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OVEREXPLOITATION OF GEOTHERMAL WELLS IN MURSKA SOBOTA, NORTHEASTERN SLOVENIA

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ABSTRACT

In the town of Murska Sobota, Northeastern Slovenia, two geothermal wells -- Sob-1 and Sob-2 -- penetrated Upper Pliocene intergranular aquifer Termal I, and some underlying Lower Pliocene aquifers. Lower Pliocene aquifers have much lower capacity than Termal I, but the waters have appreciably higher content of total dissolved solids and CO_2 gas. For five years since the beginning of the well operation, the content of total dissolved solids in the abstracted water was constantly decreasing, and reached less than a half of the starting value. Afterward, total dissolved solids contemporaneously increased in both wells, but at the same time, the content started to change.

The changes in chemical composition closely follow the changes in hydrodynamical pressures measured in the wells with a pressure-temperature gauge. In the vicinity of exploitation well, the pressures in Termal I decrease approximately every 70 minutes owing to too high pumping rate. The decrease enable more intensive incursion of waters from Lower Pliocene aquifers. When hydrodynamical pressures in Termal I recover, again the proportion of waters from the underlying aquifers decreases.

When the wells were planned, and also, many years after the beginning of their exploitation, the differences in chemical composition of Termal I and Lower Pliocene aquifers were unknown. Today, when the shortage with thermal water calls for reinjection into Termal I, we know that the water from Sob-1 is not suitable owing to too high content of total dissolved ions which may cause exolution of solids and cementation of interstital pores in the aquifer.

1. INTRODUCTION

The town of Murska Sobota is located in the Mura basin, which belongs to a widespread system of the Pannonian basins. The most important thermal aquifer in the region is Termal I which formed in Upper Pliocene by stacking of braided river deposits. It consists of an up to 100 meters thick sedimentary sequence of interbedded sands, silts and clays, in which the thickness of beds with good permeability varies between 20 and 50 meters. On the territory of Northeastern Slovenia, Termal I encompasses an area of about 1372 km^2. It outcrops along the Western margin of the Mura depression and deepens towards the East, where it reaches the depths of 1400 meters. In Murska Sobota, Termal I occurs at a depth of about 600 meters, with the water having the temperature of about 53°C (Kralj, 1995).

In December 1987 and June 1988, two exploitation wells, Sob-1 and Sob-2, have been drilled reaching 870 and 887 meters of depth, respectively. The wells are 317 meters apart and they are hydraulically interconnected. At the beginning of operation, free outflow from Sob-1 amounted to 40 l/sec. When Sob-2 has been drilled and the tests performed with Sob-1 closed, its free outflow amounted to 29.5 l/sec. When both wells were open, free outflow from Sob-1 was 20.5 l/sec, and from Sob-2 16.5 l/sec only (Zlebnik et al., 1988 a, b).

Water levels in the wells are constantly decreasing. Total dissolved solids in the abstracted water were also constantly decreasing for five years since the beginning of well exploitation. After this period, their amount increased, but it also started to vary, particularly in the Sob-1 well. The following contribution explains the changes in chemical composition of abstracted water and their origin.

2. CHANGING HYDRODYNAMIC PRESSURES AND THE WATER COMPOSITION

2.1 Pressure-temperature measuring technique and chemical analytical procedure

Since the beginning of the well operation, hydrodynamical pressure and temperature have been occasionally controlled, most commonly four times a year in a period of one week. The Leutert pressure-temperature gauge with the resolution of 0,007 bar and 0,01°C has been installed in the well at a depth of 600 meters. The gauge is computer-managed and can record the pressure and temperature data every ten seconds. In the same time, the abundances of the following major ions, dissolved gases and chemical parameters have also been controlled: NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}, Al^{3+}, F^-, Cl^-, Br^-, J^-, NO^{3