-46	PC-GW-57	PC-GW-68	PC-GW-75
Sampling Int (m)	3-12	3-12	3-12	3-12	3-12
Date Collected	880202	880607	880921	881202	890316
Temperature(°C)	22	20.3	21	21	21
pH [field/lab] lab	[3.1/2.95]3.05	[3.32/3.16](3.32)	[3.93/3.93]3.45	[3.37/3.29]2.66	[2.35/2.54]2.34
D.O. (mg/L)	----	<0.008	3.27	<0.008	<0.008
Eh(mV)	834	702	694	627	737
Alkalinity (mg/L HCO_3)	<5.0	<0.60	<0.60	<0.60	<0.60
Sum Cations (meq/L)	14.3	12.61	4.57	23.7	32.0
Sum Anions (meq/L)	19.8	26.5	4.83	25.8	55.4
Charge Balance %	-32.1	-20.3	-5.53	-8.64	-53.4

Element	mg/L				
Ca	74.1	150	37	127	72.9
Mg	4.66	10.3	2.09	9.25	4.35
Sr	1.97	3.6	0.86	3.19	2.38
Ba	0.022	0.026	0.051	0.025	0.02
Na	1.2	1.7	1.0	2.0	1.39
K	19	32	20	37.7	32
Li	0.0106	0.024	<0.010	0.24	0.031
Fe(II)	1.20	35.2	<0.10	50.5	52.0
Fe(tot)	5.04	36.8	0.011	53.5	171.1
Al	65.5	74.2	10.380	98	112.0
Mn	30.1	52	18	46	41.3
Zn	5.80	9.5	1.83	12.8	10.1
Cd	0.016	0.036	<0.005	0.048	0.056
Cu	<0.015	<0.015	<0.005	<0.005	0.006
Cr	<0.12	<0.12	<0.02	<0.02	0.165
Co	0.052	<0.035	<0.020	<0.020	<0.020
Ni	0.117	0.265	<0.025	0.29	0.173
Mo	<0.050	<0.050	<0.035	<0.035	<0.035
Pb	0.176	0.35	<0.090	0.86	0.436
Zr	0.061	0.051	<0.015	0.088	0.417
V	----	<0.2	<0.2	0.039	<0.2
U	0.7068	[0.9046]5.17	0.432	11.8	24.5
Th	----	0.290	----	----	----
SO_4	830	1100	209	1200	2610
F	46	66	8.5	14.9	15
Cl	<1.0	<0.10	<0.20	<2.0	<2.0
Br	<0.050	<0.050	0.059	<0.05	<0.05
NO_3	1.48	3.20	1.74	<0.10	3.19
HPO_4	0.26	0.45	<0.10	<0.1	<0.1
B	<0.020	----	<0.015	0.094	0.225
SiO_2	47	66	32	72	74
S^{2-}	<0.001	<0.001	<0.001	0.0012	0.0011

Selected analytical results of groundwater samples from the Osamu Utsumi Mine

Borehole	SW-02
Sample Code No.	PC-GW-38
Sampling Int (m)	3-12
Date Collected	880203
Temperature(°C)	23
pH (lab)	2.93
Cond.(mS/m)	----
Eh(mV)	885
Alkalinity (mg/L HCO_3)	<5.0
Sum Cations (meq/L)	6.27
Sum Anions (meq/L)	7.82
Charge Balance %	-11.01

Element	mg/L
Ca	23.30
Mg	2.34
Sr	1.41
Ba	0.028
Na	1.82
K	29.9
Li	<0.015
Fe(II)	1.03
Fe(tot)	8.53
Al	35.2
Mn	9.14
Zn	3.58
Cd	0.045
Cu	<0.015
Cr	<0.12
Co	0.043
Ni	0.044
Mo	<0.050
Pb	0.957
Zr	0.064
V	----
U	3.42
SO_4	458
F	8.98
Cl	1.1
Br	<0.050
NO_3	4.05
HPO_4	0.18
B	<0.020
SiO_2	54
S^{2-}	0.132

Selected analytical results of groundwater samples from the Osamu Utsumi Mine

Borehole	SW-03	SW-03	SW-03	SW-03	SW-03
Sample Code No.	PC-GW-39	PC-GW-47	PC-GW-58	PC-GW-66	PC-GW-76
Sampling Int (m)	3-12	3-12	3-12	3-12	3-12
Date Collected	880203	880607	880922	881130	890316
Temperature(°C)	22	20.0	20	20	21
pH [field/lab] lab	[3.4] 3.50	[3.57/3.43] 3.41	[4.43/4.38] 3.92	[3.45/3.53]3.19	[2.88/3.06]3.06
D.O. (mg/L)	4.52	4.37	4.60	2.73	5.44
Eh(mV)	754	786	657	834	737
Alkalinity (mg/L HCO_3)	<5.0	<0.60	<0.60	<0.60	<0.60
Sum Cations (meq/L)	9.18	5.06	0.715	5.44	14.3
Sum Anions (meq/L)	11.2	7.62	0.773	6.95	21.5
Charge Balance %	-19.9	-40.3	-7.85	-24.4	-39.8
Element		mg/L			
Ca	29.00	24.7	2.5	16.5	38.4
Mg	5.30	3.6	0.85	4.7	7.8
Sr	1.74	1.46	0.25	1.30	2.36
Ba	0.025	0.036	0.095	0.067	0.045
Na	0.69	1.6	0.8	1.0	1.0
K	29	25	12	27.9	34.3
Li	0.0078	<0.015	<0.010	<0.01	0.014
Fe(II)	<0.10	<0.10	<0.10	0.10	<0.10
Fe(tot)	0.14	0.12	<0.10	0.29	1.59
Al	44.8	23	0.790	23.10	72.5
Mn	18.4	12.6	1.0	9.87	26
Zn	6.95	4.17	0.33	4.30	12.5
Cd	0.050	0.037	<0.005	0.027	0.10
Cu	<0.015	<0.015	<0.005	0.025	<0.005
Cr	<0.12	<0.12	<0.02	<0.02	<0.020
Co	0.047	0.048	<0.020	0.029	0.071
Ni	0.050	<0.085	<0.025	0.052	0.069
Mo	<0.050	<0.050	<0.035	<0.035	<0.035
Pb	1.48	0.96	<0.090	1.01	1.3
Zr	0.108	0.054	<0.015	0.0570	0.154
V	---	<0.2	<0.2	0.020	<0.2
U	2.27	3.41	0.399	5.77	13.4
Th	---	0.030	---	---	0.24
SO_4	500	338	33.1	321.0	1000
F	12.4	9.3	0.47	3.76	10.4
Cl	2.2	<2.0	1.00	<2.0	<2.0
Br	<0.050	<0.050	0.010	<0.05	<0.05
NO_3	4.36	5.26	1.93	4.08	4.27
HPO_4	0.14	<0.05	<0.010	<0.1	<0.1
B	0.0062	---	<0.015	<0.015	0.027
SiO_2	41	38	21.4	46	54
S^{2-}	---	<0.001	<0.001	<0.001	<0.001

Selected analytical results of surface water samples from the Morro do Ferro study site

Borehole	South Stream	North Stream
Sample Code No.	PC-SW-04	PC-SW-05
Sampling Int (m)	---	---
Date Collected	870729	870810
Temperature (°C)	---	---
pH (Lab)	6.3	4.9
Cond.(mS/m)	---	---
Eh(mV)	---	---
Alkalinity (mg/L HCO_3)	4	4
Sum Cations (meq/L)	0.07	0.10
Sum Anions (meq/L)	0.09	0.11
Charge Balance %	-32.4	-7.5
Element	**mg/L**	
Ca	0.15	0.20
Mg	0.012	0.015
Sr	0.002	0.006
Ba	0.003	0.005
Na	0.11	0.12
K	2.0	2.6
Li	<0.02	<0.02
Fe(II)	<0.10	<0.10
Fe(tot)	<0.10	<0.10
Al	<0.02	<0.02
Mn	<0.004	<0.02
Zn	<0.02	<0.02
Cd	<0.02	<0.02
Cu	<0.015	<0.015
Cr	<0.05	<0.05
Co	<0.035	<0.035
Ni	<0.02	<0.02
Mo	<0.03	<0.03
Ag	<0.02	<0.05
Pb	<0.10	<0.10
Zr	<0.01	---
SO_4	0.50	1.5
F	<0.01	---
Cl	0.50	0.26
Br	---	<0.01
NO_3	<0.02	0.18
HPO_4	<0.05	<0.05
B	<0.02	<0.02
SiO_2	9.30	12.0

Selected analytical results of groundwater samples from the Morro do Ferro study site

Borehole	MF 10	MF 10	MF 10
Sample Code No.	PC-GW-12*	PC-GW-33	PC-GW-48
Sampling Int (m)	30-70	50-74	50-74
Date Collected	861212	880127	880608
Temperature (°C)	---	22	21
pH [field/lab] lab	6.0	[4.60/6.57] 6.21	[6.37/6.77] 5.82
Cond.(mS/m)	---	---	---
Eh(mV)	---	534	-93
Alkalinity (mg/L HCO_3)	7.39	12	18.9
Sum Cations (meq/L)	0.218	0.010	0.053
Sum Anions (meq/L)	0.121	0.228	0.318
Charge Balance %	57.0	-78.5	-142.8
Element		mg/L	
Ca	1.2	0.20	<0.05
Mg	0.42	0.02	0.09
Sr	0.05	0.005	0.004
Ba	0.09	≤0.001	0.002
Na	0.65	0.079	<0.05
K	0.86	0.14	0.35
Li	---	<0.015	<0.015
Fe(II)	---	0.55	0.53
Fe(tot)	0.06	0.58	0.54
Al	0.15	0.014	<0.06
Mn	1.38	0.427	0.338
Zn	<0.033	0.10	0.14
Cd	---	0.0014	<0.005
Cu	<0.02	0.0024	<0.015
Cr	<0.05	<0.12	0.012
Co	---	<0.035	<0.002
Ni	<0.02	0.0029	<0.003
Mo	---	<0.050	<0.050
Ag	0.05	---	---
Pb	<0.10	<0.100	<0.050
Zr	---	<0.045	<0.045
V	---	---	<0.2
U	---	0.003	0.0008
Th	---	---	0.00006
SO_4	---	0.2	<0.1
F	---	0.07	0.10
Cl	---	0.84	<0.10
Br	---	0.002	<0.050
NO_3	---	0.004	<0.01
HPO_4	---	<1.0	0.09
B	0.01	<0.0038	---
SiO_2	1.2	1.2	1.1
S^{2-}	---	<0.0005	<0.0001

* This analysis is incomplete and sampling procedures may have given rise to contamination.

Selected analytical results of groundwater samples from the Morro do Ferro study site

Borehole	MF 10	MF 10	MF 10
Sample Code No.	PC-GW-52	PC-GW-69	PC-GW-83
Sampling Int (m)	50-74	50-74	50-74
Date Collected	880912	881206	890405
Temperature(°C)	21	22	22
pH [field/lab] lab	[6.13/6.38] 5.95	[5.91/5.94] 5.63	[6.05/6.10] 6.10
D. O.(mg/L)	3.6	3.0	4.3
Eh(mV)	335	448	504
Alkalinity (mg/L HCO_3)	2.8	2.9	3.0
Sum Cations (meq/L)	0.094	0.097	0.090
Sum Anions (meq/L)	0.096	0.113	0.084
Charge Balance %	-3.13	-15.1	7.36
Element		mg/L	
Ca	0.13	<0.035	0.238
Mg	<0.07	<0.070	0.352
Sr	0.007	0.004	0.0050
Ba	0.006	0.004	0.0040
Na	0.5	0.10	0.043
K	1.0	2.2	0.20
Li	<0.10	<0.01	<0.010
Fe(II)	0.65	0.46	0.73
Fe(tot)	0.66	0.52	0.76
Al	<0.050	<0.05	<0.05
Mn	0.309	0.308	0.277
Zn	0.119	0.143	0.124
Cd	<0.005	<0.005	<0.005
Cu	<0.005	<0.005	<0.005
Cr	<0.02	<0.02	<0.020
Co	<0.020	<0.020	<0.020
Ni	<0.025	<0.025	<0.025
Mo	<0.035	<0.035	<0.035
Pb	<0.090	<0.09	<0.09
Zr	<0.015	<0.0015	<0.015
V	<0.02	<0.0015	<0.2
U	<0.001	0.001	0.001
SO_4	1.0	3.1	1.5
F	0.1	0.2	0.07
Cl	0.79	<2.00	<2.0
Br	0.009	<0.05	<0.05
NO_3	0.13	<0.10	<0.10
HPO_4	<0.10	<0.1	<0.1
B	<0.015	<0.015	<0.015
SiO_2	1.2	1.1	1.1
S^{2-}	<0.001	----	---

Selected analytical results of groundwater samples from the Morro do Ferro study site

Borehole	MF 11	MF 11	MF 11	MF 11	MF 11
Sample Code No.	PC-GW-35	PC-GW-49	PC-GW-53	PC-GW-70	PC-GW-82
Sampling Int (m)	30-40	30-40	30-40	30-40	30-40
Date Collected	880128	880613	880914	881212	890404
Temperature (°C)	22	22.8	20	23	22
pH [field/lab] lab	[5.2/6.28] 6.02	[5.12/5.60] 5.71	[5.35/5.24] 5.65	[5.26/6.13] 5.44	[5.31/5.62] 4.96
D.O. (mg/L)	6.4	8.2	7.8	7.5	8.5
Eh(mV)	458	617	585	657	525
Alkalinity (mg/L HCO_3)	1.0	1.0	0.1	0.6	0.8
Sum Cations (meq/L)	0.040	0.027	0.012	0.022	0.019
Sum Anions (meq/L)	0.053	0.058	0.048	0.012	0.022
Charge Balance %	-27.0	-74.0	-118	58.2	-15.8

Element			mg/L		
Ca	0.17	<0.20	<0.07	<0.03	<0.03
Mg	<0.1	0.03	<0.07	<0.07	0.029
Sr	0.003	0.002	0.004	0.002	0.0015
Ba	0.010	0.001	0.004	0.003	0.003
Na	0.05	0.16	0.05	0.05	0.09
K	0.24	0.19	0.14	0.15	0.16
Li	<0.015	<0.015	<0.010	<0.01	0.0003
Fe(II)	0.19	<0.10	<0.10	<0.10	<0.10
Fe(tot)	0.24	0.05	<0.10	<0.010	<0.010
Al	<0.06	<0.06	<0.050	0.07	0.002
Mn	0.183	0.080	0.048	0.053	0.05
Zn	0.03	<0.03	0.014	0.014	0.05
Cd	<0.005	<0.005	<0.005	<0.005	<0.0005
Cu	<0.015	<0.015	<0.005	<0.005	0.004
Cr	<0.12	<0.12	<0.02	<0.02	<0.020
Co	<0.035	<0.035	<0.020	<0.020	<0.0005
Ni	<0.025	<0.085	<0.025	<0.025	<0.025
Mo	<0.050	<0.050	<0.035	<0.035	<0.0005
Pb	<0.100	<0.050	<0.090	<0.09	0.002
Zr	<0.045	<0.045	<0.015	<0.0015	<0.015
V	---	<0.2	<0.2	<0.0015	<0.2
U	0.0008	0.0012	<0.001	0.001	0.0006
Th	---	0.0002	---	---	0.000003
SO_4	0.5	<0.1	0.5	<2.0	<2.0
F	0.06	0.11	0.145	0.04	0.1
Cl	0.78	0.99	0.98	<2.0	<2.0
Br	0.0009	<0.050	<0.005	<0.05	<0.05
NO_3	0.064	0.07	0.06	<0.10	0.25
HPO_4	<1.0	0.21	<0.10	<0.1	<0.1
B	0.0016	---	<0.015	<0.015	<0.015
SiO_2	1.2	1.0	1.1	1.11	1.08
S^{2-}	<0.0005	<0.0001	<0.001	<0.001	<0.001

Selected analytical results of groundwater samples from the Morro do Ferro study site

Borehole	MF 12	MF 12	MF12
Sample Code No.	PC-GW-18	PC-GW-34	PC-GW-50
Sampling Int (m)	20-70	45-71	45-71
Date Collected	870707	880128	880614
Temperature (°C)	23	23	21
pH (lab)	7.0	[5.7/6.36] 7.09	[5.99/6.19] 6.55
Cond.(mS/m)	---	---	---
Eh(mV)	---	303	212
Alkalinity (mg/L HCO_3)	12	19.3	22
Sum Cations (meq/L)	0.33	0.922	0.935
Sum Anions (meq/L)	0.28	0.923	0.895
Charge Balance %	14.8	-0.153	4.32
Element		mg/L	
Ca	1.18	8.18	8.48
Mg	0.28	0.61	0.70
Sr	0.041	0.301	0.346
Ba	0.004	0.0007	<0.001
Na	1.95	0.69	0.84
K	4.1	11.0	11.2
Li	<0.02	<0.015	<0.015
Fe(II)	---	1.31	0.74
Fe(tot)	1.0	1.33	0.79
Al	<0.1	0.22	0.21
Mn	0.48	1.56	1.68
Zn	<0.033	0.45	0.27
Cd	<0.024	<0.005	<0.005
Cu	<0.043	<0.015	<0.015
Cr	<0.12	<0.12	<0.12
Co	<0.035	<0.035	<0.035
Ni	<0.085	<0.025	<0.085
Mo	<0.6	<0.050	<0.050
Pb	---	<0.100	<0.050
Zr	---	<0.045	<0.045
V	---	---	<0.2
U	---	0.0005	0.00075
Th	---	---	0.00007
SO_4	0.92	9.41	9.5
F	0.68	7.0	5.3
Cl	1.04	1.5	<0.10
Br	<0.05	0.0003	<0.050
NO_3	<0.1	<0.1	1.0
HPO_4	<0.1	<1.0	<0.05
B	<0.02	0.001	---
SiO_2	3.0	33.4	33.4
S^{2-}	---	----	<0.001

Selected analytical results of groundwater samples from the Morro do Ferro study site

Borehole	MF 12	MF 12	MF 12
Sample Code No.	PC-GW-56	PC-GW-71	PC-GW-85
Sampling Int (m)	45-71	45-71	45-71
Date Collected	880919	881214	890411
Temperature(°C)	24	23	22
pH [field/lab] lab	[6.13/6.20] 6.14	[6.11] 6.50	[6.22/6.63] 6.13
D.O. (mg/L)	0.20	0.32	0.6
Eh(mV)	212	388	446
Alkalinity (mg/L HCO_3)	18.7	18.3	23.6
Sum Cations (meq/L)	0.725	1.06	0.788
Sum Anions (meq/L)	0.750	0.95	0.921
Charge Balance %	-3.5	11.1	-15.6

Element		mg/L	
Ca	6.7	9.5	6.75
Mg	0.50	0.72	0.51
Sr	0.22	0.36	0.2
Ba	0.003	0.001	0.0002
Na	0.5	0.70	0.72
K	9.06	11	10.5
Li	<0.010	<0.01	0.0006
Fe(II)	0.66	0.57	----
Fe(tot)	0.68	0.58	0.557
Al	0.42	0.32	0.12
Mn	1.2	1.87	1.45
Zn	0.80	0.28	0.6
Cd	<0.005	<0.005	<0.0005
Cu	<0.005	<0.005	<0.0005
Cr	<0.02	<0.02	<0.020
Co	<0.020	<0.020	<0.0005
Ni	<0.025	<0.025	<0.025
Mo	<0.035	<0.035	0.0007
Rb	----	----	0.016
Cs	----	----	0.001
Pb	<0.090	<0.09	0.0007
Zr	<0.015	<0.0015	<0.015
V	<0.2	<0.0015	<0.2
U	<0.001	0.001	0.004
Th	----	----	0.000029
SO_4	10	9.6	10.1
F	4.4	5.5	6.0
Cl	0.13	<2.0	0.3
Br	<0.005	<0.05	<0.05
NO_3	0.02	<0.10	<0.10
HPO_4	<0.010	<0.1	<0.1
B	<0.015	<0.015	0.019
SiO_2	30	37	33
S^{2-}	<0.002	----	----

Selected analytical results of groundwater samples from the Morro do Ferro study site

Borehole	MF 13	MF 13
Sample Code No.	PC-GW-73	PC-GW-84
Sampling Int (m)	45-71	45-71
Date Collected	881220	890407
Temperature(°C)	22	23
pH [field/lab] lab	[5.45] 5.55	[5.19/5.10] 4.70
D.O. (mg/L)	6.74	4.00
Eh(mV)	663	659
Alkalinity (mg/L HCO_3)	0.61	0.34
Sum Cations (meq/L)	0.071	0.024
Sum Anions (meq/L)	0.067	0.020
Charge Balance %	5.50	19.7
Element		**mg/L**
Ca	0.585	<0.035
Mg	<0.070	0.057
Sr	0.002	0.002
Ba	0.003	0.003
Na	0.12	0.05
K	0.48	<0.10
Li	<0.01	0.0004
Fe(II)	<0.10	<0.10
Fe(tot)	0.010	<0.010
Al	0.16	0.094
Mn	0.041	0.0060
Zn	0.030	<0.050
Cd	<0.005	<0.0005
Cu	<0.005	<0.001
Cr	<0.02	<0.020
Co	<0.020	<0.0005
Ni	<0.025	<0.025
Mo	<0.035	<0.0005
Pb	<0.09	<0.0009
Zr	<0.0015	<0.0005
V	<0.0015	<0.2
U	0.001	0.00045
SO_4	1.0	<2.0
F	0.64	0.16
Cl	<2.00	<2.0
Br	<0.05	<0.05
NO_3	0.16	0.36
HPO_4	<0.1	<0.01
B	<0.015	<0.015
SiO_2	2.58	1.18
S^{2-}	<0.001	<0.001

Appendix 3

Selected analytical results of groundwater samples from the Osamu Utsumi mine and Morro do Ferro study sites.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole		F1(9-1WC11)	F1(9-1WC11)	F1(9-1WC11)	F1(9-1WC11)
Sample Code No.		PC-GW-09	PC-GW-14	PC-GW-15	PC-GW-17
Sampling Int (m)		96.5-125.7	96.5-125.7	96.5-125.7	96.5-125.7
Date Collected		861113	870106	870210	870506
Temperature(°C)		20.5	21.0	20.0	22.5
pH (lab)		5.8	5.4	5.5	5.5
Cond.(mS/m)		6.2	6.0	---	[6.2]
Eh(mV)		325	---	---	203
Alkalinity (mg/L HCO_3)		[13]	[12]	[13]	[11]
Element	**Analytical Method**		**mg/L**		
Ca	ICP (AA)	0.41 (0.59)	0.37 (0.85)	0.73 (0.63)	0.82 (0.75)
Mg	ICP (AA)	0.11 (<0.05)	0.05 (<0.05)	<0.14 (<0.1)	<0.14 (<0.10)
Sr	ICP (AA)	0.09 (0.006)	0.10 (0.006)	0.053 (0.05)	0.064 (0.07)
Ba	ICP (AA)	0.42 (0.15)	0.45 (0.14)	0.15 (0.15)	0.17 (0.16)
Na	ICP	1.29	0.57	0.23	0.38
K	ICP	7.63	10.24	13.3	13.4
Li	ICP	---	---	---	<0.02
Fe(II)	[COLOR]	[1.60]	[1.53]	[1.62]	[2.03]
Fe(tot)	ICP (AA)	[1.70] 1.51 (1.08)	[1.62] 1.58 (1.46)	[1.67] 1.63 (1.60)	[2.06] (1.94)
Al	ICP (AA)	0.31 (0.07)	0.17 (0.14)	<0.06 (<0.1)	0.03
Mn	ICP (AA)	0.27 (0.26)	0.31 (0.25)	0.27 (0.26)	0.35 (0.33)
Zn	ICP (AA)	0.15 (0.14)	0.12 (0.12)	0.11 (0.2)	0.13 (0.11)
Cd	ICP (AA)	(<0.02)	(<0.02)	---	<0.024 (<0.02)
Cu	ICP (AA)	(<0.02)	(<0.02)	<0.043 (<0.01)	<0.043 (<0.02)
Cr	ICP (AA)	(<0.05)	(<0.05)	<0.12 (<0.02)	<0.12 (<0.05)
Co	ICP	---	---	<0.035	<0.035
Ni	ICP (AA)	(<0.02)	(<0.02)	<0.085 (<0.01)	<0.085 (<0.02)
Mo	ICP	---	---	<0.60	<0.60
Ag	(AA)	(<0.02)	(<0.02)	(<0.02)	--- (<0.05)
Pb	(AA)	(<0.10)	(<0.10)	(<0.10)	--- (<0.10)
Zr		---	---	---	<0.01
SO_4	IC [N]	[19]	[15.8]	15.4 [16.4]	18.8
F	ISE [ISE]	[0.74]	[0.47]	0.50 [0.59]	0.55
Cl	IC	---	---	<0.10	<0.10
Br	IC	---	---	<0.005	<0.05
NO_3	IC	---	---	<0.05	<0.02
HPO_4	IC	---	---	<0.10	<0.05
B	ICP (AA)	(<0.01)	(<0.02)	(<0.02)	<0.02 (<0.02)
SiO_2	ICP (AA)	32.5 (36)	32.7 (36.5)	35.1 (36.0)	32.1 (33.17)

Values reported from BGS except ( ) = CENA, Piracicaba, and [ ] Urânio do Brasil, PdeC.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole	F1 (9-1WC11)	F1 (9-1WC11)
Sample Code No.	PC-GW-22	PC-GW-23
Sampling Int (m)	96.5-125.7	96.5-125.7
Date Collected	870820	870917
Temperature (°C)	[20.5]	[20.4]
pH (lab)	[6.1]	[5.7]
Cond.(mS/m)	[6.1]	[6.2]
Eh(mV)	[220]	---
Alkalinity (mg/L HCO_3)	[8]	[8]

Element	Analytical Method	mg/L	
Ca	ICP (AA)	0.51 (0.16)	0.518 (0.18)
Mg	ICP (AA)	0.043	0.042 (<0.10)
Sr	ICP (AA)	0.034 (0.03)	0.035 (0.03)
Ba	ICP (AA)	0.107 (0.04)	0.108 (0.09)
Na	ICP	0.16	0.196
K	ICP	12.0	12.0
Li	ICP	<0.02	<0.02
Fe(II)	[COLOR]	[1.12]	[1.24]
Fe(tot)	ICP (AA)	[1.18] (1.06)	[1.33]
Al	ICP (AA)	0.04	0.04
Mn	ICP (AA)	0.15 (0.14)	0.14 (0.14)
Zn	ICP (AA)	0.045	0.036 (0.03)
Cd	ICP (AA)	<0.1	<0.01 (<0.02)
Cu	ICP (AA)	<0.015	<0.015 (<0.02)
Cr	ICP (AA)	<0.12	<0.12 (<0.05)
Co	ICP	<0.035	<0.035
Ni	ICP (AA)	<0.020	<0.020 (<0.02)
Mo	ICP	<0.030	<0.030
Ag	(AA)	--- (<0.05)	---
Pb	(AA)	--- (<0.10)	---
Zr		<0.01	<0.01
SO_4	IC [N]	14.5	14.8
F	ISE [ISE]	0.34	0.29
Cl	IC	<0.2	<0.20
Br	IC	---	---
NO_3	IC	<0.02	---
HPO_4	IC	<0.05	<0.02
2B	ICP (AA)	<0.01 (<0.02)	<0.02
SiO2	ICP (AA)	32.53 (36.17)	32.31

Values reported from BGS except ( ) = CENA, Piracicaba and [ ] Urânio do Brasil, PdeC.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole	F1 (9-1WC11)	F1 (9-1WC11)	F1 (9-1WC11)
Sample Code No.	PC-GW-40	PC-GW-42	PC-GW-51
Sampling Int (m)	96.5-125.7	96.5-125.7	96.5-125.7
Date Collected	880208	880601	880707
Temperature(°C)	[23]	[21.3]	22
pH [field/lab] lab	[--/5.67] 2.35	[5.25/5.53] 5.51	4.87/4.06
D.O. (mg/L)	0.19	----	----
Eh(mV)	----	[146]	338
Alkalinity (mg/L HCO_3)	[11.3] <5.0	[11.4] <5.0	<5.0

Element	Analytical Method	mg/L		
Ca	ICP	0.52 *1.44	0.43 (0.47)	0.45 ((0.46/0.48))
Mg	ICP	<0.14 *0.032	0.06 (0.10)	0.07 ((0.12/0.07))
Sr	ICP	0.040 *0.044	0.041 (0.0438)	0.044 ((0.045/0.046))
Ba	ICP	0.111 *0.076	0.119 (0.133)	0.124 ((0.135/0.137))
Na	[AA] ICP	[0.57] 0.19 *0.12	[0.44] 0.20 (0.23)	0.19 ((<0.20/<0.20))
K	[AA] ICP	[10.0] 10.9 *7.2	[11.0] 12.6 (13.1)	12.0 ((13.1/12.7))
Li	ICP	<0.015 *0.0005	<0.015	<0.010
Fe(II)	[COLOR]	[1.2] ---	[1.26] ---	----
Fe(tot)	[COLOR] ICP	[1.23] 1.19 *0.63	[1.29] 1.30 (0.14)	1.32 ((0.28/0.20))
Al	ICP	0.07 *0.19	<0.06 (<0.5)	<0.050 ((<0.5))
Mn	ICP	0.173 *0.12	0.180 (0.19)	0.104 ((0.19/0.20))
Zn	ICP	0.07 *0.136	0.07 (0.102)	0.081 ((0.093/0.115))
Cd	ICP	<0.005 *<d.l.	<0.005 (<0.050)	<0.005 ((<0.005))
Cu	ICP	<0.015 *<d.l.	<0.015 (<0.050)	<0.005 ((<0.05))
Cr	ICP	<0.12 *<d.l.	<0.12 (0.011)	<0.02 ((<0.01))
Co	ICP	<0.035 *<d.l.	<0.035 (<0.002)	---- ((<0.002))
Ni	ICP	0.029 *<d.l.	<0.085 (<0.003)	<0.025 ((<0.003))
Mo	ICP	<0.050 *0.0027	<0.050	<0.035
Pb		<0.100 *<d.l.	<0.050 (<0.2)	<0.090 ((<0.2))
Zr		<0.045 *<d.l.	<0.045	<0.015
V		----	[<0.2]	----
U	ICP/MS	[0.0014]{0.007}	[0.0003] 0.0045	((<0.001/0.0014))
Th	ICP/MS	----	<0.00005	---
SO_4	IC [N]	[18.1] 15.80*--/8.40	[20.0]15.8/15.0	15.5
F	ISE [ISE]	[0.40] 0.43 *---	[0.41] 0.31	0.30
Cl	IC	52.5 *---	0.18	1.38
Br	IC	<0.050 *---	<0.050	<0.005
NO_3	IC	<0.10 *---	<0.01	0.02
HPO_4	IC	0.18 *---	<0.05	<0.10
B	ICP	<0.020 *0.0025		<0.015
SiO_2	ICP	31 *18.6	30 (37.0)	33 ((37.0/37.2))
S^{2-}	[ISE]	[0.005]	[0.004]	---

Values reported from BGS except ( ) = CENA, Piracicaba and [ ] Urânio do Brasil, PdeC, { } = PUC, Miekeley, (( )) = U.S.G.S. data, J.W. Ball, number before slash is on filtered sample, after slash is on unfiltered sample. Alkalinities reported for methyl orange, Gran's titrations. *Values reported from BGS on x40 concentrates.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole	F1 (9-1WC11)	F1 (9-1WC11)	F1 (9-1WC11)
Sample Code No.	PC-GW-54	PC-GW-63	PC-GW-77
Sampling Int (m)	96.5-125.7	96.5-125.7	96.5-125.7
Date Collected	880915	881129	890320 {890412}
Temperature(°C)	21	21	22
pH [field/lab] lab	[5.35/5.64] 6.08	[5.37/5.47] 6.08	[5.27/6.45] 5.27 {5.36}
D.O. (mg/L)	<0.008	<0.008	<0.008
Eh(mV)	308	239/207	217 {301}
Alkalinity (mg/L HCO_3)	[3.10,2.58]7.89	[13,11.5/7.79]	[3.38,12.2]<5.0

Element	Analytical Method	mg/L		
Ca	ICP (AA)	0.59 (0.82)	0.622	0.431
Mg	ICP (AA)	<0.07 (0.28)	0.077	0.141 {0.050}
Sr	ICP (AA)	0.060 (0.06)	0.039	0.038 {0.038}
Ba	ICP (AA)	0.156 (0.16)	0.115	0.112 {0.125}
Na	ICP	0.19 [0.64]	0.229 [0.52]	0.166 [0.49] {0.181}
K	ICP	13.30 [11.0]	13.2 [12.2]	14.2 [11.0]
Li	ICP	<0.010	<0.01	<0.010 {0.002}
Fe(II)	[COLOR]	---- [1.76]	---- [1.50]	---- [1.14]
Fe(tot)	ICP (AA)	1.720 [1.77] (2.09)	1.21 [1.52]	1.14 [1.17]
Al	ICP (AA)	<0.050 (0.39)	<0.05	0.09 {0.053}
Mn	ICP (AA)	0.260 (0.30)	0.161	0.164 {0.125}
Zn	ICP (AA)	0.106 (0.12)	0.067	0.066 {0.079}
Cd	ICP (AA)	<0.005 (<0.02)	<0.005	<0.005 {<0.0005}
Cu	ICP (AA)	<0.005 (<0.02)	<0.005	<0.005 {0.014}
Cr	ICP (AA)	<0.02 (0.05)	<0.02	<0.02
Co	ICP	----	<0.020	<0.020 {<0.0005}
Ni	ICP (AA)	<0.025 (<0.02)	<0.025	<0.025
Mo	ICP	<0.035	<0.035	<0.035 {0.011}
Rb		----	----	{0.026}
Cs		----	----	{<0.0005}
Pb	(AA)	<0.015 (0.15)	<0.09	<0.09 {0.001}
Zr		----	<0.0015	<0.015 {<0.0005}
V		---- [<0.2]	<0.015 [<0.2]	---- [<0.2]
U		----[0.005]((0.0035))	----[0.005]	----[0.0065] {0.00412}
Th		----	----	{0.000015}
SO_4	IC [N]	18.9 [25.5]	15.1 [17.6]	18.4 [25.5]
F	ISE [ISE]	0.40 [0.56]	0.29 [0.25]	0.68 [0.29]
Cl	IC	1.09	<2.0	<2.0
Br	IC	<0.020	<0.05	<0.05
NO_3	IC	<0.02	<0.10	<0.10
HPO_4	IC	<0.10 (<0.31)	<0.1	<0.1
B	ICP (AA)	<0.015 (<0.02)	<0.015	<0.015
SiO_2	ICP (AA)	32 (31.6)	33	31
S^{2-}		----[0.0038]	----[0.0056]	----[0.0040]

Values reported from BGS except ( ) = CENA, Piracicaba and [ ] Urânio do Brasil, PdeC, { } = ICP-MS from Degueldre, PSI. Alkalinities reported for methyl orange, Gran's titrations. (( )) = PUC, Miekeley.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole		F2 (9-1VC24)	F2 (9-1VC24)	F2 (9-1VC24)	F2 (9-1VC24)
Sample Code No.		PC-GW-13	PC-GW-16	PC-GW-20	PC-GW-25
Sampling Int (m)		45-60	45-60	45-60	45-60
Date Collected		861215	870212	870724	870928
Temperature (°C)		21.5	21.0	[21.0]	[21.0]
pH (lab)		5.8	5.8	[5.6]	[5.66]
Cond.(mS/m)		5.7	---	6.0	[6.3]
Eh(mV)		311	---	190	---
Alkalinity (mg/L HCO_3)		[10]	[13]	[11]	[11]
Element	**Analytical Method**		**mg/L**		
Ca	ICP (AA)	1.37 (2.10)	1.65 (1.32)	2.11 (1.91)	2.26 (1.87)
Mg	ICP (AA)	0.07 (<0.05)	<0.14 (<0.1)	<0.14 (<0.10)	0.044 (<0.10)
Sr	ICP (AA)	0.10 (0.007)	0.048 (0.04)	0.064 (0.07)	0.064 (0.07)
Ba	ICP (AA)	0.31 (0.11)	0.095 (0.09)	0.116 (0.11)	0.11 (0.09)
Na	ICP	0.52	0.19	0.14	0.109 [1.46]
K	ICP	9.26	11.3	11.8	11.7 [11.0]
Li	ICP	---	---	<0.02	<0.02
Fe(II)	[COLOR]	[0.58]	[0.89]	[0.56]	[0.61]
Fe(tot)	ICP (AA)	[0.79] 0.85 (0.97)	[0.95] 0.89 (0.9)	[0.58]	[0.73]
Al	ICP (AA)	0.44 (0.35)	0.35 (<0.1)	0.28	0.259
Mn	ICP (AA)	0.18 (0.19)	0.13 (0.11)	0.22 (0.20)	0.174 (0.17)
Zn	ICP (AA)	0.23 (0.23)	0.20 (0.21)	0.282 (0.33)	0.167 (0.17)
Cd	ICP (AA)	--- (<0.02)	---	<0.01 (<0.02)	<0.01 (<0.02)
Cu	ICP (AA)	(<0.02)	0.043 (<0.01)	<0.43 (<0.02)	<0.015 (<0.01)
Cr	ICP (AA)	(<0.05)	(<0.02)	<0.12 (<0.05)	<0.12 (<0.05)
Co	ICP	--- ---	<0.035	<0.035	<0.035
Ni	ICP (AA)	(<0.02)	<0.085 (<0.01)	<0.085 (<0.02)	<0.02 (<0.02)
Mo	ICP	--- ---	<0.060	<0.030	<0.030
Ag	(AA)	--- (<0.02)	(<0.02)	---	---
Pb	(AA)	--- (<0.10)	(<0.01)	<0.1 (<0.10)	<0.10 (<0.10)
U		---	---	---	{0.0068}
SO_4	IC [N]	[17]	12.6 [11.8]	14.0	12.9 [16.6]
F	ISE [ISE]	[1.74]	1.36 [1.88]	1.96	1.72 [2.25]
Cl	IC	---	<0.10	<0.2	<0.2
Br	IC	---	<0.005	---	<0.02
NO_3	IC	---	<0.010	<0.02	0.03
HPO_4	IC	---	<0.01	<0.05	0.06
B	ICP (AA)	(<0.01)_	(<0.02)	---	---
SiO_2	ICP (AA)	31.0 (35.0)	33.4 (35.7)	30.39 (31.03)	31.03 (33.17)

Values reported from BGS except ( ) = CENA, Piracicaba and [ ] Urânio do Brasil, PdeC, { } = PUC, Miekeley.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole	F2 (9-1VC24)	F2 (9-1VC24)	F2 (9-1VC24)
Sample Code No.	PC-GW-41	PC-GW-43	PC-GW-60
Sampling Int (m)	45 - 60	45 - 60	45 - 60
Date Collected	880209	880602	880923
Temperature(°C)	[22]	[21.0]	22
pH [field/lab] lab	[5.6/6.05] 6.11	[5.72/6.08] 5.98	[5.73/5.81] 6.06
D.O.(mg/L)	0.57	0.72	0.21
Eh(mV)	339	323	262
Alkalinity (mg/L HCO_3)	[14.8] <5.0	[13.3] 6.7	6.76 [6.20/9.47]

Element	Analytical Method	mg/L		
Ca	ICP	2.28 *0.28	2.11 ((2.40))	1.80 (2.12)
Mg	ICP	0.17 *0.028	0.07 ((<0.05))	<0.007 (0.24)
Sr	ICP	0.063 *0.071	0.064 ((0.779))	0.061 (0.06)
Ba	ICP	0.110 *0.024	0.104 ((0.119))	0.104 (0.10)
Na	[AA] ICP	[0.38] 0.14 *0.092	[0.45] 0.13 ((<0.20))	0.18 [0.44]
K	[AA] ICP	[9.50] 10.8 *6.2	[10.7] 11.8 ((12.5))	10.80 [10.9]
Li	ICP	<0.015 *0.0010	<0.015	<0.010
Fe(II)	[COLOR]	[0.98] ----	[1.05] ----	--- [0.92]
Fe(tot)	[COLOR] ICP	[1.01] 0.97 *0.74	[1.11] 0.92 ((<0.10))	0.881 [0.935](1.02)
Al	ICP	0.28 *0.038	0.23 ((<0.5))	0.220 (0.51)
Mn	ICP	0.185 *0.10	0.187 ((0.21))	0.169 (0.19)
Zn	ICP	0.15 *0.049	0.11 ((0.177))	0.169 (0.17)
Cd	ICP	<0.005 *<d.l.	<0.005 ((<0.005))	<0.005 (<0.02)
Cu	ICP	<0.015 *<d.l.	<0.015 ((<0.050))	<0.005 (<0.02)
Cr	ICP	<0.12 *<d.l.	<0.12 ((<0.010))	<0.02 (<0.05)
Co	ICP	<0.035 *<d.l.	<0.035 ((<0.002))	<0.020
Ni	ICP	<0.025 *<d.l.	<0.085 ((<0.003))	<0.025 (<0.02)
Mo	ICP	<0.050 *0.0065	<0.050	<0.035
Pb		<0.100 *<d.l.	<0.050 ((<0.2))	<0.090 (0.14)
Zr		<0.045 *<d.l.	<0.045	<0.015
V		----	[<0.2]	--- [<0.2]
U	ICP/MS	[0.0014] 0.0017	[0.0014] 0.0056	--- [<0.001]
Th	ICP/MS	----	<0.00005	---
SO_4	IC [N]	[16.8] 12.6 *11.5/9.15	[16.0] 12.8/12.1	12.6 [20/17.4]
F	ISE [ISE]	[12.1] 2.50	[2.18] 1.78	1.73 [1.83]
Cl	IC	<1.0 *1.28	<0.10	0.20
Br	IC	<0.050 *0.006	<0.050	<0.005
NO_3	IC	<0.10 *0.011	<0.01	0.04
HPO_4	IC	0.15 *0.0007	<0.05	<0.010
B	ICP	0.078 *0.0018	----	<0.015 (<0.02)
SiO_2	ICP	30 *19.1	29 ((35.0))	30 (30)
S^{2-}	[ISE]	[0.004]	[0.004]	[≤0.001]

Values reported from BGS except [ ] Urânio do Brasil, PdeC. *Values reported from BGS on x40 concentrates, ( ) = CENA, Piracicaba. (( )) U.S.G.S. data, J.W. Ball.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole		F2 (9-1VC24)	F2 (9-1VC24)
Sample Code No.		PC-GW-64	PC-GW-78
Sampling Int (m)		45 - 60	45 - 60
Date Collected		881129	890320 {890416}
Temperature(°C)		21	21
pH [field/lab] lab		[5.88/5.84] 5.75	[5.90/6.42] 5.73 {5.73}
D.O (mg/L)		<0.008	<0.008
Eh(mV)		270	191 {262}
Alkalinity (mg/L HCO_3)		[13.0/11.5,20.0/18.7] <5.0	[12.0,17.5/16.8] 10.1
Element	**Analytical Method**		**mg/L**
Ca	ICP (AA)	2.66 (128.8)	2.95
Mg	ICP (AA)	0.070 (4.64)	0.070 {0.086}
Sr	ICP (AA)	0.079 (2.28)	0.009 {0.071}
Ba	ICP (AA)	0.126 (0.04)	0.131 {0.119}
Na	ICP	0.142 [0.50]	0.099 [0.49]{0.141}
K	ICP	13.2 [12.4]	15.0 [12.0]
Li	ICP	<0.01	<0.010 {0.0008}
Fe(II)	[COLOR]	--- [1.16]	--- [1.67]
Fe(tot)	ICP (AA)	1.19 [1.18] (100.5)	1.45 [1.70]
Al	ICP (AA)	0.27 (5.45)	0.319 {0.168}
Mn	ICP (AA)	0.241 (21.16)	0.318 {0.213}
Zn	ICP (AA)	0.173 (3.69)	0.211 {0.189}
Cd	ICP (AA)	<0.005 (<0.02)	<0.005 {<0.0005}
Cu	ICP (AA)	<0.005 (<0.02)	<0.005 {<0.0005}
Cr	ICP (AA)	<0.02 (0.37)	<0.02
Co	ICP	<0.020	<0.020 {<0.0005}
Ni	ICP (AA)	<0.025 (<0.02)	<0.025
Mo	ICP	<0.035	<0.035 {0.005}
Ag	(AA)	---	--- {<0.0005}
Pb	(AA)	<0.09 (0.18)	<0.09 {0.0006}
Zr		<0.0015	<0.015 {<0.0005}
V		<0.015 [<0.2]	--- [<0.2]
U		--- [0.013]	--- [0.009] {0.0059}
Th		---	{0.00018}
Sn		---	{<0.0001}
Rb		---	{0.029}
Cs		---	{<0.0005}
La		---	{0.062}
SO_4	IC [N]	12.2 [14.4]	14.2 [23.0]
F	ISE [ISE]	2.16 [2.32]	2.68 [2.45]
Cl	IC	<2.0	<2.0
Br	IC	<0.05	<0.05
NO_3	IC	<0.10	<0.10
HPO_4	IC	<0.1 (0.62)	<0.1
B	ICP (AA)	<0.015 (<0.02)	<0.015
SiO_2	ICP (AA)	31 (39.4)	29
S^{2-}		---- [0.0021]	---- [0.019]

Values reported from BGS except [ ] Urânio do Brasil, PdeC. { } = PSI, Degueldre.
Alkalinities reported for methyl orange, Gran's titrations.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole	F3 (9-1NH47)	F3 (9-1NH47)	F3 (9-1NH47)
Sample Code No.	PC-GW-36	PC-GW-45	PC-GW-55[d]
Sampling Int (m)	50 - 77.6	50 - 77.6	50 - 77.6
Date Collected	880201	880606	880916
Temperature(°C)	[22]	[22.2]	[22]
pH [field/lab] lab	[5.45/5.29] 3.56	[5.21/6.06] 3.99	[5.10/5.28] 2.99
D.O. (mg/L)	<0.008	<0.008	<0.008
Eh(mV)	[448]	[414]	[338]
Alkalinity (mg/L HCO_3)	[18.4] <5.0	[11.4] <5.0	[2.65 10.1] <5.0

Element	Analytical Method		mg/L	
Ca	ICP	74.00 *43.0	99.7 ((114))	102.00 (120.5)
Mg	ICP	3.00 *1.4	3.43 ((4.09))	3.60 (4.41)
Sr	ICP	1.45 *0.852	1.99 ((2.46))	2.090 (2.12)
Ba	ICP	0.050 *0.010	0.049 ((0.055))	0.051 (0.05)
Na	[AA] ICP	[1.49] 0.78 *0.32	[1.52] 0.83 ((<0.20))	0.61 [1.95]
K	[AA] ICP	[34.2] 33.10 *19.3	[39.9] 39.5 ((42.5))	42.60 [42.5]
Li	ICP	<0.015 *0.0034	<0.015	<0.010
Fe(II)	[COLOR]	[53.4] ---	[76.9] ---	--- [88.7]
Fe(tot)	[COLOR] ICP	[53.5] 48.6 *23.8	[11.4] 74.4 ((74.0))	78.100 [89.9] (93.44)
Al	ICP	1.85 *1.11	3.28 ((3.1))	4.180 (4.66)
Mn	ICP	12.3 *6.48	17.3 ((19.5))	17.700 (20.22)
Zn	ICP	2.02 *1.05	2.86 ((3.38))	3.150 (3.38)
Cd	ICP	<0.005 *0.0008	<0.005 ((<0.005))	<0.005 (<0.02)
Cu	ICP	<0.015 *0.0014	<0.015 ((<0.050))	<0.005 (0.03)
Cr	ICP	<0.12 *---	<0.12 ((<0.010))	<0.02 (0.46)
Co	ICP	<0.035 *<d.l.	<0.035 ((0.0077))	<0.020
Ni	ICP	<0.025 *0.0009	<0.085 ((0.0092))	<0.025 (0.03)
Mo	ICP	<0.050 *<d.l.	<0.050	<0.035
Pb		<0.100 *---	<0.050 ((<0.2))	<0.090 (0.29)
Zr		<0.045 *<d.l.	<0.045	<0.015
V		----	[<0.2]	--- [<0.2]
U	ICP/MS	[0.0045]	[0.008] 0.0017	--- [<0.001]
Th	ICP/MS	---	0.0002	---
SO_4	IC [N]	[360] 442.00 *--/187	[605] 510	540.0 [630.0]
F	ISE [ISE]	[4.27] 6.44 *---	[6.39] 5.89	6.44 [7.66]
Cl	IC	2.9 *---	0.44	<0.20
Br	IC	<0.050 *---	0.084	<0.010
NO_3	IC	<0.10 *---	0.02	0.18
HPO_4	IC	<1.0 *---	<0.05	<0.10 (0.74)
B	ICP	0.078 *0.052	----	0.145 (<0.02)
SiO_2	ICP	34 *2.38	34 ((46.1))	36 (37.89)
S^{2-}	[ISE]		[<0.0001]	--- [<0.001]

Values reported from BGS except [ ] Urânio do Brasil, PdeC, ( ) = CENA, Piracicaba. Alkalinity is methyl orange, Gran's titration respectively. *Values reported from BGS on x40 concentrates (( )) = U.S.G.S. data, J.W. Ball [d] indicates duplicates, averaged if within 10 %.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole	F3 (9-1NH47)	F3 (9-1NH47)
Sample Code No.	PC-GW-65	PC-GW-79
Sampling Int (m)	50 - 77.6	50 - 77.6
Date Collected	881130	890321 {890414}
Temperature(°C)	22	23
pH [field/lab] lab	[5.35/5.14] 3.49	[5.03/5.24] 3.40 {4.93}
D.O. (mg/L)	<0.008	<0.008
Eh(mV)	225	319 {356}
Alkalinity (mg/L HCO_3)	[1.78/9.98] 5.0	[2.06/15.32] (<5.0)

Element	Analytical Method		mg/L
Ca	ICP (AA)	122.0 (2.89)	131.0
Mg	ICP (AA)	4.16 (<0.10)	4.33 {3.42}
Sr	ICP (AA)	2.35 (0.08)	2.56 {2.80}
Ba	ICP (AA)	0.049 (0.12)	0.044 {0.049}
Na	ICP	0.357 [2.24]	0.942 [2.30]{1.07}
K	ICP	469.0 [44.5]	46.2 [46.5]
Li	ICP	<0.01	0.017 {0.013}
Fe(II)	[COLOR]	--- [98.9]	---- [117.5]
Fe(tot)	ICP (AA)	91.8 [99.4] (1.32)	1.02 [118.5]
Al	ICP (AA)	5.14 (0.54)	6.54 {5.90}
Mn	ICP (AA)	20.0 (0.27)	21.50 {20.0}
Zn	ICP (AA)	8.77 (0.17)	4.26 {3.59}
Cd	ICP (AA)	<0.005 (<0.02)	<0.005 {<0.0005}
Cu	ICP (AA)	<0.005 (<0.02)	<0.005 {<0.0005}
Cr	ICP (AA)	<0.02 (<0.05)	0.092
Co	ICP	<0.020	<0.020 {<0.005}
Ni	ICP (AA)	<0.025 (<0.02)	<0.025
Mo	ICP	<0.035	<0.035 {0.002}
Ag	(AA)	---	---- {<0.0005}
Pb	(AA)	<0.09 (0.11)	<0.09 {0.0008}
Zr		<0.0015	<0.015 {<0.0005}
V		0.035 [<0.2]	--- [<0.2]
U		--- [0.019/2.306]	--- [0.001] {0.0020}
Th		----	{0.0003}
Rb		----	{0.103}
Cs		----	{0.0007}
La		----	{0.033}
SO_4	IC [N]	573.0 [835.0]	745.0 [985.0]
F	ISE [ISE]	5.04 [8.07]	9.66 [8.81]
Cl	IC	<2.0	<2.0
Br	IC	<0.05	<0.05
NO_3	IC	<0.10	0.44
HPO_4	IC	<0.1 (<0.043)	<0.1
B	ICP (AA)	0.204 (<0.02)	0.235
SiO_2	ICP (AA)	38 (30.44)	35
S^{2-}		--- [0.0018]	---- [0.0028]

Values reported from BGS except [ ] Urânio do Brasil, PdeC, ( ) = CENA, Piracicaba.
{ } = PSI, Degueldre. Alkalinity is methyl orange, Gran's titration respectively.
[d] indicates duplicates, averaged if within 10 %.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole	F5 (MI-55)	F5 (MI-55)	F5 (MI-55)
Sample Code No.	PC-GW-62	PC-GW-72	PC-GW-80
Sampling Int (m)	275-300	275-300	275-300
Date Collected	881128	881220	890413 {890413}
Temperature(°C)	24	-----	24
pH [field/lab] lab	[6.25/6.39] 5.56	[6.00] 5.98	[5.83/6.38] 6.02 {6.16}
D.O. (mg/L)	<0.008	<0.008	<0.008
Eh(mV)	255	----	462 {78}
Alkalinity (mg/L HCO_3)	[26.5,32.4]<5.0	[31.4,56.1]15.9	[23.5,28.1]16.0

Element	Analytical Method	mg/L		
Ca	ICP (AA)	15.6 (19.8)	11.2 (10.35)	7.88
Mg	ICP (AA)	0.145 (5.28)	0.249 (0.39)	0.46 {0.240}
Sr	ICP (AA)	0.366 (1.33)	0.272 (0.25)	0.204 {0.189}
Ba	ICP (AA)	0.105 (0.06)	0.110 (<0.02)	0.102 {0.138}
Na	ICP	0.612 [1.04]	0.799 [1.28]	0.600 [1.06]{0.656}
K	ICP	13.8 [12.4]	13.0 [12.0]	11.6 [12.0]
Li	ICP	<0.01	<0.01	<0.010 {0.002}
Fe(II)	[COLOR]	---- [9.25]	---- [9.96]	---- [6.13]
Fe(tot)	ICP (AA)	15.2 [9.35] (0.80)	8.71 [10.59] (8.64)	5.68 [6.27]
Al	ICP (AA)	1.05 (25.7)	0.51 (0.75)	0.183 {0.092}
Mn	ICP (AA)	6.86 (10.73)	3.02 (2.88)	2.29 {2.05}
Zn	ICP (AA)	0.490 (4.29)	0.182 (0.16)	0.115 {0.144}
Cd	ICP (AA)	<0.005 (0.04)	<0.005 (<0.02)	<0.005 {<0.0005}
Cu	ICP (AA)	<0.005 (0.10)	<0.005 (<0.02)	<0.005 {<0.0005}
Cr	ICP (AA)	<0.02 (0.28)	<0.02 (<0.05)	<0.02
Co	ICP	<0.020	<0.020	<0.020 {<0.0005}
Ni	ICP (AA)	<0.025 (0.06)	<0.025 (<0.02)	<0.025
Mo	ICP	<0.035	<0.035	<0.035 {0.014}
Pb	(AA)	<0.09 (1.49)	<0.09 (0.17)	<0.09 {0.0005}
Zr		<0.0015	<0.0015	<0.015 {<0.0005}
V		<0.015 [<0.2]	<0.015 [<0.2]	---- [<0.2]
U		---- [0.008]	---- [0.011]	---- [0.003] {0.00176}
Th		----	----	{0.000033}
Rb		----	----	{0.021}
Cs		----	----	{<0.0005}
La		----	----	{0.002}
SO_4	IC [N]	50.9 [55.5]	29.7 [31.0]	20.9 [34.0]
F	ISE [ISE]	6.18 [7.14]	6.15 [6.17]	5.50 [6.45]
Cl	IC	<2.0	<2.0	<2.0
Br	IC	<0.05	<0.05	<0.05
NO_3	IC	<0.10	<0.10	<0.10
HPO_4	IC	<0.1 (0.96	<0.1 (<0.31)	<0.1
B	ICP (AA)	0.230 (<0.02)	0.020 (<0.02)	<0.015
SiO_2	ICP (AA)	37 (50.4)	38 (36.5)	34
S^{2-}		----[<0.001]	----[<0.001]	----[0.0014]

Values reported from BGS except [ ] Urânio do Brasil, PdeC. Alkalinities reported for methyl orange, Gran's titration. ( ) = CENA, Piracicaba. { } = PSI, Degueldre.

Chemical analyses of surface and groundwater samples from the Osamu Utsumi Mine

Borehole		9-1UC16 (Pilot	SHAFT	SUPPLY DAM
Sample Code No.		PC-GW-21 Hole)	PC-GW-28	PC-SW-03
Sampling Int (m)		---	0-40	---
Date Collected		870729	871007	870709
Temperature (°C)		[21.02]	[20.05]	[17.5]
pH (lab)		[5.5]	[5.7]	[6.5]
Cond.(mS/m)		[6.0]	[6.4]	[6.0]
Eh(mV)		---	---	---
Alkalinity (mg/L HCO_3)		[15]	[20]	[9]
Element	Analytical Method		mg/L	
Ca	ICP (AA)	2.59 (2.20)	59.6 (60.0)	0.14 (<0.10)
Mg	ICP (AA)	0.134 (<0.10)	2.23 (2.34)	<0.14 (<0.10)
Sr	ICP (AA)	0.108 (0.10)	1.61 (1.60)	0.01 (0.01)
Ba	ICP (AA)	0.137 (0.12)	0.059 (0.05)	0.014 (0.01)
Na	ICP	0.22	1.35	0.19
K	ICP	12.2	21.8	2.2
Li	ICP	<0.02	<0.02	<0.02
Fe(II)	[COLOR]	---	[44.5]	[0.012]
Fe(tot)	ICP (AA)	--- (0.03)	[44.7] (40.89)	[1.14] (<0.02)
Al	ICP (AA)	0.71 (0.40)	7.8 (7.55)	<0.02 (<0.05)
Mn	ICP (AA)	0.203 (0.18)	12.7 (13.54)	0.097 (0.08)
Zn	ICP (AA)	0.121 (0.12)	0.184 (0.20)	<0.033 (<0.20)
Cd	ICP (AA)	<0.1 (<0.02)	<0.01 (<0.2)	<0.01 (<0.02)
Cu	ICP (AA)	0.018 (<0.02)	<0.015 (<0.02)	<0.043 (<0.02)
Cr	ICP (AA)	<0.12 (<0.05)	<0.12 (<0.05)	<0.12 (<0.05)
Co	ICP	<0.035	<0.035	<0.035
Ni	ICP (AA)	<0.020 (<0.02)	<0.02 (<0.02)	<0.085 (<0.02)
Mo	ICP	<0.03	<0.03	<0.03
Ag	(AA)	--- <0.05	--- <0.05	---- (<0.05)
Pb	(AA)	<0.2 (<0.10)	--- (<0.10)	--- (<0.10)
Zr		<0.01	<0.01	<0.01
SO_4	IC [N]	24.9	278	0.98
F	ISE [ISE]	0.75	10.3	0.13
Cl	IC	<0.20	<0.20	<0.20
Br	IC	<0.01	---	---
NO_3	IC	0.29	<0.02	0.19
HPO_4	IC	<0.05	<0.02	<0.05
B	ICP (AA)	--- (<0.02)	--- (<0.02)	--- (<0.02)
SiO_2	ICP (AA)	31.67 (32.31)	36.81 (40.45)	7.92 (8.13)

Values reported from BGS except [ ] Urânio do Brasil, PdeC and ( ) = CENA, Piracicaba.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

		Piezometer Station	Piezometer Station
Borehole		PM 22	PM 22
Sample Code No.		PC-GW-19	PC-GW-27
Sampling Int (m)		0 - 20	0 - 20
Date Collected		870707	871002
Temperature (°C)		[21.5]	[20.0]
pH (lab)		[6.7]	[6.2]
Cond.(mS/m)		[6.0]	[6.3]
Eh(mV)		---	---
Alkalinity (mg/L HCO_3)		[28]	[30]

Element	Analytical Method	mg/L	
Ca	ICP (AA)	5.11 (4.72)	5.4 (4.65)
Mg	ICP (AA)	0.36 (0.38)	0.749 (0.16)
Sr	ICP (AA)	0.152 (0.16)	0.154 (0.15)
Ba	ICP (AA)	0.04 (0.04)	0.043 (0.03)
Na	ICP	0.45	0.417
K	ICP	13.4	13.9
Li	ICP	<0.02	<0.02
Fe(II)	[COLOR]	[2.04]	[2.08]
Fe(tot)	ICP (AA)	[2.23] (1.80)	[2.13] (1.86)
Al	ICP (AA)	0.034 (<0.05)	0.048 (<0.05)
Mn	ICP (AA)	0.19 (1.77)	1.80 (1.79)
Zn	ICP (AA)	<0.033 (<0.02)	0.74 (0.07)
Cd	ICP (AA)	<0.1 (<0.02)	<0.01 (<0.02)
Cu	ICP (AA)	<0.043 (<0.02)	<0.015(<0.02)
Cr	ICP (AA)	<0.12 (<0.05)	<0.12 (<0.05)
Co	ICP	<0.035	<0.035
Ni	ICP (AA)	<0.085 (<0.02)	<0.02 (<0.02)
Mo	ICP	<0.03	<0.03
Ag	(AA)	--- (<0.05)	--- (<0.05)
Pb	(AA)	--- (<0.10)	<0.2 (<0.10)
Zr		<0.01	<0.01
V		----	----
U		----	----
SO_4	IC [N]	9.97	10.4
F	ISE [ISE]	4.45	4.15
Cl	IC	<0.20	<0.20
Br	IC	---	---
NO_3	IC	---	0.04
HPO_4	IC	<0.05	<0.02
B	ICP (AA)	--- (<0.02)	--- (<0.02)
SiO_2	ICP (AA)	41.94 (42.14)	42.37 (44.94)
S^{2-}		----	----

Values reported from BGS except [ ] Urânio do Brasil, PdeC and ( ) = CENA, Piracicaba.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole	F4 (8-1UK11)	F4 (8-1UK11)
Sample Code No.	PC-GW-44	PC-GW-59
Sampling Int (m)	76.2 - 200	76.2 - 200
Date Collected	880603	880922
Temperature(°C)	[21.9]	[23]
pH [field/lab] lab	[5.71/6.30] 6.15	[6.47/6.31] 6.27
D.O. (mg/L)	0.263	0.037
Eh(mV)	[400]	255
Alkalinity (mg/L HCO_3)	[15.8] 10.4	15.5 [24,23]

Element	Analytical Method	mg/L	
Ca	ICP	12.5 ((14.1))	6.54 (7.29)
Mg	ICP	0.46 ((0.70))	0.29 (0.46)
Sr	ICP	0.281 ((0.346))	0.137 (0.14)
Ba	ICP	0.063 ((0.074))	0.056 (0.65)
Na	[AA] ICP	[1.00] 0.39 ((<0.20))	0.29 [1.12]
K	[AA] ICP	[14.0] 14.3 (14.6))	11.50 [14.0]
Li	ICP	<0.015	<0.010
Fe(II)	[COLOR]	[4.22] ----	---- [5.78]
Fe(tot)	[COLOR] ICP	[4.24] 3.82 ((<0.10))	3.64 (4.13) [6.03]
Al	ICP	1.78 ((1.1))	0.55 (0.91)
Mn	ICP	5.24 ((5.66))	2.08 (2.21)
Zn	ICP	0.69 ((0.721))	0.228 (0.25)
Cd	ICP	<0.005 ((<0.005))	<0.005 (<0.02)
Cu	ICP	<0.015 ((<0.050))	<0.005 (<0.02)
Cr	ICP	<0.12 ((<0.010))	<0.02 (0.07)
Co	ICP	<0.035 ((0.0022))	<0.02
Ni	ICP	<0.085 ((0.0073))	<0.020
Mo	ICP	<0.050 ((<0.2))	<0.025 (<0.02)
Pb		<0.050	<0.035
Zr		<0.045	<0.090 (0.17)
V		[<0.2]	<0.015
U	ICP/MS	[0.0025] 0.0678	----
Th	ICP/MS	0.0001	----
SO_4	IC [N]	[78.0] 46.3	13.6 [14.0]
F	ISE [ISE]	[8.33] 6.78	6.37 [1.83]
Cl	IC	1.95	0.18
Br	IC	<0.050	<0.010
NO_3	IC	<0.01	0.04
HPO_4	IC	<0.05	<0.10 (<0.31)
B	ICP	----	<0.015 (<0.02)
SiO_2	ICP	37 ((43.9))	39.4 (40)
S^{2-}	[ISE]	[<0.001]	[<0.001]

Values reported from BGS except [ ] Urânio do Brasil, PdeC and ( ) = CENA, Piracicaba. (( )) = U.S.G.S. data J.W. Ball.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

	SW-01	SW-01	SW-01
Borehole	SW-01	SW-01	SW-01
Sample Code No.	PC-GW-37	PC-GW-46	PC-GW-57
Sampling Int (m)	3 - 12	3 - 12	3 - 12
Date Collected	880202	880607	880921
Temperature(°C)	[22]	[20.3]	21
pH [field/lab] lab	[3.1/2.95] 3.05	[3.32/3.16] 3.32	[3.93/3.93] 3.45
D.O. (mg/L)	----	<0.008	3.27
Eh(mV)	[834]	[702]	[694]
Alkalinity (mg/L HCO_3)	[<0.60] <5.0	[<0.60] <5.0	<5.0 [<0.61]

Element	Analytical Method	mg/L		
Ca	ICP	74.10 *11.4	128 ((71))	34.30 (40.24)
Mg	ICP	4.66 *0.75	8.37 ((12.2))	1.86 (2.32)
Sr	ICP	1.97 *0.432	3.39 ((3.81))	0.859 (0.87)
Ba	ICP	0.022 *0.0060	0.021 ((0.031))	0.051 (0.05)
Na	[AA] ICP	[1.45] 0.87 *0.42	[2.03] 1.45 ((<0.20))	0.64 [1.36]
K	[AA] ICP	[19.0] 18.90 *9.3	[33.0] 31.2 ((35.8))	18.70 [21.0]
Li	ICP	<0.015 *0.0106	0.024	<0.010
Fe(II)	[COLOR]	[1.20] ----	[35.2] ----	---- [<0.10]
Fe(tot)	[COLOR] ICP	[5.04] 4.22 *0.45	[36.8] 29.6 ((9.56))	0.011 [<0.10](0.54)
Al	ICP	65.5 *5.1	74.2 ((102))	9.780 (10.84)
Mn	ICP	30.1 *---	45.8 ((58.9))	16.9 (18.85)
Zn	ICP	5.80 *1.16	8.39 ((10.7))	1.730 (1.92)
Cd	ICP	0.016 *0.003	0.025 ((0.047))	<0.005 (<0.02)
Cu	ICP	<0.015 *0.0009	<0.015 ((0.095))	<0.005 (0.04)
Cr	ICP	<0.12 *<d.l.	<0.12 ((<0.010))	<0.02 (0.25)
Co	ICP	0.052 *0.008	<0.035 ((0.135))	<0.020
Ni	ICP	0.117 *0.031	0.224 ((0.305))	<0.025 (0.04)
Mo	ICP	<0.050 *<d.l.	<0.050	<0.035
Pb		0.176 *0.065	0.301/0.39 ((0.530))	<0.090 (0.33)
Zr		0.061 *0.014	0.051	<0.015
V		----	[<0.2]	---- [<0.2]
U	ICP/MS	[0.7068]	[0.9046] 5.17	---- [0.432]
Th	ICP/MS	----	0.290	----
SO_4	IC [N]	[780] 878.0 *--/94.5	[1175] 1135/914	209.0 [375.0]
F	ISE [ISE]	[52.3] 41.3 *--	[75.2] 57.5	6.32 [10.75]
Cl	IC	<1.0 *---	<0.10	<0.20
Br	IC	<0.050 *---	<0.050	0.059
NO_3	IC	1.48 *---	3.20	1.74
HPO_4	IC	0.26 *---	0.45	<0.10 (<0.31)
B	ICP	<0.020 *0.0026	----	<0.015 (<0.02)
SiO_2	ICP	47 *0.70	66 ((105))	32 (33.63)
S^{2-}	[ISE]	[<0.001]	[<0.001]	---- [<0.001]

Values reported from BGS except [ ] Urânio do Brasil, PdeC and ( ) = CENA, Piracicaba. *Values reported from BGS on x40 concentrates. (( )) = U.S.G.S. data J.W. Ball.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole	SW-01	SW-01
Sample Code No.	PC-GW-68	PC-GW-75
Sampling Int (m)	3 - 12	3 - 12
Date Collected	881202	890316
Temperature(°C)	21	21
pH [field/lab] lab	[3.37/3.29] 2.66	[2.35/2.54] 2.34
D.O. (mg/L)	<0.008	<0.008
Eh(mV)	627	737
Alkalinity (mg/L HCO_3)	<5.0 [<0.61]	<5.0 [<0.60]

Element	Analytical Method		mg/L
Ca	ICP (AA)	108.0 (146.5)	72.9
Mg	ICP (AA)	7.45 (11.04)	4.35
Sr	ICP (AA)	2.97 (3.40)	2.38
Ba	ICP (AA)	0.025 (0.03)	0.02
Na	ICP	1.36 [2.62]	1.39 [2.40]
K	ICP	37.7 [38.0]	32.8 [31.5]
Li	ICP	0.24	0.031
Fe(II)	[COLOR]	---- [50.5]	---- [52.0]
Fe(tot)	ICP (AA)	46.3 [53.5] (65.49)	88.3 [171.1]
Al	ICP (AA)	83.9 (111.7)	112.0
Mn	ICP (AA)	39.4 (53.03)	41.3
Zn	ICP (AA)	12.3 (13.24)	10.1
Cd	ICP (AA)	0.048 (0.08)	0.056
Cu	ICP (AA)	<0.005 (0.18)	0.006
Cr	ICP (AA)	<0.02 (0.78)	0.165
Co	ICP	<0.020	<0.020
Ni	ICP (AA)	0.260 (0.33)	0.173
Mo	ICP	<0.035	<0.035
Ag	(AA)	----	----
Pb	(AA)	0.86 (1.82)	0.436
Zr		0.088	0.417
V		0.039 [<0.2]	---- [<0.2]
U		---- [11.8]	---- [24.5]
SO_4	IC [N]	1190.0 [1350.0]	2610.0 [3290]
F	ISE [ISE]	14.90 [61.5]	1.47 [88.6]
Cl	IC	<2.0	<2.0
Br	IC	<0.05	<0.05
NO_3	IC	<0.10	3.19
HPO_4	IC	<0.1 (2.11)	<0.1
B	ICP (AA)	0.094 (0.02)	0.225
SiO_2	ICP (AA)	72 (94.3)	74
S^{2-}		---- [<0.001]	---- [<0.001]

Values reported from BGS except [ ] Urânio do Brasil, PdeC and ( ) = CENA, Piracicaba.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole	SW-02
Sample Code No.	PC-GW-38
Sampling Int (m)	3 - 12
Date Collected	880203
Temperature(°C)	[23]
pH [field/lab] lab	[3.2/---] 2.93
Cond.(mS/m)	----
Eh(mV)	[638]
Alkalinity (mg/L HCO_3)	[<0.60] <5.0

Element	Analytical Method	mg/L
Ca	ICP (AA)	23.30
Mg	ICP (AA)	2.34
Sr	ICP (AA)	1.41
Ba	ICP (AA)	0.028
Na	ICP	[2.35] 1.00
K	ICP	[39.7] 29.9
Li	ICP	<0.015
Fe(II)	[COLOR]	[0.33] ----
Fe(tot)	ICP (AA)	[2.42] 2.13
Al	ICP (AA)	35.2
Mn	ICP (AA)	9.14
Zn	ICP (AA)	3.58
Cd	ICP (AA)	0.045
Cu	ICP (AA)	<0.015
Cr	ICP (AA)	<0.12
Co	ICP	0.043
Ni	ICP (AA)	0.044
Mo	ICP	<0.050
Pb	(AA)	0.957
Zr		0.064
V		----
U	ICP/MS	[4.01] 3.42
SO_4	IC [N]	[55] 458
F	ISE [ISE]	[10.7] 8.98
Cl	IC	1.1
Br	IC	<0.050
NO_3	IC	4.05
HPO_4	IC	0.18
B	ICP (AA)	<0.020
SiO_2	ICP (AA)	54
S^{2-}	(ISE, ppb)	----

Values reported from BGS except [ ] Urânio do Brasil, PdeC.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole	SW-03	SW-03	SW-03
Sample Code No.	PC-GW-39	PC-GW-47	PC-GW-58[d]
Sampling Int (m)	3 - 12	3 - 12	3 - 12
Date Collected	880203	880607	880922
Temperature(°C)	[22]	[20.0]	20
pH [field/lab] lab	[3.4/3.23] 3.50	[3.57/3.43] 3.41	[4.43/4.38] 3.92
D.O. (mg/L)	4.52	4.37	4.60
Eh(mV)	[754]	[786]	[657]
Alkalinity (mg/L HCO_3)	[<0.60] <5.0	[<0.60] <5.0	<5.0 [<0.61]

Element	Analytical Method	mg/L		
Ca	ICP	29.00 *3.98	24.7	2.46 (2.65)
Mg	ICP	5.30 *0.79	3.6	0.85 (0.85)
Sr	ICP	1.74 *0.418	1.46	0.248 (0.26)
Ba	ICP	0.025 *0.0060	0.036	0.095 (0.09)
Na	[AA] ICP	[2.00] 0.69 *0.36	[2.62] 0.62	0.17 [1.56]
K	[AA] ICP	[33.4] 24.50 *14.8	[25.1] 24.5	11.80 [13.3]
Li	ICP	<0.015 *0.0078	<0.015	<0.010
Fe(II)	[COLOR]	[<0.10] ---	[<0.10] ---	--- [<0.10]
Fe(tot)	[COLOR] ICP	[0.14] 0.11 *0.29	[0.12] 0.21	<0.010[<0.10](0.07)
Al	ICP	44.8 *2.2	23	0.790 (1.18)
Mn	ICP	18.4 *---	12.6	0.962 (1.05)
Zn	ICP	6.95 *1.37	4.17	0.325 (0.35)
Cd	ICP	0.050 *0.0081	0.037	<0.005 (<0.02)
Cu	ICP	<0.015 *0.0008	<0.015	<0.005 (<0.02)
Cr	ICP	<0.12 *<d.l.	<0.12	<0.02 (0.07)
Co	ICP	0.047 *0.007	0.048	<0.020
Ni	ICP	0.050 *0.012	<0.085	<0.025 (0.02)
Mo	ICP	<0.050 *<d.l.	<0.050	<0.035
Pb		1.48 *0.358	0.96	<0.090 (0.21)
Zr		0.108 *0.026	0.054	<0.015
V		----	[<0.2]	--- [<0.2]
U	ICP/MS	[1.98] 2.54	[1.22] 5.60	--- [0.399]
Th	ICP/MS	---	0.030	---
SO_4	IC [N]	[605] 802 *--/167.7	[445] 338	33.1 [8.8]
F	ISE [ISE]	[10.9] 12.78 *---	[10.5] 8.12	0.48 [0.46]
Cl	IC	2.2 *---	<2.0	1.00
Br	IC	<0.050 *---	<0.050	0.010
NO_3	IC	4.36 *---	5.26	1.93
HPO_4	IC	0.14 *---	<0.05	<0.010 (0.31)
B	ICP	<0.020 *0.0062	----	<0.015 (<0.02)
SiO_2	ICP	41 *4.85	38	21 (21.7)
S^{2-}	[ISE]	----	[<0.001]	--- [<0.001]

Values reported from BGS except [ ] Urânio do Brasil, PdeC. Alkalinities reported for methyl orange, Gran's titrations. *Values reported from BGS on x40 concentrates.

[d] indicates duplicate analyses, averaged if within 10 % otherwise best value.

Chemical analyses of groundwater samples from the Osamu Utsumi Mine

Borehole	SW-03	SW-03
Sample Code No.	PC-GW-66	PC-GW-76
Sampling Int (m)	3 - 12	3 - 12
Date Collected	881130	890316 {890416}
Temperature(°C)	20	21
pH [field/lab] lab	[3.45/3.53] 3.19	[2.88/3.06] 2.68 {3.4}
D.O. (mg/L)	2.73	5.44
Eh(mV)	[834]	[737] {719}
Alkalinity (mg/L HCO_3)	<5.0 [<0.61]	<5.0 [<0.61]

Element	Analytical Method	mg/L	
Ca	ICP (AA)	17.8 (15.18)	38.4
Mg	ICP (AA)	4.7 (0.50)	8.20
Sr	ICP (AA)	1.30	2.23
Ba	ICP (AA)	0.067 (0.10)	0.024
Na	ICP	0.694 [1.30]	0.672 [1.39]
K	ICP	27.9 [25.5]	36.0 [32.5]
Li	ICP	<0.01	0.014
Fe(II)	[COLOR]	---- [0.10]	---- [<0.10]
Fe(tot)	ICP (AA)	0.353 [0.29](13.98)	1.18 [1.59]
Al	ICP (AA)	23.10 (1.37)	78.2
Mn	ICP (AA)	9.87	28.1
Zn	ICP (AA)	4.30	12.5
Cd	ICP (AA)	0.027 (<0.02)	0.093
Cu	ICP (AA)	0.025 (<0.02)	<0.005
Cr	ICP (AA)	<0.02 (<0.05)	<0.020
Co	ICP	0.029	0.071
Ni	ICP (AA)	0.052	0.069
Mo	ICP	<0.035	<0.035
Ag	(AA)	----	----
Pb	(AA)	1.01	1.5
Zr		0.0570	0.154
V		0.020 [<0.2]	---- [<0.2]
U		---- [5.77]	---- [14.6]
SO_4	IC [N]	321.0 [396.0]	1070.0 [1315.0]
F	ISE [ISE]	3.59 [3.93]	10.41 [24.4]
Cl	IC	<2.0	<2.0
Br	IC	<0.05	<0.05
NO_3	IC	4.08	4.27
HPO_4	IC	<0.1 (0.71)	<0.1
B	ICP (AA)	<0.015 (<0.02)	0.027
SiO_2	ICP (AA)	46 (37.4)	54
S^{2-}		---- [<0.001]	---- [<0.001]

Values reported from BGS except [ ] Urânio do Brasil, PdeC. Alkalinities reported for methyl orange, Gran's titrations.

Chemical analyses of surface water samples from the Morro do Ferro study site

Borehole	South Stream	North Stream
Sample Code No.	PC-SW-04	PC-SW-05
Sampling Int (m)	---	---
Date Collected	870729	870810
Temperature (°C)	---	---
pH (Lab)	[6.3]	[4.9]
Cond.(mS/m)	---	---
Eh(mV)	---	---
Alkalinity (mg/L HCO_3)	[9]	[3]

Element	Analytical Method	mg/L	
Ca	ICP (AA)	0.15 (<0.10)	0.20 (<0.10)
Mg	ICP (AA)	0.012 (<0.10)	0.015 (<0.10)
Sr	ICP (AA)	0.002 (<0.01)	0.006 (<0.01)
Ba	ICP (AA)	0.003 (<0.01)	0.005 (<0.01)
Na	ICP	0.11	0.12
K	ICP	1.7	2.6
Li	ICP	<0.02	<0.02
Fe(II)	[COLOR]	[<0.10]	[<0.10]
Fe(tot)	ICP (AA)	[<0.10] (<0.02)	[<0.10]
Al	ICP (AA)	<0.02 (<0.05)	<0.02 (<0.05)
Mn	ICP (AA)	<0.004 (<0.01)	0.19 (<0.02)
Zn	ICP (AA)	<0.033 (<0.02)	<0.033 (<0.02)
Cd	ICP (AA)	<0.1 (<0.02)	<0.1 (<0.02)
Cu	ICP (AA)	<0.015 (<0.02)	<0.015 (<0.02)
Cr	ICP (AA)	<0.12 (<0.05)	0.12 (<0.05)
Co	ICP	<0.035	<0.035
Ni	ICP (AA)	<0.020 (<0.02)	<0.020 (<0.02)
Mo	ICP	<0.030	<0.030
Ag	(AA)	--- (<0.02)	---- (<0.05)
Pb	(AA)	<0.2 (<0.10)	<0.2 (<0.10)
Zr		<0.01	---
SO_4	IC [N]	<0.2	0.36
F	ISE [ISE]	<0.01	---
Cl	IC	1.51	0.26
Br	IC	---	<0.01
NO_3	IC	<0.02	0.18
HPO_4	IC	<0.05	<0.05
B	ICP (AA)	--- (<0.02)	--- (<0.02)
SiO_2	ICP (AA)	9.63 (9.01)	11.56 (12.20)

Values reported from BGS except [ ] Urânio do Brasil, PdeC and ( ) = CENA, Piracicaba.

Chemical analyses of groundwater samples from the Morro do Ferro study site

Borehole		MF 10	MF 10	MF 10
Sample Code No.		PC-GW-52	PC-GW-69	PC-GW-83
Sampling Int (m)		50-74	50-74	50-74
Date Collected		880912	881206	890405 {890406}
Temperature(°C)		21	22	22
pH [field/lab] lab		[6.13/6.38] 5.95	[5.91/6.70] 5.63	[6.05/6.10] 5.61 {5.97}
D. O.(mg/L)		3.6	3.0	4.3
Eh(mV)		335	448	504 {488}
Alkalinity (mg/L HCO_3)		[2.76,10.7] <5.0	[2.89,9.98] <5.0	[3.04,11.2] <5.0
Element	**Analytical Method**		**mg/L**	
Ca	ICP (AA)	0.13 (<0.1)	<0.035 (9.54)	0.238
Mg	ICP (AA)	<0.07 (0.23)	<0.070 (0.43)	0.352 {0.026}
Sr	ICP (AA)	0.007 (<0.01)	0.004 (0.22)	0.0050 {0.001}
Ba	ICP (AA)	0.006 (<0.02)	0.004 (0.04)	0.0040 {0.0015}
Na	ICP	0.25 [0.20,0.82]	0.057[0.10,0.12]	0.043 [<0.10]{0.046}
K	ICP	<0.60 [0.24/1.02]	<0.60[2.00,2.40]	<0.6 [0.14,0.20]
Li	ICP	<0.010	<0.01	<0.010 {0.0003}
Fe(II)	[COLOR]	--- [0.62,0.72]	---- [0.46]	---- [0.73]
Fe(tot)	ICP (AA)	0.558[0.66,0.73](0.69)	0.597[0.52](2.8)	0.720 [0.76]
Al	ICP (AA)	<0.050 (0.26)	<0.05 (1.66)	<0.05 {0.0065}
Mn	ICP (AA)	0.309 (0.32)	0.308 (3.25)	0.277 {0.005}
Zn	ICP (AA)	0.119 (0.12)	0.143	0.124 {0.009}
Cd	ICP (AA)	<0.005 (<0.02)	<0.005	<0.005
Cu	ICP (AA)	<0.005 (0.02)	<0.005 (<0.02)	<0.005 {0.0026}
Cr	ICP (AA)	<0.02 (<0.05)	<0.02 (<0.05)	<0.020
Co	ICP	<0.020	<0.020	<0.020
Ni	ICP (AA)	<0.025 (<0.02)	<0.025 (<0.02)	<0.025
Mo	ICP	<0.035	<0.035	<0.035
Pb	(AA)	<0.090 (0.22)	<0.09 (0.12)	<0.09
Zr		<0.015	<0.0015	<0.015
V		[<0.2]	<0.0015 [<0.2]	[<0.2]
U		[<0.001]	[0.001]	[0.001] {0.00029}
Th		----	----	{0.000030}
SO_4	IC [N]	<1.0 [5.4]	3.1 [<5.0]	<2.0 [<5.0]
F	ISE [ISE]	0.11 [<0.10]	0.11 [0.19,0.35]	0.07 [<0.10]
Cl	IC	0.79	<2.00	<2.0
Br	IC	0.009	<0.05	<0.05
NO_3	IC	0.13	<0.10	<0.10
HPO_4	IC	<0.10 (0.43)	<0.1 (0.34)	<0.01
B	ICP (AA)	<0.015 (<0.02)	<0.015	<0.015
SiO_2	ICP (AA)	1.2 (1.26)	1.11 (41.3)	1.12
S^{2-}		[<0.001]	[<0.001]	----

Values reported from BGS except [ ] Urânio do Brasil, PdeC and ( ) = CENA, Piracicaba. Alkalinities reported for methyl orange, Gran's titrations.
{ } = ICP-MS results from Degueldre, PSI.

Chemical analyses of groundwater samples from the Morro do Ferro study site

Borehole		MF 10	MF 10	MF 10
Sample Code No.		PC-GW-12[i]	PC-GW-33	PC-GW-48
Sampling Int (m)		30-70	50-74	50-74
Date Collected		861212	880127	880608
Temperature (°C)		-----	[22]	[21.8]
pH [field/lab] lab		6.0	[4.6/6.57] 6.21	[6.37/6.77] 5.82
D.O. (mg/L)		---	3.94	1.95
Eh(mV)		---	[533]	[-93]
Alkalinity (mg/L HCO_3)		[7.39]	[12] <5.0	[18.9] <5.0
Element	**Analytical Method**		**mg/L**	
Ca	ICP	1.24 (1.19)	0.20 *0.14	<0.20 (<0.05)
Mg	ICP	0.42 (0.40)	<0.1 *0.023	0.11 (0.06)
Sr	ICP	0.05 (0.004)	0.005 *0.0037	0.004 (<0.002)
Ba	ICP	0.09 (0.03)	<0.001 *0.0062	0.002 (<0.005)
Na	[AA] ICP	0.65	[0.09] <0.05 *0.067	[0.09] <0.05 (<0.20)
K	[AA] ICP	0.86	[0.14] <1.0 *0.14	[0.35] <1.0 (<0.3)
Li	ICP	---	<0.015 *---	<0.015
Fe(II)	[COLOR]	---	[0.55] ----	[2.31] ---
Fe(tot)	[COLOR] ICP	0.06 (0.06)	[0.5] 0.30 *0.27	[2.32] 0.54 (<0.10)
Al	ICP	0.15 (0.08)	<0.06 *0.014	<0.06 (<0.5)
Mn	ICP	1.38 (1.30)	0.427 *0.31	0.345 (0.33)
Zn	ICP	<0.033(<0.02)	0.11 *0.082	0.11 (0.158)
Cd	ICP	---	<0.005 *0.0014	<0.005 (<0.005)
Cu	ICP	(<0.02)	<0.015 *0.0024	<0.015 (<0.050)
Cr	ICP	(<0.05)	<0.12 *<d.l.	<0.12 (0.012)
Co	ICP	---	<0.035 *<d.l.	<0.035 (<0.002)
Ni	ICP	(<0.02)	<0.025 *0.0029	<0.085 (<0.003)
Mo	ICP	---	<0.050 *<d.l.	<0.050 (<0.2)
Ag		(0.05)	---	---
Pb		(<0.10)	<0.100 *<d.l.	<0.050
Zr		---	<0.045 *<d.l.	<0.045
V		---	---	[<0.2]
U	ICP/MS	---	[0.003]	[<0.0003] 0.02008
Th	ICP/MS	---	---	0.00006
SO_4	IC/ICP	---	[8.0] <1.00 *0.13/0.13	[<5.0] <0.1
F	ISE	---	[0.07] <0.10 *---	[0.11] 0.08
Cl	IC	---	<1.0 *0.84	<0.10
Br	IC	---	<0.050 *0.002	<0.050
NO_3	IC	---	<0.10 *0.004	<0.01
HPO_4	IC	---	<1.0 *<d.l.	0.09
B	ICP	(0.01)	<0.020 *0.0038	---
SiO_2	ICP	(1.2)	1.2 *1.04	1.1 (1.1)
S^{2-}	[ISE]	---	[<0.0005]	[<0.0001]

[i] This analysis is incomplete and sampling procedures may have given rise to contamination. Values reported from BGS except [ ] Urânio do Brasil, PdeC and ( ) = CENA, Piracicaba. *Values reported from BGS on x40 concentrates. Alkalinities reported for methyl orange, Gran's titrations.

Chemical analyses of groundwater samples from the Morro do Ferro study site

Borehole	MF 11	MF 11	MF 11
Sample Code No.	PC-GW-35	PC-GW-49	PC-GW-53
Sampling Int (m)	30-40	30-40	30-40
Date Collected	880128	880613	880914
Temperature (°C)	[22]	[22.8]	20
pH [field/lab] lab	[5.2/6.28] 6.02	[5.12/5.60] 5.71	[5.35/5.24] 5.65
D.O. (mg/L)	6.4	8.2	7.8
Eh(mV)	[458]	[617]	585
Alkalinity (mg/L HCO_3)	[26.6] <5.0	[12.0] <5.0	[0.13,6.95] <5.0

Element	Analytical Method		mg/L	
Ca	ICP	0.17 *0.15	<0.20	<0.07 (0.11)
Mg	ICP	<0.1 *0.12	0.03	<0.07 (0.24)
Sr	ICP	0.003 *0.0084	0.002	0.004 (<0.01)
Ba	ICP	0.010 *0.0028	0.001	0.004 (<0.02)
Na	[AA] ICP	[0.18] <0.05 *0.047	[0.16] <0.05	0.03 [0.08]
K	[AA] ICP	[0.24] <1.0 *0.23	[0.19] <1.0	<0.60 [0.14]
Li	ICP	<0.015 *---	<0.015	<0.010
Fe(II)	[COLOR]	[0.19] ----	[<0.10] ----	--- [<0.10]
Fe(tot)	[COLOR] ICP	[0.24] 0.02 *0.28	[<0.10] 0.05	<0.010 [<0.10] (0.03)
Al	ICP	<0.06 *0.016	<0.06	<0.050 (0.29)
Mn	ICP	0.183 *0.16	0.080	0.048 (0.05)
Zn	ICP	0.03 *0.029	<0.03	0.014 (<0.02)
Cd	ICP	<0.005 *<d.l.	<0.005	<0.005 (<0.02)
Cu	ICP	<0.015 *0.0021	<0.015	<0.005 (0.03)
Cr	ICP	<0.12 *<d.l.	<0.12	<0.02 (0.05)
Co	ICP	<0.035 *<d.l.	<0.035	<0.020
Ni	ICP	<0.025 *0.0016	<0.085	<0.025 (<0.02)
Mo	ICP	<0.050 *<d.l.	<0.050	<0.035
Pb		<0.100 *<d.l.	<0.050	<0.090 (0.17)
Zr		<0.045 *<d.l.	<0.045	<0.015
V		----	[<0.2]	--- [<0.2]
U	ICP/MS	[0.0003]0.0008	[0.0003]0.0012	--- [<0.001]
Th	ICP/MS	---	0.0002	---
SO_4	IC/ICP	[11.2] <1.00 *0.12/1.73	[<5.0] <0.1	<1.0 [5.4]
F	ISE	[0.06] <0.10 *---	[<0.10] 0.11	0.13 [0.16]
Cl	IC	<1.0 *0.78	0.99	0.98
Br	IC	<0.050 *0.0009	<0.050	<0.005
NO_3	IC	<0.10 *0.064	0.07	0.06
HPO_4	IC	<1.0 *<d.l.	0.21	<0.10
B	ICP	<0.020 *0.0016	---	<0.015
SiO_2	ICP	1.2 *0.67	1.0	1.1 (1.2)
S^{2-}	[ISE]	[<0.0005]	[<0.0001]	--- [<0.001]

Values reported from BGS except [ ] Urânio do Brasil, PdeC and ( ) = CENA, Piracicaba. Alkalinities reported for methyl orange, Gran's titrations.
*Values reported from BGS on x40 concentrates.

Chemical analyses of groundwater samples from the Morro do Ferro study site

Borehole	MF 11	MF 11
Sample Code No.	PC-GW-70	PC-GW-82
Sampling Int (m)	30-40	30-40
Date Collected	881212	890404 {890408}
Temperature(°C)	23	22
pH (lab)	[5/26/6.13] 5.44	[5.31/5.62]4.96 {5.51}
D.O. (mg/L)	7.5	8.5
Eh(mV)	657	525 {590}
Alkalinity (mg/L HCO_3)	[0.58,6.24] <5.0	[0.77 6.86] <5.0

Element	Analytical Method	mg/L	
Ca	ICP (AA)	<0.03 (<0.10)	<0.035
Mg	ICP (AA) {ICP-MS}	<0.07 (<0.10)	<0.070 {0.029}
Sr	ICP (AA) {ICP-MS}	0.002 (<0.01)	0.0020 {0.001}
Ba	ICP (AA) {ICP-MS}	0.003 (<0.02)	0.0030 {0.0028}
Na	ICP {ICP-MS}	0.05 [<0.10]	<0.030 [0.12] {0.057}
K	ICP	<0.60 [0.15]	<0.6 [0.16]
Li	ICP {ICP-MS}	<0.01	<0.010 {0.0003}
Fe(II)	[COLOR]	[<0.10]	[<0.10]
Fe(tot)	ICP (AA)	<0.010 [<0.10](<0.02)	<0.010 [<0.10]
Al	ICP (AA) {ICP-MS}	0.07 (0.31)	0.103 {0.0023}
Mn	ICP (AA) {ICP-MS}	0.053 (0.06)	0.063 {0.034}
Zn	ICP (AA) {ICP-MS}	0.014 (<0.02)	<0.050 {0.050}
Cd	ICP (AA) {ICP-MS}	<0.005 (<0.02)	<0.005 {<0.0005}
Cu	ICP (AA) {ICP-MS}	<0.005 (<0.02)	<0.005 {0.0042}
Cr	ICP (AA)	<0.02 (<0.05)	<0.020
Co	ICP {ICP-MS}	<0.020	<0.020 {<0.0005}
Ni	ICP (AA)	<0.025 (<0.02)	<0.025
Mo	ICP {ICP-MS}	<0.035	<0.035 {<0.0005}
Pb	(AA) {ICP-MS}	<0.09 (0.15)	0.098 {0.0023}
Zr		<0.0015	<0.015
V		<0.0015 [<0.2]	[<0.2]
U	{ICP-MS}	[0.001]	[0.004] {0.0005}
Th	{ICP-MS}	---	{0.000003}
SO_4	IC [N]	<2.0 [<5.0]	<2.0 [<5.0]
F	ISE [ISE]	0.04 [0.36]	0.27 [<0.10]
Cl	IC	<2.0	<2.0
Br	IC	<0.05	<0.05
NO_3	IC	<0.10	0.25
HPO_4	IC	<0.1 (0.31)	<0.1
B	ICP (AA)	<0.015 (<0.02)	<0.015
SiO_2	ICP (AA)	1.11 (2.31)	1.08
S^{2-}		[<0.001]	[<0.001]

Values reported from BGS except [ ] Urânio do Brasil, PdeC and ( ) = CENA, Piracicaba and { } = PSI. Alkalinities reported for methyl orange, Gran's titrations.

Chemical analyses of groundwater samples from the Morro do Ferro study site

Borehole	MF 12	MF 12	MF12
Sample Code No.	PC-GW-18	PC-GW-34	PC-GW-50
Sampling Int (m)	20-70	45-71	45-71
Date Collected	870707	880128	880614
Temperature (°C)	[23]	[25]	[21]
pH [field/lab] lab	7.0	[5.7/6.36] 7.09	[5.99/6.19] 6.55
D.O. (mg/L)	---	1.66	9.27
Eh(mV)	---	303	212
Alkalinity (mg/L HCO_3)	12 [18]	[35.3] 19.3	[34.7] <5.0

Element	Analytical Method		mg/L	
Ca	ICP	1.18	8.18 *3.32	8.16 (8.79)
Mg	ICP	0.28	0.61 *0.28	0.62 (0.79)
Sr	ICP	0.041	0.301 *0.137	0.329 (0.363)
Ba	ICP	0.004	<0.001 *0.0007	<0.001 (<0.005)
Na	[AA] ICP	1.95	[1.09] 0.69 *0.30	[0.97] 0.67 (0.88)
K	[AA] ICP	4.1	[10.5] 11.5 *5.1	[9.47] 11.80 (12.4)
Li	ICP	<0.02	<0.015 *---	<0.015
Fe(II)	[COLOR]	---	[1.31] ----	[0.74] ----
Fe(tot)	[COLOR] ICP	<0.02 [1.0]	[1.33] <0.02 *0.015	[0.79] 1.28 (<0.10)
Al	ICP	<0.1	0.22 *0.12	0.21 (<0.5)
Mn	ICP	0.48	1.56 *0.64	1.68 (1.75)
Zn	ICP	<0.033	0.45 *0.27	0.27 (0.343)
Cd	ICP	<0.024	<0.005 *<d.l.	<0.005 (<0.005)
Cu	ICP	<0.043	<0.015 *<d.l.	<0.015 (<0.050)
Cr	ICP	<0.12	<0.12 *<d.l.	<0.12 (0.017)
Co	ICP	<0.035	<0.035 *<d.l.	<0.035 (<0.002)
Ni	ICP	<0.085	<0.025 *<d.l.	<0.085 (<0.003)
Mo	ICP	<0.6	<0.050 *<d.l.	<0.050 (<0.2)
Pb		---	<0.100 *<d.l.	<0.050
Zr		---	<0.045 *0.0015	<0.045
V		---	----	[<0.2]
U	ICP/MS	---	[0.0008] 0.0003	[0.0008] 0.0007
Th	ICP/MS	---	----	0.00007
SO_4	IC	0.92	[13.2] 9.41*4.98/4.08	[13.6] 9.7
F	ISE	0.68	[5.95] 7.91 *---	[4.96] 5.54
Cl	IC	1.04	1.1 *1.94	<0.10
Br	IC	<0.05	<0.050 *0.0003	<0.050
NO_3	IC	<0.1	<0.1 *0.0009	1.0
HPO_4	IC	<0.1	<1.0 *<d.l.	<0.05
B	ICP	<0.02	<0.02 *0.001	---
SiO_2	ICP	3.0	33.4 *7.72	33.4 (40.6)
S^{2-}	[ISE]	---	0.003	[<0.001]

Values reported from BGS except [ ] Urânio do Brasil, PdeC. Alkalinities reported for methyl orange, Gran's titrations. *Values reported from BGS on x40 concentrates. ( ) U.S.G.S. data, J.W. Ball.

Chemical analyses of groundwater samples from the Morro do Ferro study site

Borehole		MF 12	MF 12	MF 12
Sample Code No.		PC-GW-56	PC-GW-71	PC-GW-85
Sampling Int (m)		45-71	45-71	45-71
Date Collected		880919	881214	890411 {890409}
Temperature(°C)		24	----	22
pH [field/lab] lab		[6.13/6.20] 6.14	[6.11] 6.50	[6.22/6.63] 6.13 {6.22}
D.O. (mg/L)		0.145	0.265	0.60
Eh(mV)		212	-----	446 {418}
Alkalinity (mg/L HCO_3)		[18.7,24.6] <5.0	[18.3,26.8] 23.7	[23.6,31.2] 23.8

Element	Analytical Method	mg/L		
Ca	ICP (AA)	5.30 (6.10)	9.56 (9.39)	6.75
Mg	ICP (AA)	0.38 (0.62)	0.729 (0.71)	0.534 {0.499}
Sr	ICP (AA)	0.214 (0.23)	0.376 (0.34)	0.2720 {0.126}
Ba	ICP (AA)	0.003 (<0.02)	0.001 (<0.02)	<0.0008 {0.00019}
Na	ICP	0.43 [0.80]	0.705 [0.80/0.32]	0.503 [0.72/1.04]
K	ICP	9.06 [0.94]?	12.5 [0.4/9.78]	10.6 [8.40/10.4]
Li	ICP	<0.010	<0.01	<0.010 {0.0006}
Fe(II)	[COLOR]	---- [0.66]	---- [0.57]	---- [---]
Fe(tot)	ICP (AA)	0.596 [0.68]	1.83 [0.58] (1.85)	0.557 [---]
Al	ICP (AA)	0.240	0.16 (0.47)	0.0226 {0.134}
Mn	ICP (AA)	1.140	1.90 (1.84)	1.45 {0.495}
Zn	ICP (AA)	0.776	0.288 (0.27)	0.399 {0.826}
Cd	ICP (AA)	<0.005	<0.005 (<0.02)	<0.005 {<0.0005}
Cu	ICP (AA)	<0.005	<0.005 (<0.02)	<0.005 0.0005
Cr	ICP (AA)	<0.02	<0.02 (<0.05)	<0.020
Co	ICP	<0.020	<0.020	<0.020 {<0.0005}
Ni	ICP (AA)	<0.025	<0.025 (<0.02)	<0.025
Mo	ICP	<0.035	<0.035	<0.035 {0.0007}
Rb		----	----	{0.016}
Cs		----	----	{0.001}
Pb	(AA)	<0.090 (0.18)	<0.09 (0.15)	<0.09 {0.0007}
Zr		<0.015	<0.0015	<0.015
V		---- [<0.2]	<0.0015 [<0.2]	---- [<0.2]
U		----[<0.001]	---- [0.001]	-- [0.006] {0.0012}
Th		----	----	{0.000029}
SO_4	IC [N]	8.7 [14.0]	9.6 [<5.0]	10.1 [16.8]
F	ISE [ISE]	3.98 [4.83]	6.80 [4.15]	5.52 [6.48]
Cl	IC	0.13	<2.0	<2.0
Br	IC	<0.005	<0.05	<0.05
NO_3	IC	0.02	<0.10	<0.10
HPO_4	IC	<0.010	<0.1	<0.1
B	ICP (AA)	<0.015 (<0.02)	<0.015 (<0.02)	0.019
SiO_2	ICP (AA)	30 (30.2)	37 (37.6)	33
S^{2-}		---- [<0.002]	---- [<0.001]	---- [---]

Values reported from BGS except [ ] Urânio do Brasil, PdeC. Alkalinities reported for methyl orange, Gran's titrations. ( ) = CENA, Piracicaba. { } = ICP-MS results from Degueldre, PSI.

Chemical analyses of groundwater samples from the Morro do Ferro study site

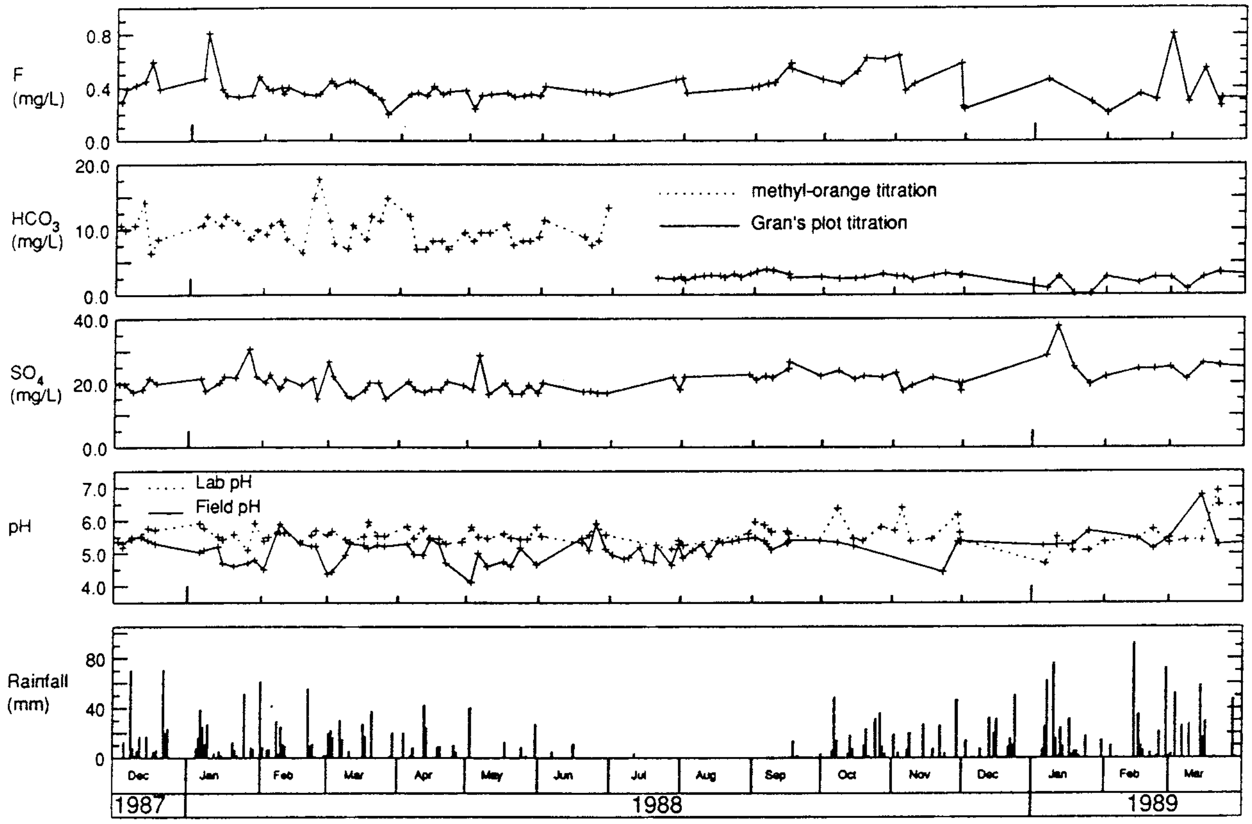
Borehole		MF 13	MF 13
Sample Code No.		PC-GW-73	PC-GW-84
Sampling Int (m)		45 - 71	45 - 71
Date Collected		881220	890407
Temperature(°C)		----	23
pH [field/lab] lab		[5.45] 5.55	[5.19/5.10] 4.70 {5.19}
D.O. (mg/L)		[6.74]	[4.00]
Eh(mV)		----	659 {632}
Alkalinity (mg/L HCO_3)		[0.61,22.5] <5.0	[0.34,9.36] <5.0
Element	**Analytical Method**		**mg/L**
Ca	ICP (AA)	0.585 (<0.10)	<0.035
Mg	ICP (AA)	<0.070 (<0.10)	<0.070 {0.057}
Sr	ICP (AA)	0.002 (<0.01)	0.0010 {0.003}
Ba	ICP (AA)	0.003 (<0.02)	0.0020 {0.0039}
Na	ICP	0.123 [0.24]	0.071 [<0.10]{0.034}
K	ICP	<0.6 [0.48]	<0.6 [<0.10]
Li	ICP	<0.01	<0.010 {0.0004}
Fe(II)	[COLOR]	---- [<0.10]	---- [<0.10]
Fe(tot)	ICP (AA)	0.010 [<0.10](<0.02)	<0.010 [<0.10]
Al	ICP (AA)	0.16 (0.35)	0.094 {0.002}
Mn	ICP (AA)	0.041 (0.040)	0.0060 {0.144}
Zn	ICP (AA)	0.030 (0.02)	<0.050 {0.087}
Cd	ICP (AA)	<0.005 (<0.02)	<0.005 {<0.0005}
Cu	ICP (AA)	<0.005 (<0.02)	<0.005 {0.0012}
Cr	ICP (AA)	<0.02 (<0.05)	<0.020
Co	ICP	<0.020	<0.020 {<0.0005}
Ni	ICP (AA)	<0.025 (<0.02)	<0.025
Mo	ICP	<0.035	<0.035 {<0.0005}
Rb		----	--- {<0.0007}
Cs		----	--- {<0.0005}
Pb	(AA)	<0.09 (<0.10)	<0.09 {0.0009}
Zr		<0.0015	<0.015 {<0.0005}
V		<0.0015 [<0.2]	---- [<0.2]
U		---- [0.001]	---[0.0004]{0.00047}
SO_4	IC [N]	<2.0 [<5.0]	<2.0 [6.4]
F	ISE [ISE]	0.04 [0.64]	0.16 [<0.10]
Cl	IC	<2.00	<2.0
Br	IC	<0.05	<0.05
NO_3	IC	0.16	0.36
HPO_4	IC	<0.1	<0.01
B	ICP (AA)	<0.015 (<0.02)	<0.015
SiO_2	ICP (AA)	2.58 (3.47)	1.18
S^{2-}		[<0.001]	[<0.001]

Values reported from BGS except [ ] Urânio do Brasil, PdeC and ( ) = CENA, Piracicaba. Alkalinities reported for methyl orange, Gran's titrations.

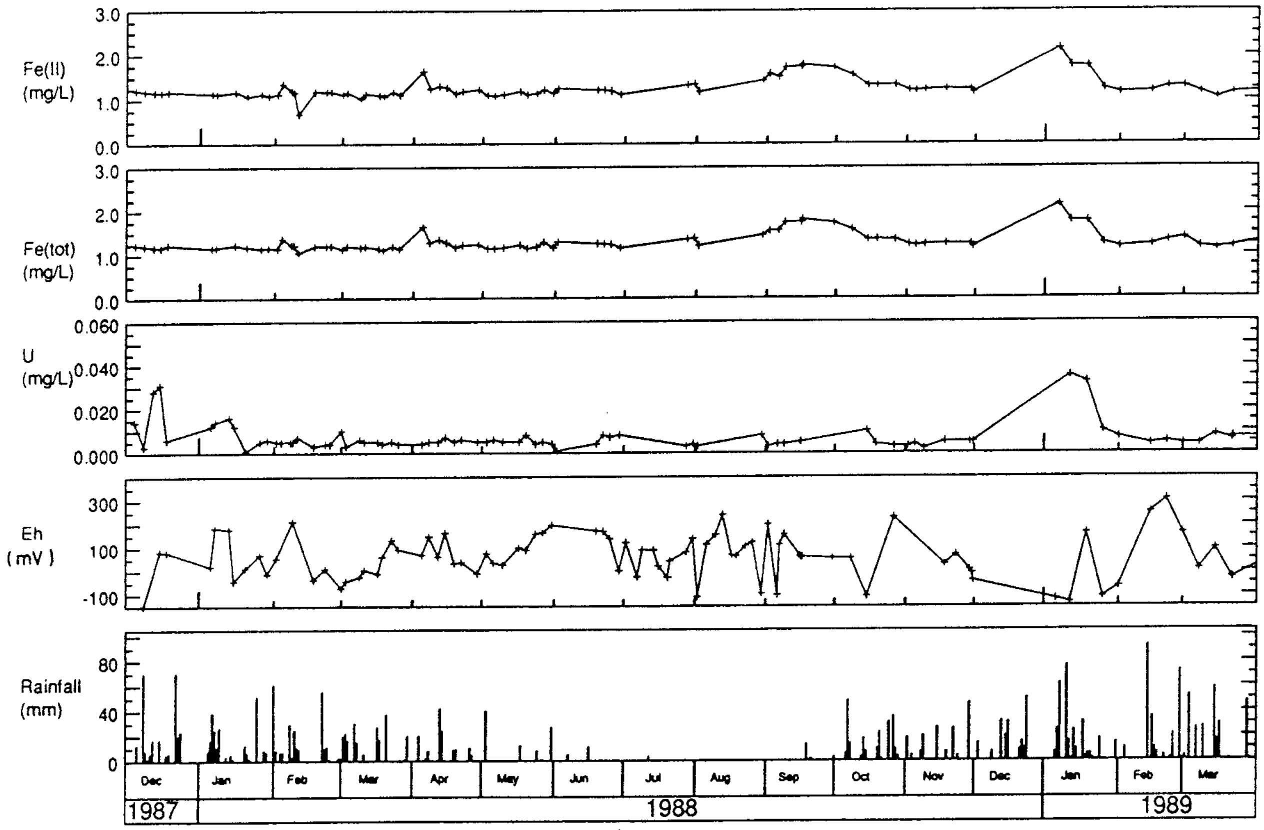
Appendix 4

Results from long-term monitoring for detection of seasonal patterns.

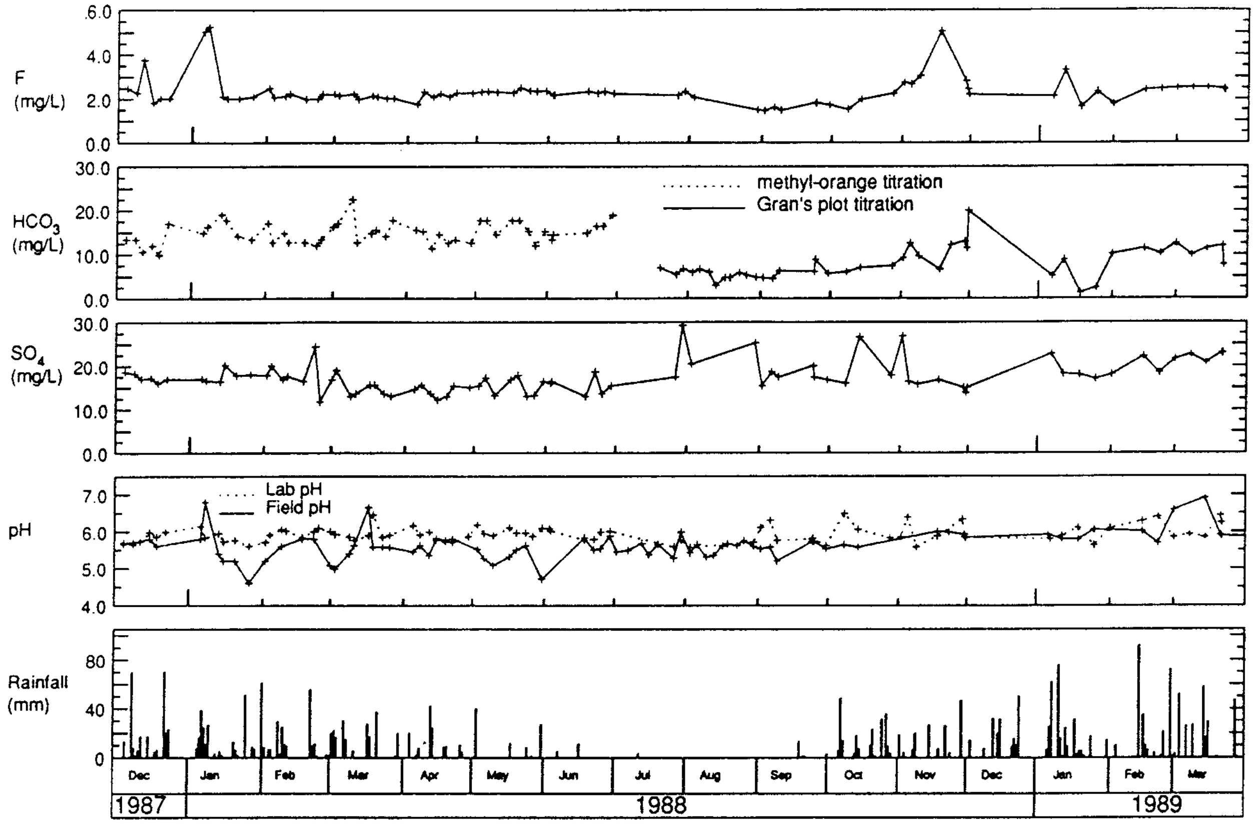
F1 (9-1WC11), Dec. 1987 - Mar. 1989



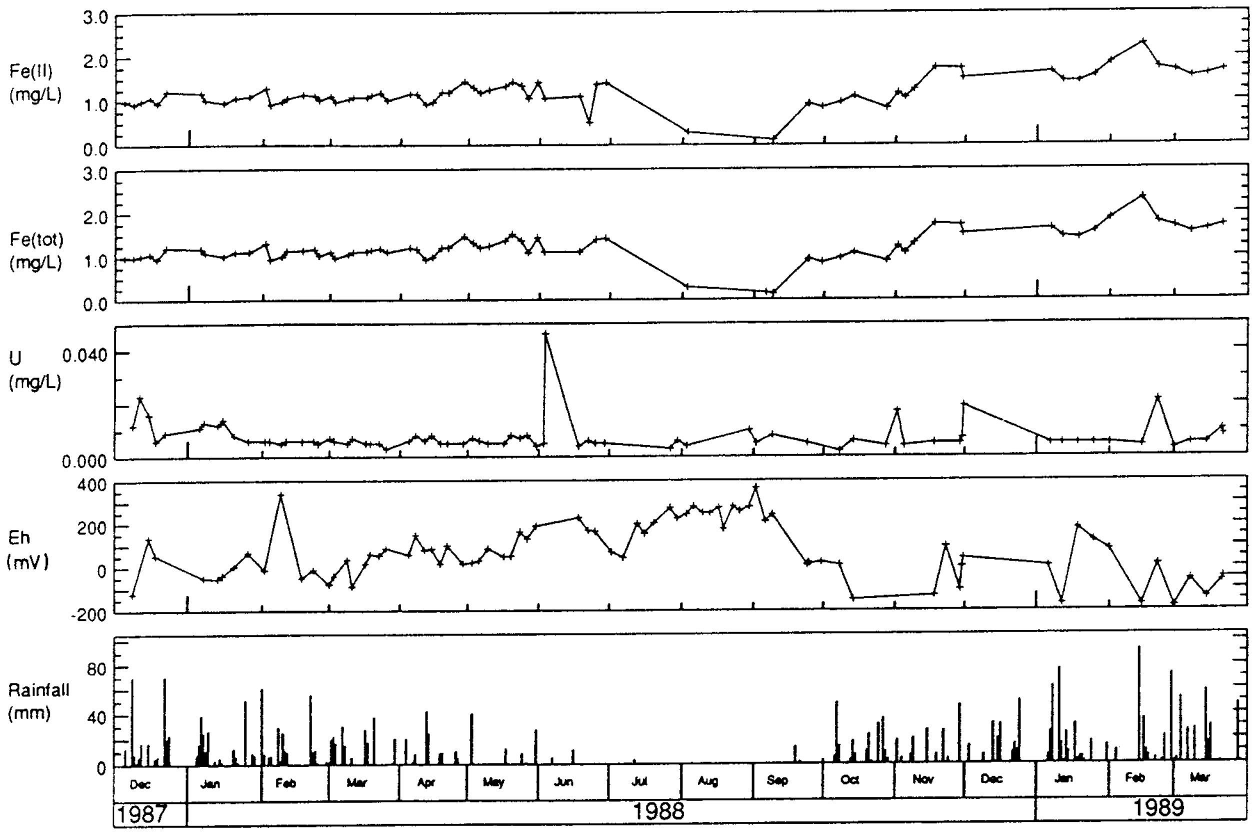
F1 (9-1WC11), Dec. 1987 - Mar. 1989



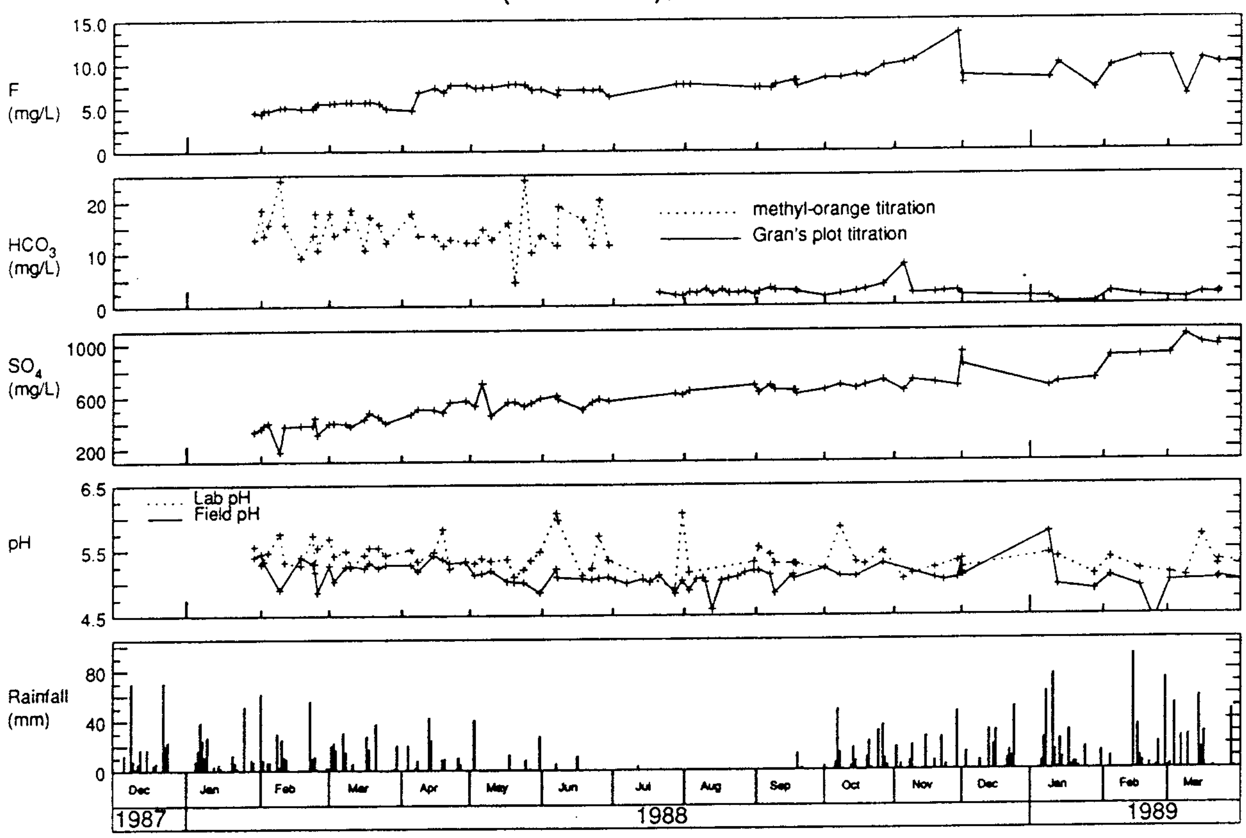
F2 (9-1VC24), Dec. 1987 - Mar. 1989



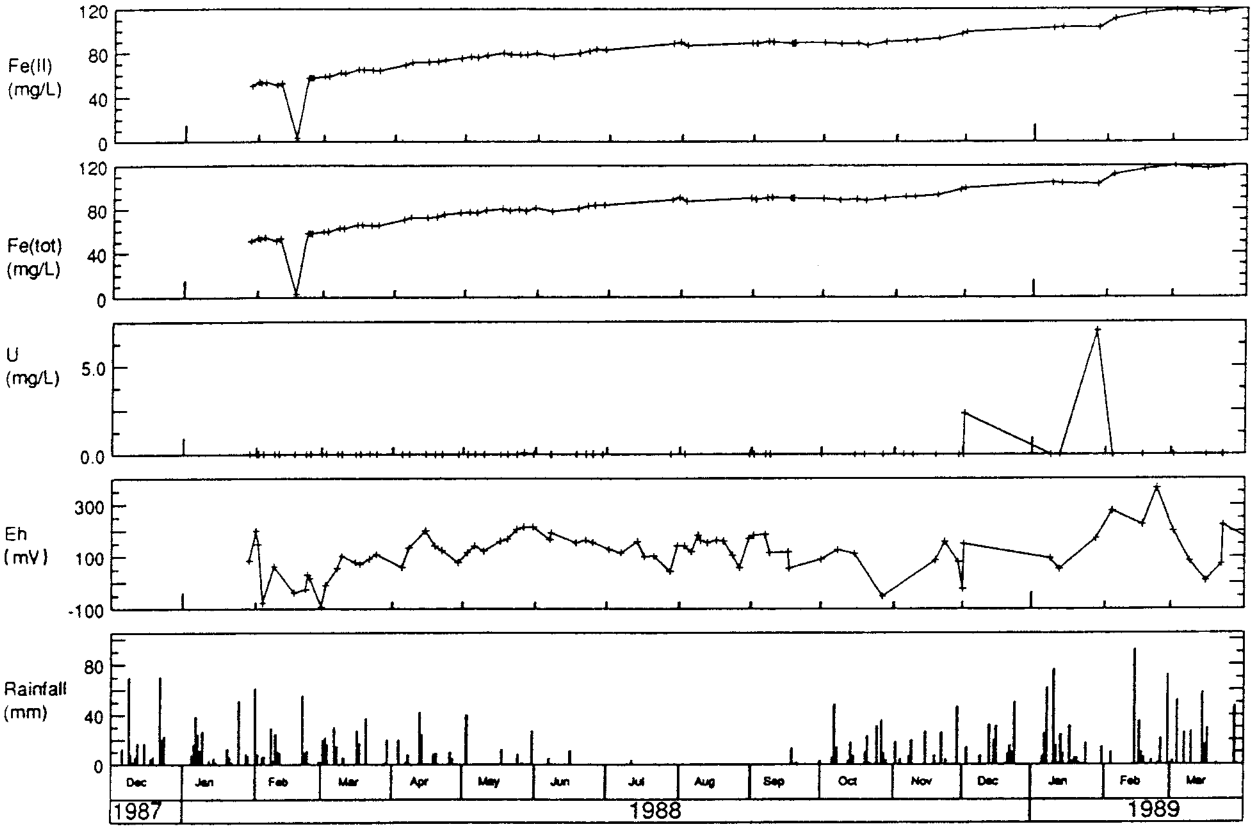
F2 (9-1VC24), Dec. 1987 - Mar. 1989



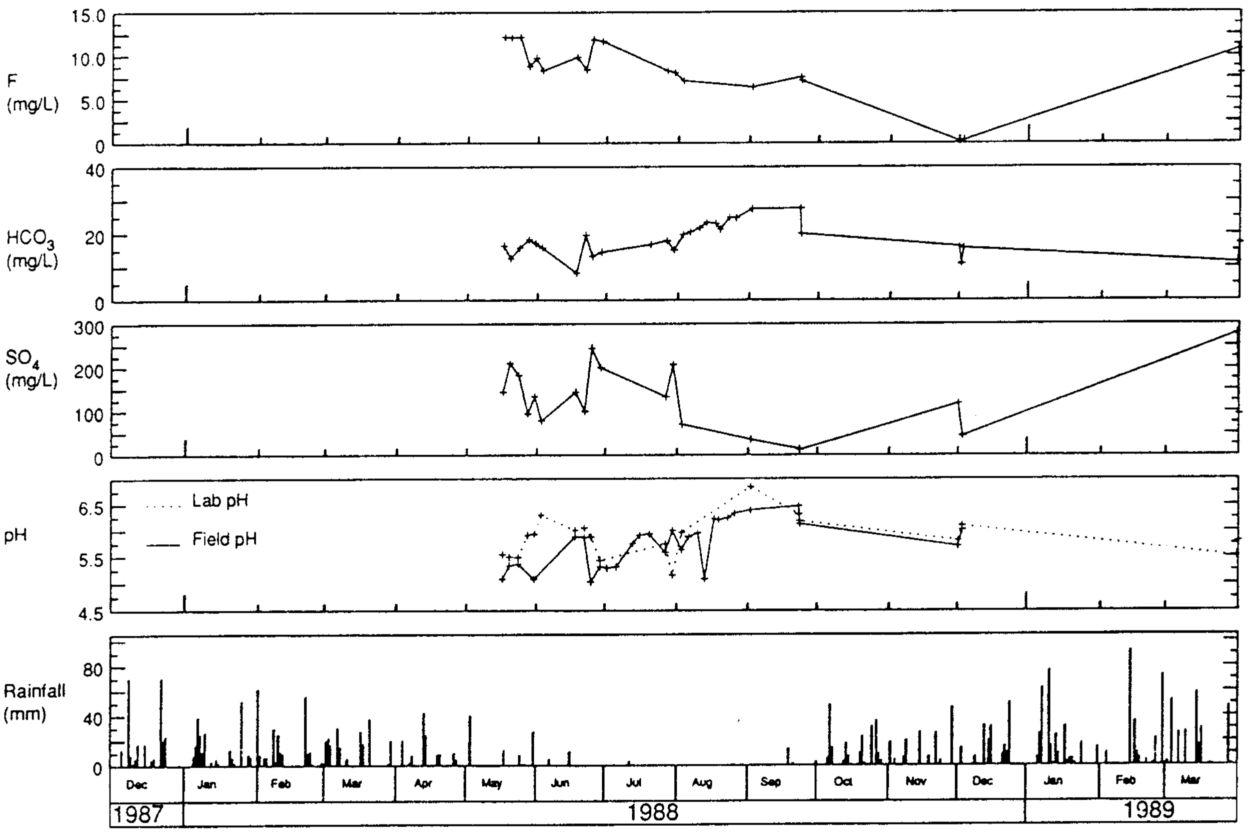
F3 (9-1NH47), Dec. 1987 - Mar. 1989



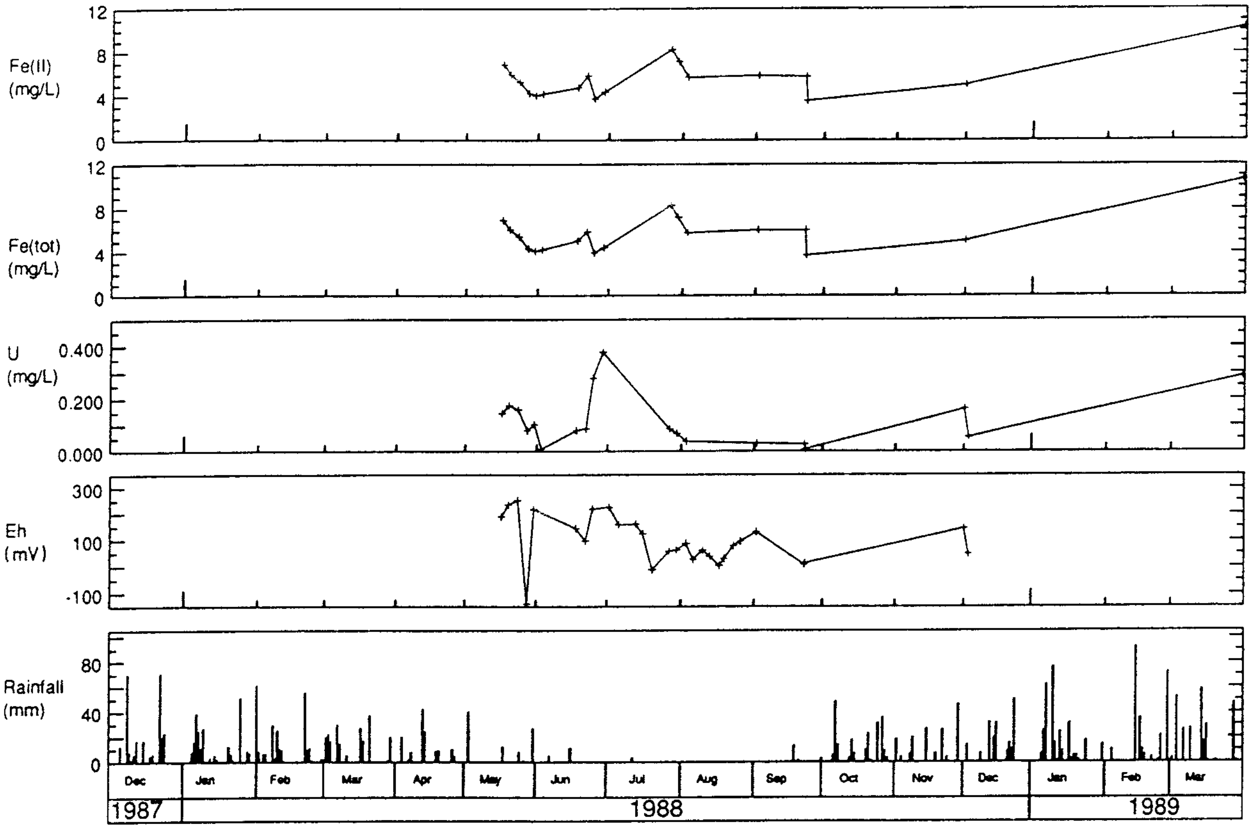
F3 (9-1NH47), Dec. 1987 - Mar. 1989



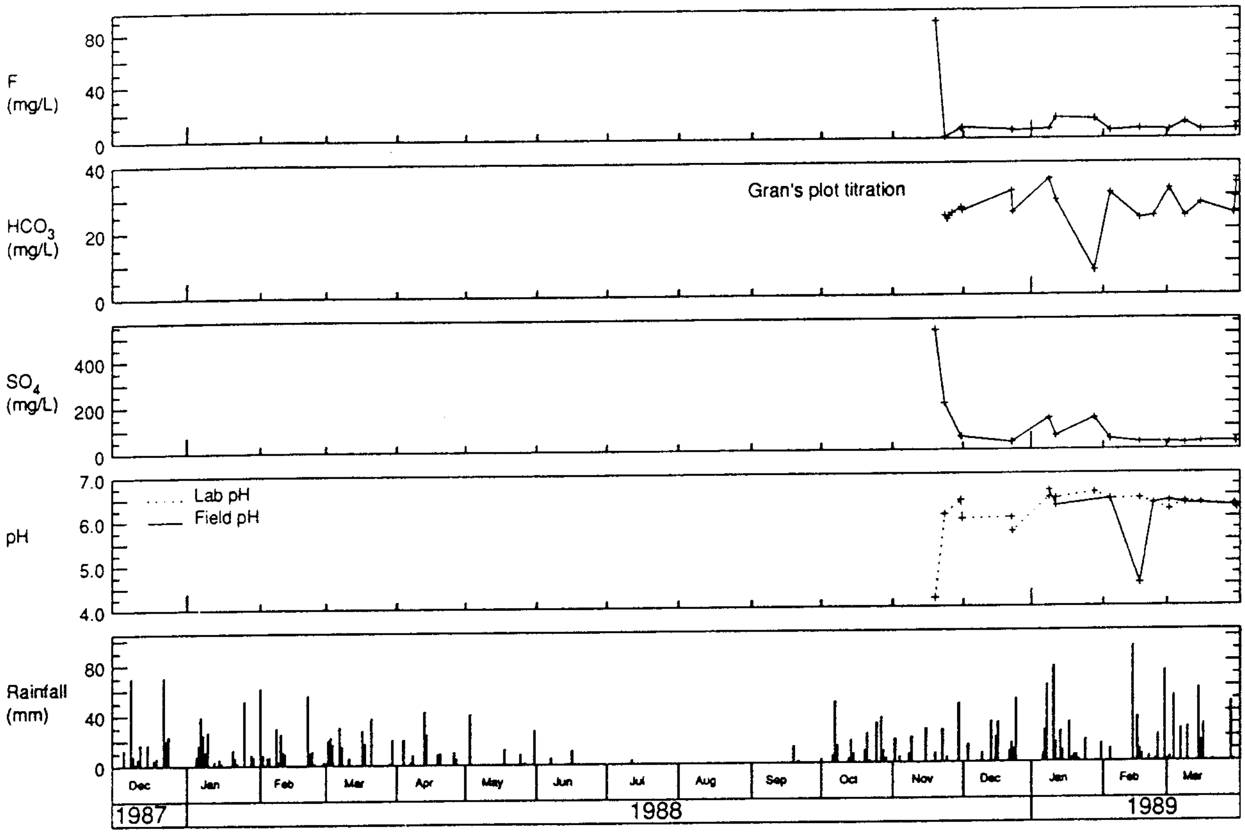
F4 (8-1UK11), Dec. 1987 - Mar. 1989

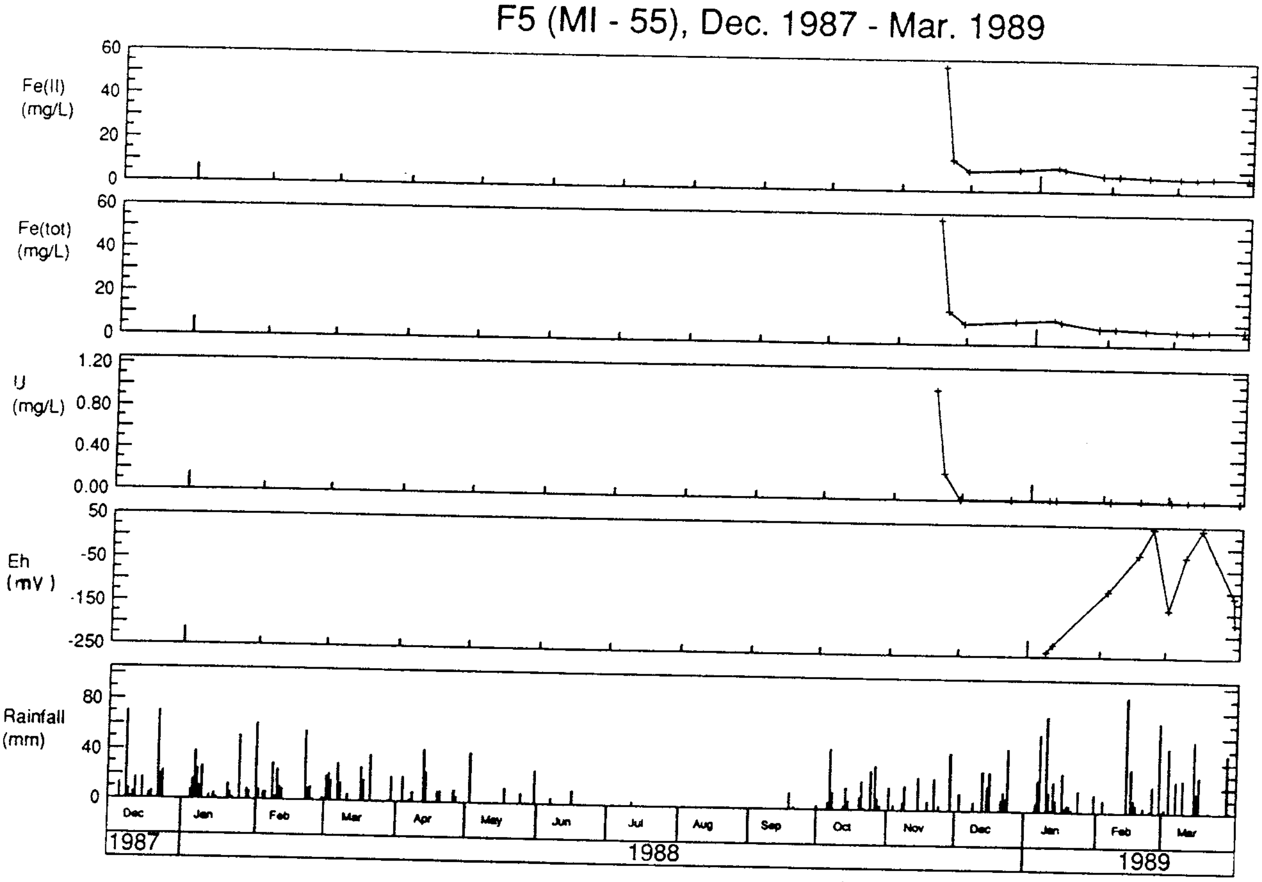


F4 (8-1UK11), Dec. 1987 - Mar. 1989

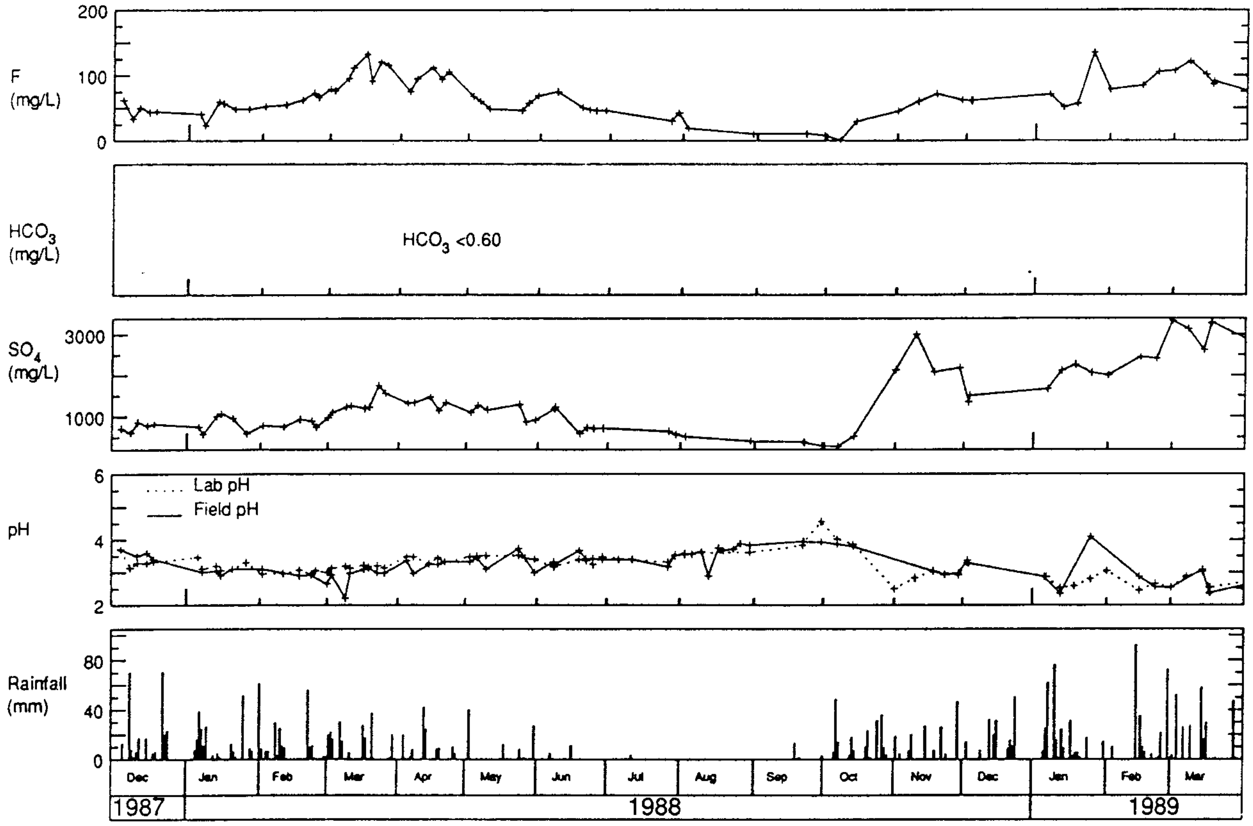


F5 (MI-55), Dec. 1987 - Mar. 1989

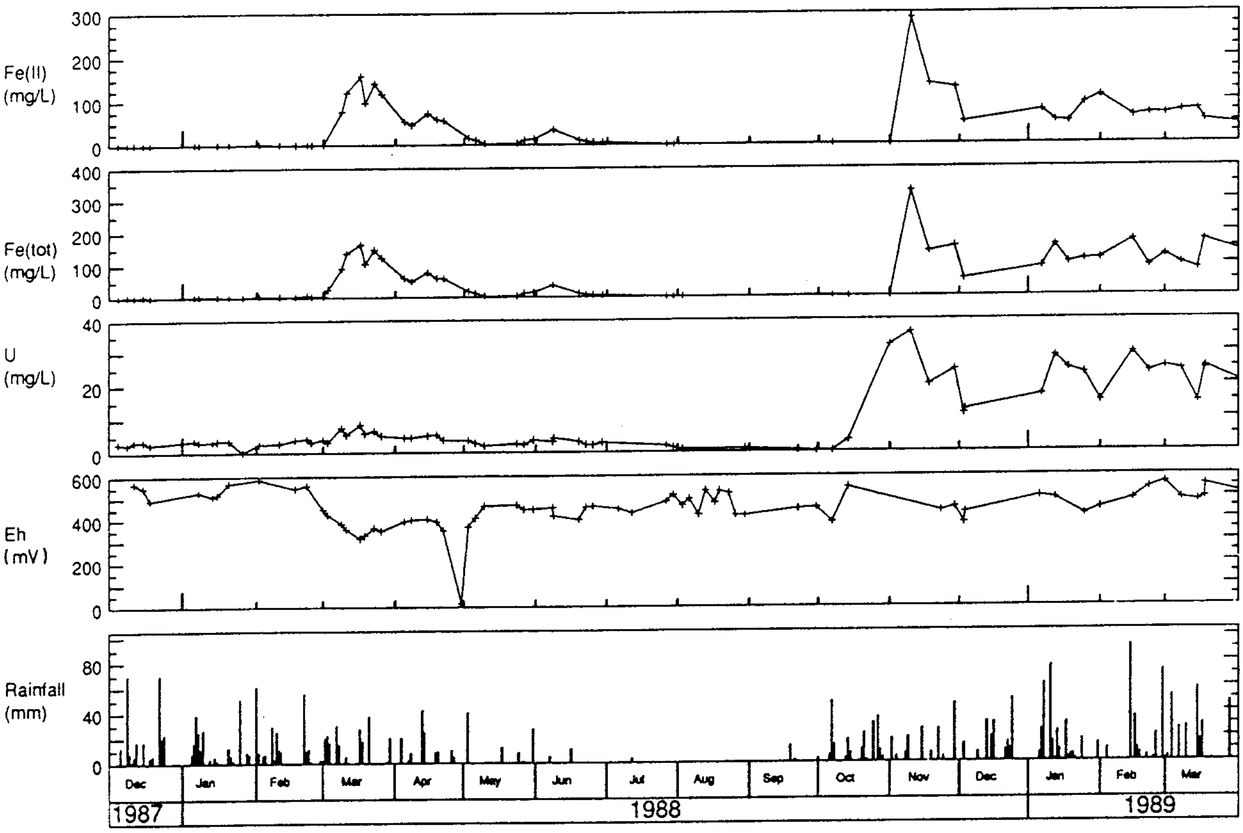



F5 (MI - 55), Dec. 1987 - Mar. 1989
Fe(II) (mg/L)
Fe(tot) (mg/L)
U (mg/L)
Eh (mV)
Rainfall (mm)
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
1987
1988
1989

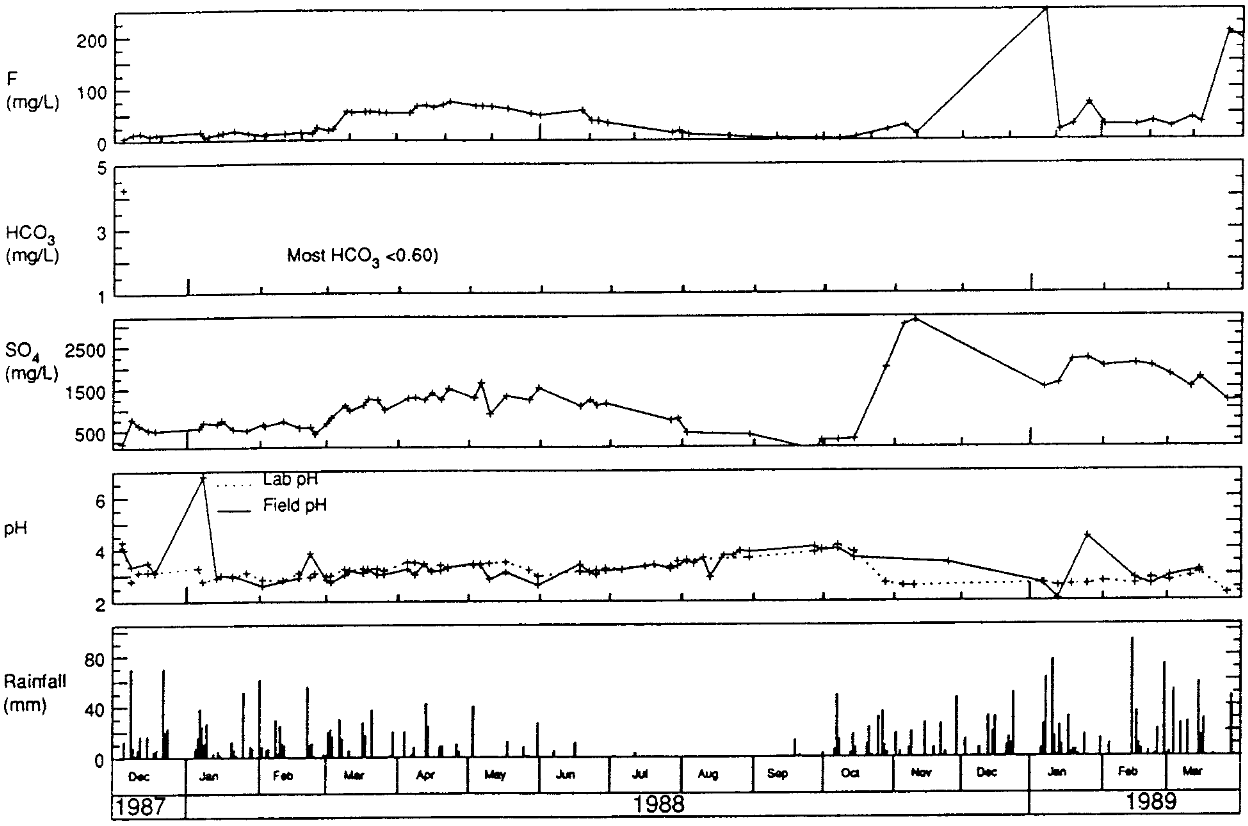
SW-01, Dec. 1987 - Mar. 1989



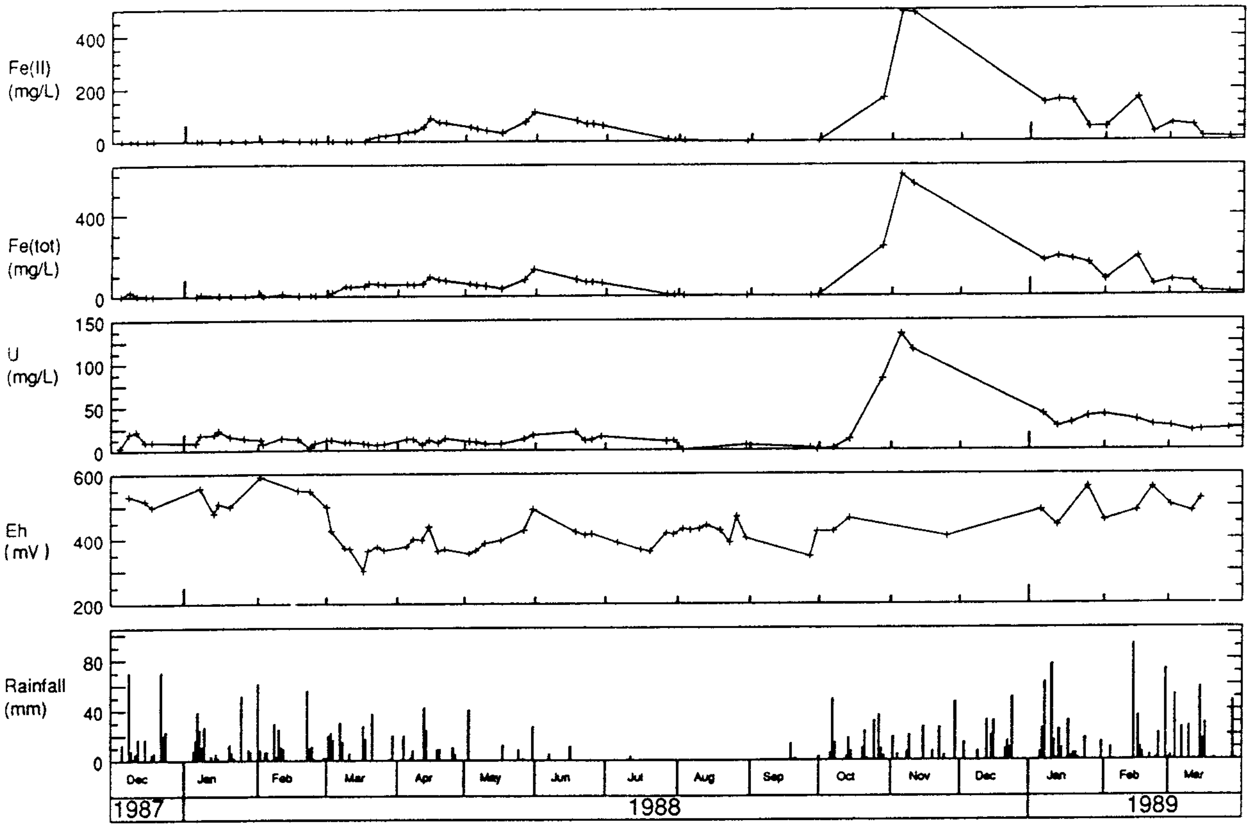
SW-01, Dec. 1987 - Mar. 1989



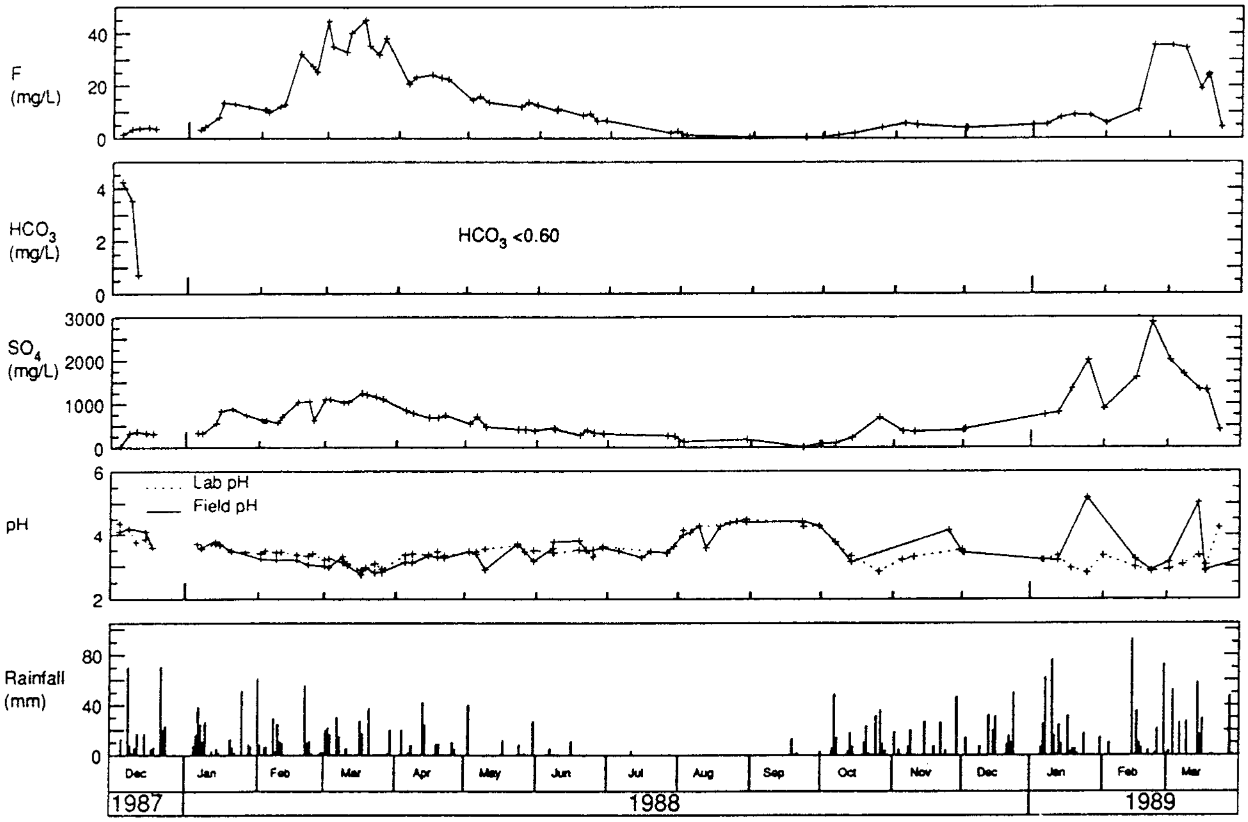
SW-02, Dec. 1987 - Mar. 1989



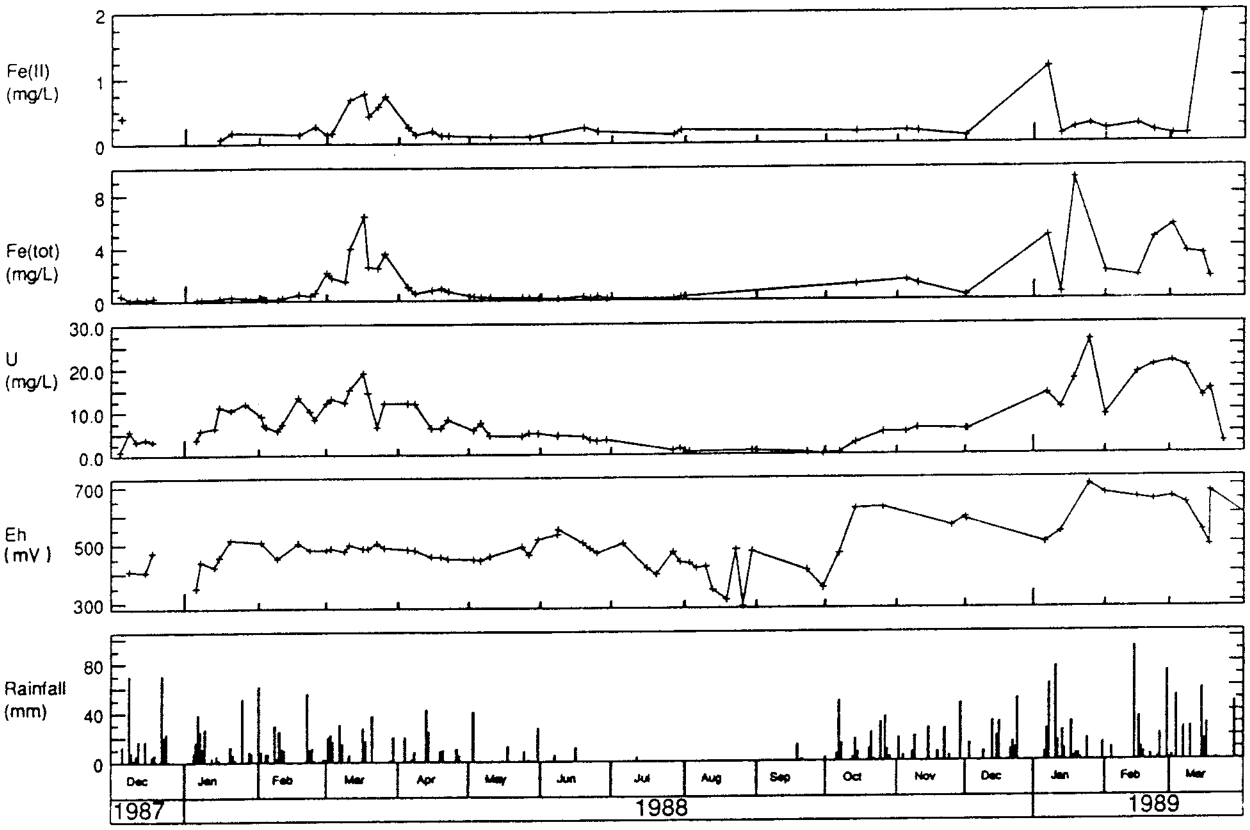
SW-02, Dec. 1987 - Mar. 1989



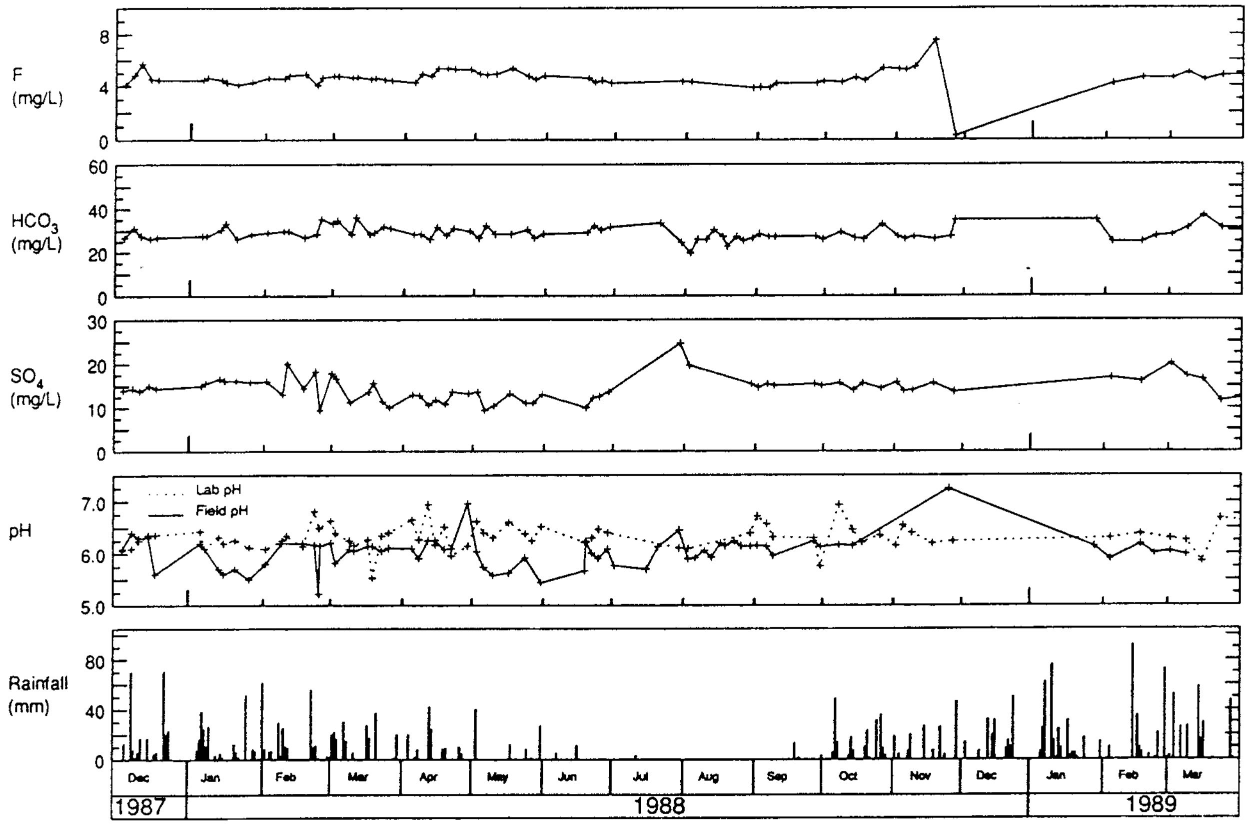
SW-03, Dec. 1987 - Mar. 1989



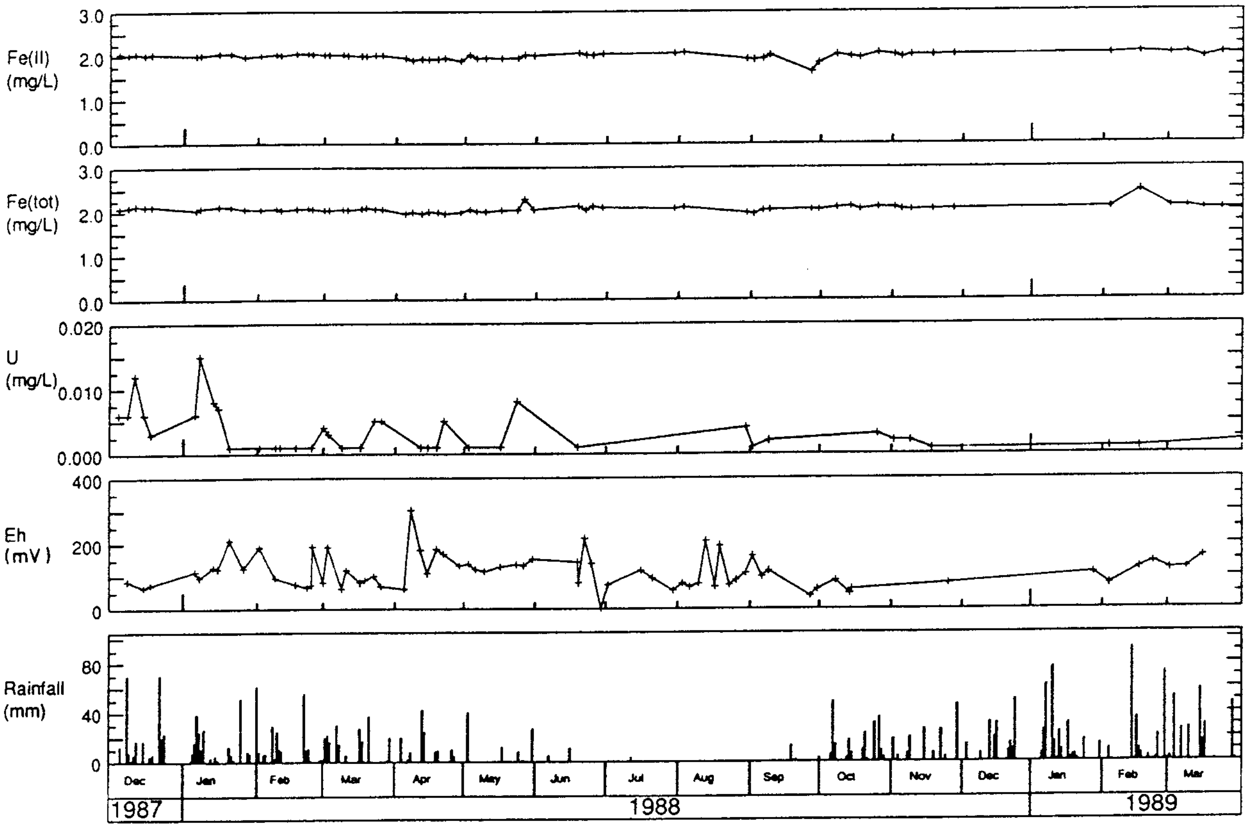
SW-03, Dec. 1987 - Mar. 1989



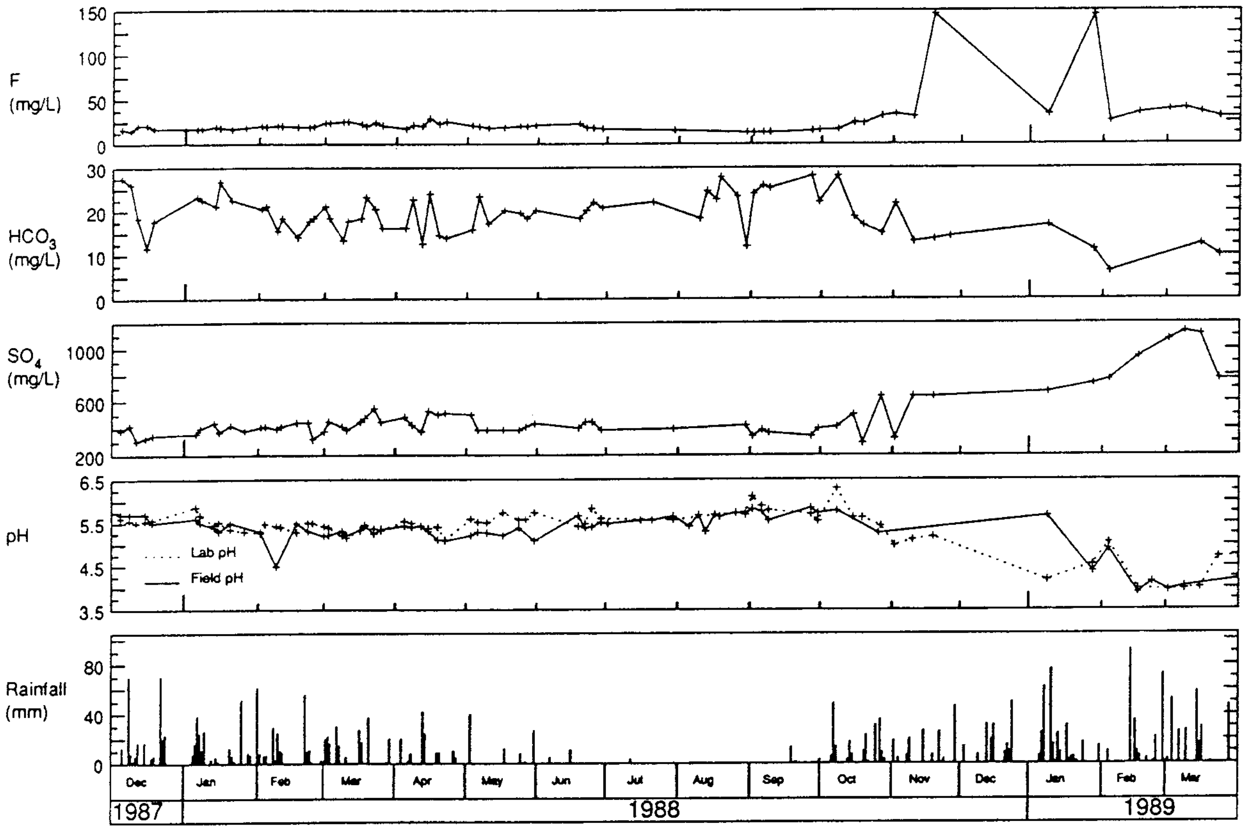
PIEZOMETER STATION 22, Dec. 1987 - Mar. 1989



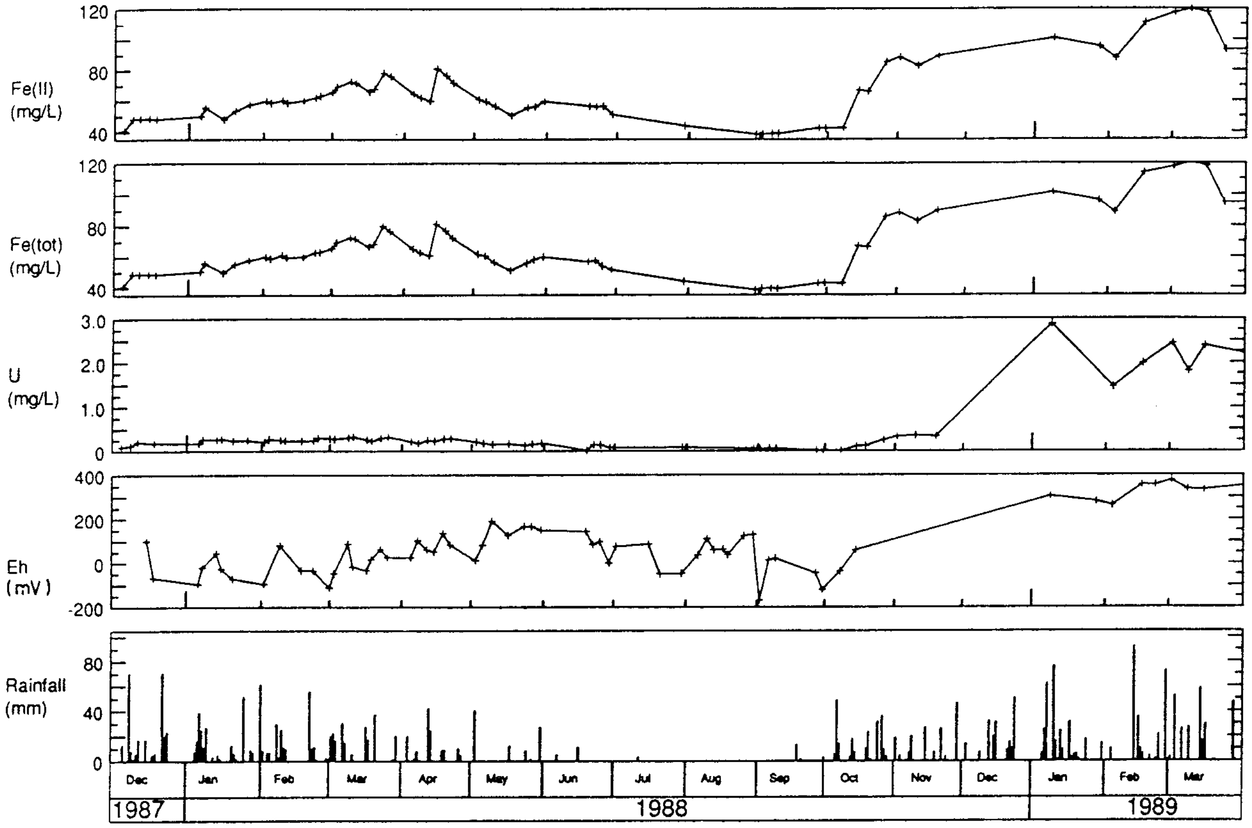
PIEZOMETER STATION 22, Dec. 1987 - Mar. 1989



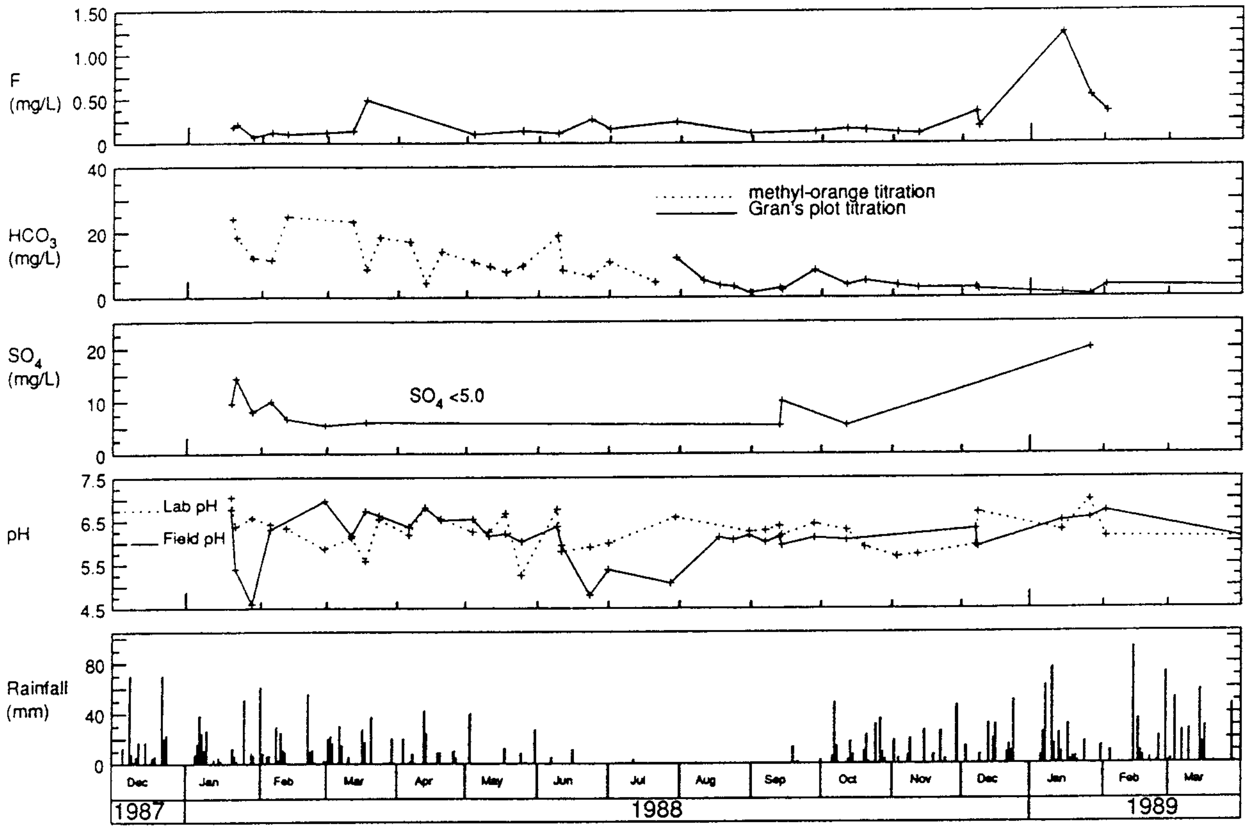
SHAFT, Dec. 1987 - Mar. 1989



SHAFT, Dec. 1987 - Mar. 1989



MF 10, Dec. 1987 - Mar. 1989



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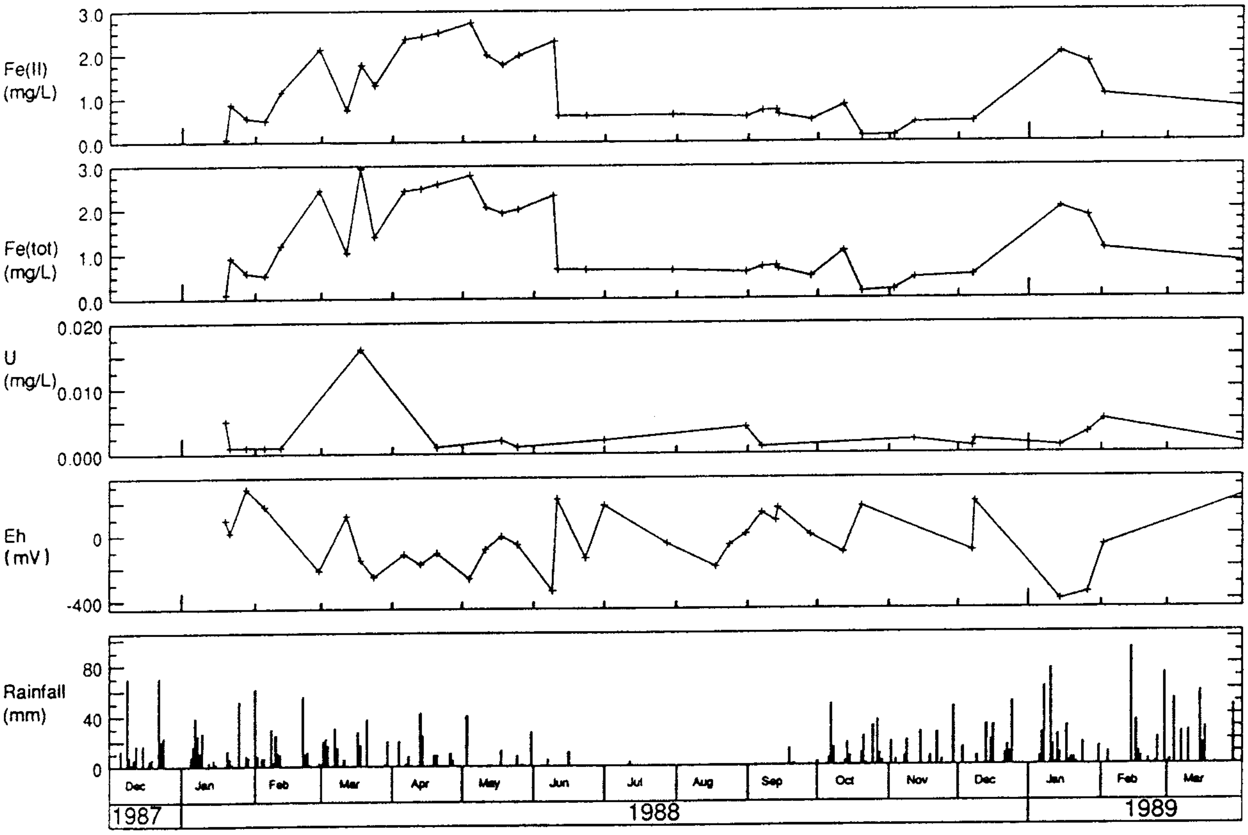
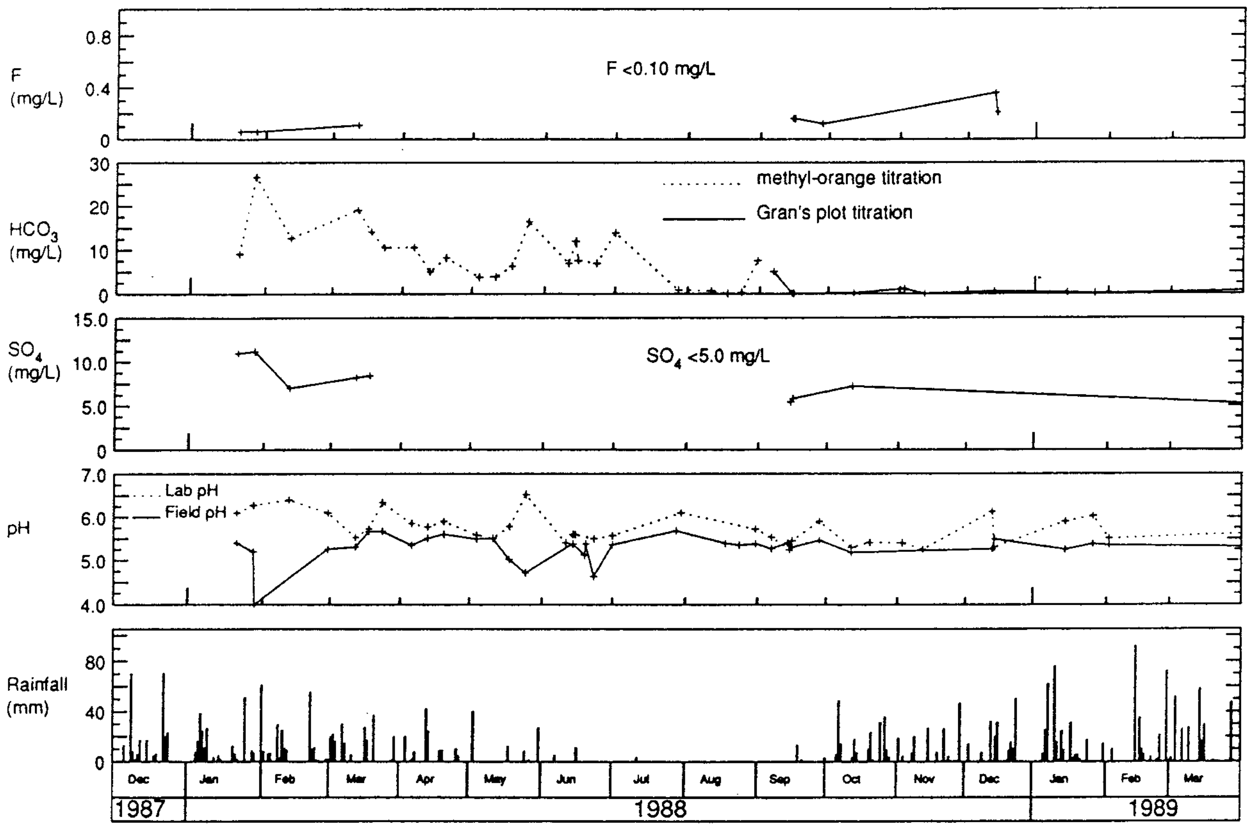


MF 11, Dec. 1987 - Mar. 1989



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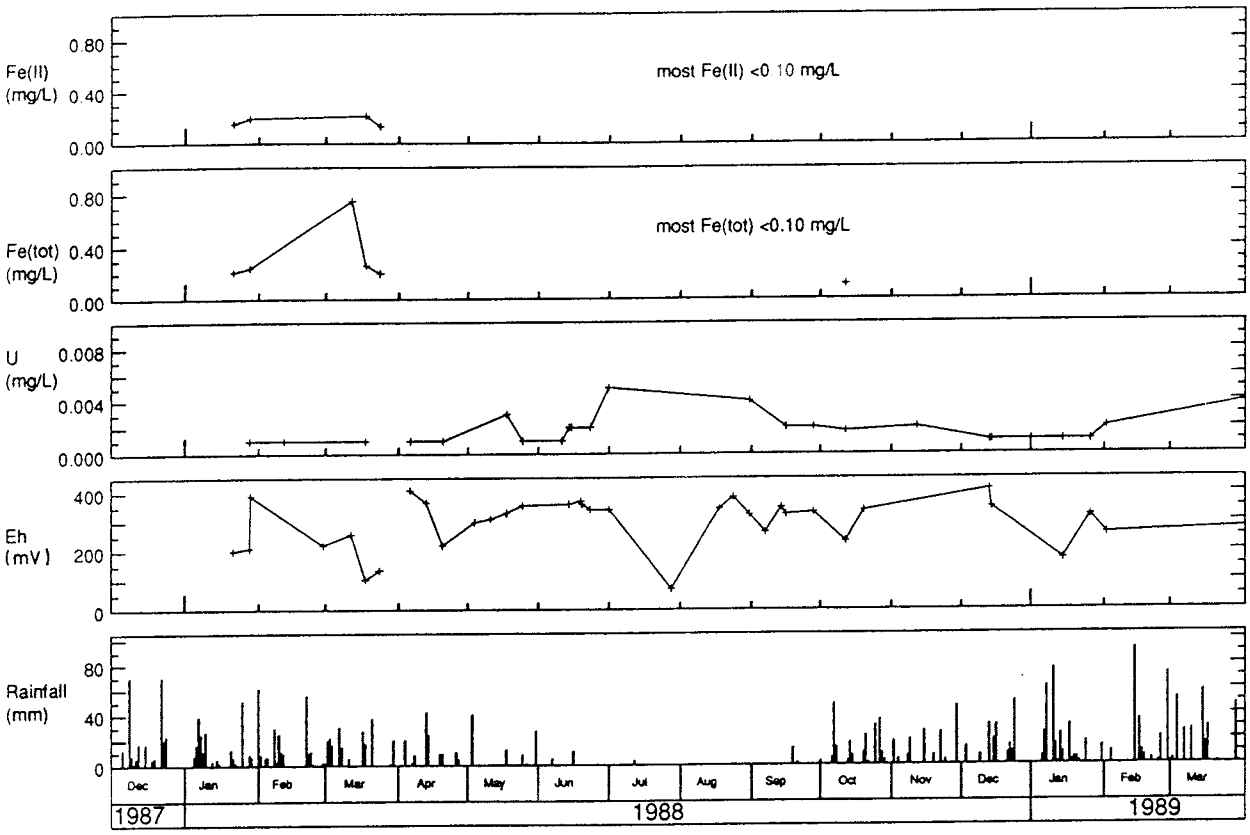
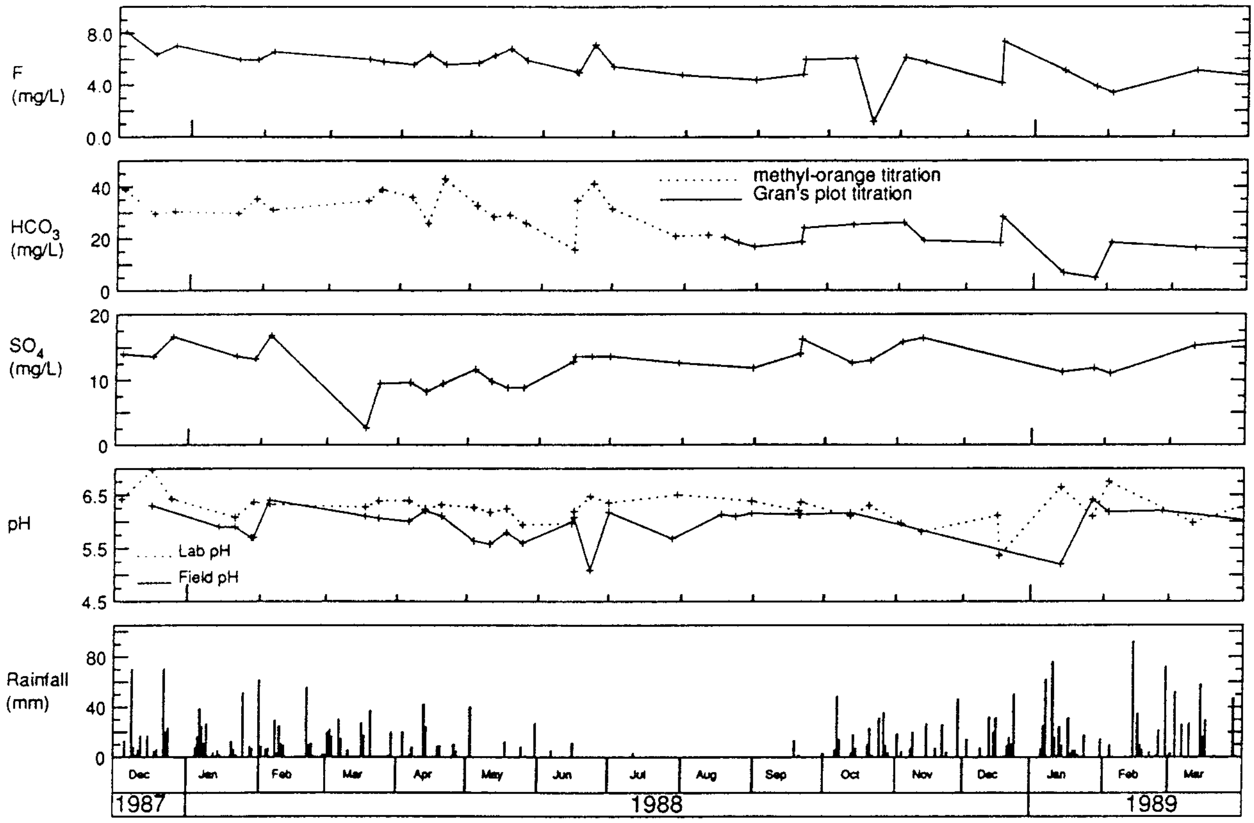
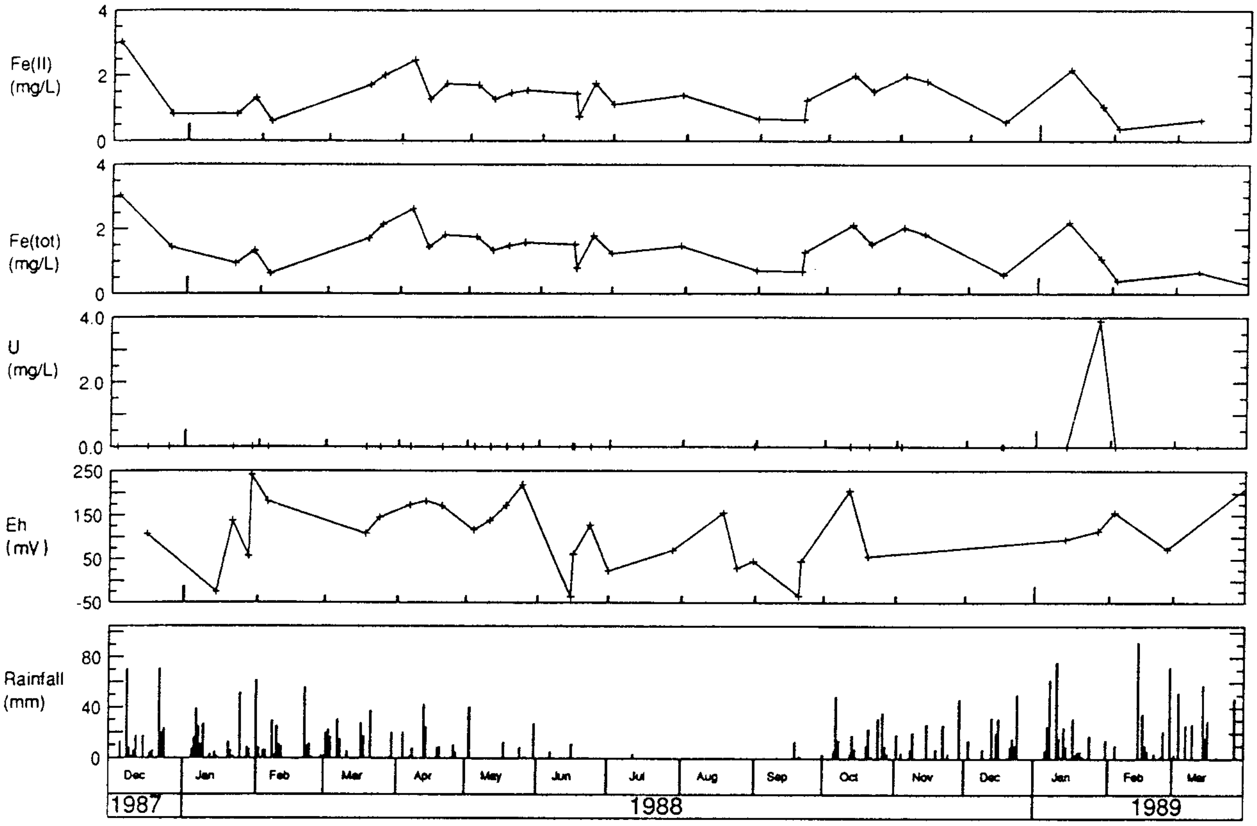


MF 12, Dec. 1987 - Mar. 1989



MF 12, Dec. 1987 - Mar. 1989



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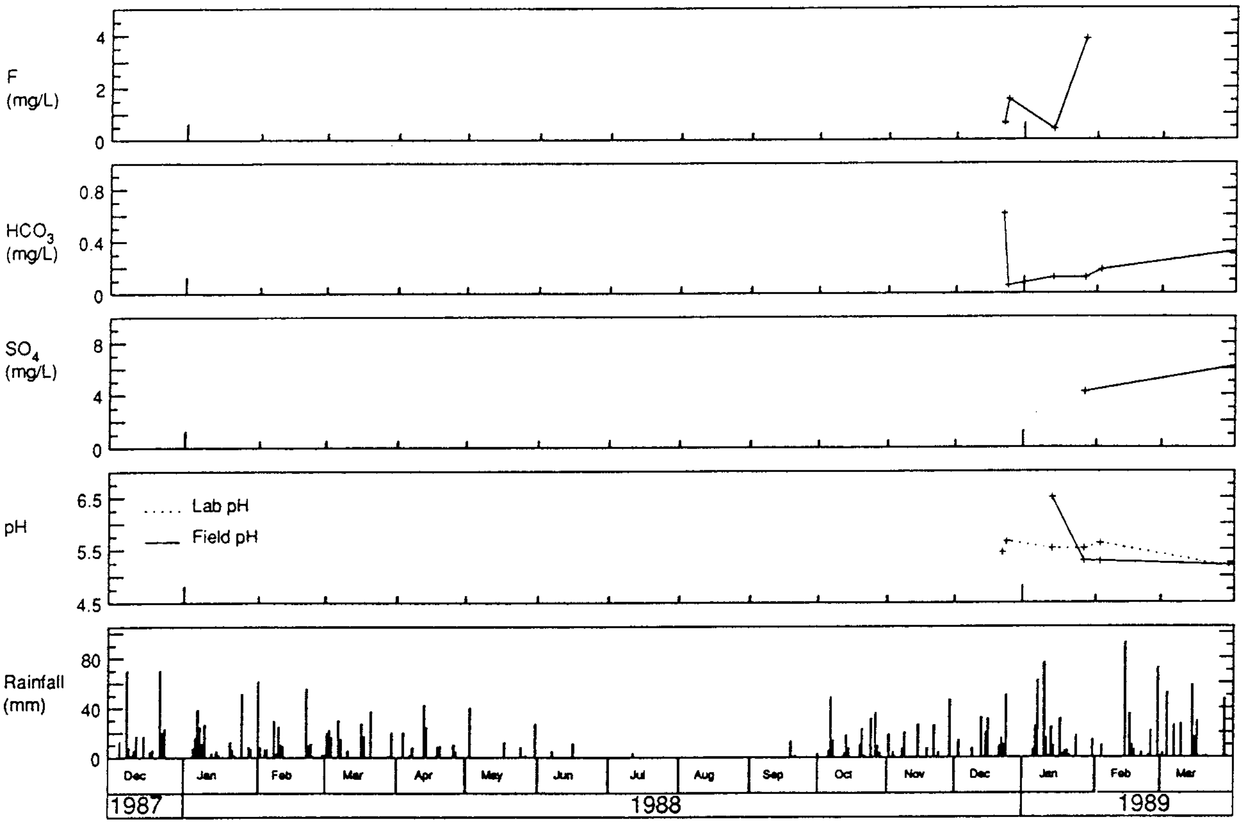

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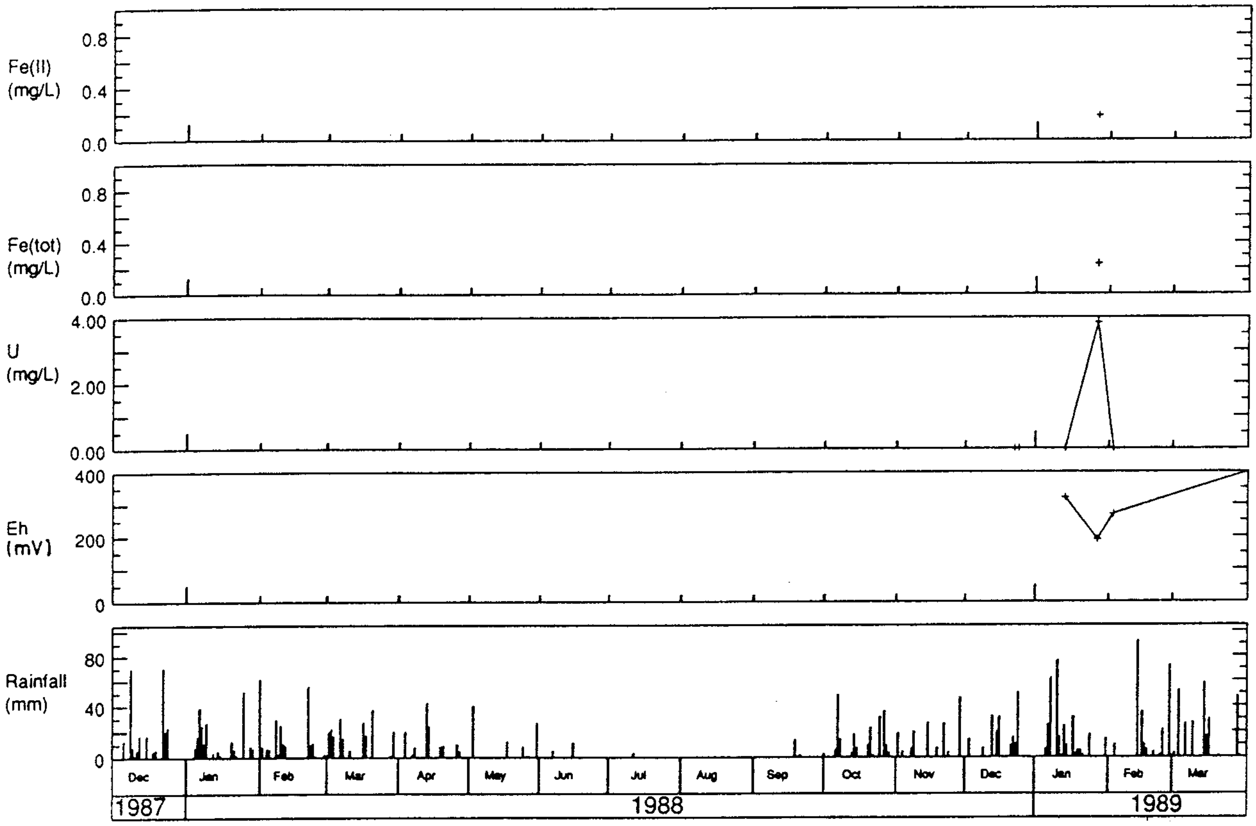

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[1]Starprog AB
[2]SKB AB
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Rolf Hesböl, Ignasi Puigdomenech, Sverker Evans
Studsvik Nuclear
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Statistical estimation and stochastic simulation using PROPER
Lars Lovius[1], Sven Norman[1], Nils Kjellbert[2]
[1]Starprog AB
[2]SKB AB
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University of Gothenburg, Department of General and Marine Microbiology, Gothenburg
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Lars Werme[1], Patrik Sellin[1], Roy Forsyth[2]
[1]Swedish Nuclear Fuel and waste Management Co (SKB)
[2]Studsvik Nuclear
May 1990

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Ulla Bergström, Sture Nordlinder
Studsvik Nuclear
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Outline of regional geology, mineralogy and geochemistry, Poços de Caldas, Minas Gerais, Brazil
H. D. Schorscher[1], M. E. Shea[2]
[1]University of Sao Paulo
[2]Battelle, Chicago
December 1990

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Mineralogy, petrology and geochemistry of the Poços de Caldas analogue study sites, Minas Gerais, Brazil
I: Osamu Utsumi uranium mine
N. Waber[1], H. D. Schorscher[2], A. B. MacKenzie[3], T. Peters[1]
[1]University of Bern
[2]University of Sao Paulo
[3]Scottish Universities Research & Reactor Centre (SURRC), Glasgow
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Mineralogy, petrology and geochemistry of the Poços de Caldas analogue study sites, Minas Gerais, Brazil
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University of Bern
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M. E. Shea
Battelle, Chicago
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Geomorphological and hydrogeological features of the Poços de Caldas caldera, and the Osamu Utsumi mine and Morro do Ferro analogue study sites, Brazil
D. C. Holmes[1], A. E. Pitty[2], R. Noy[1]
[1]British Geological Survey, Keyworth
[2]INTERRA/ECL, Leicestershire, UK
December 1990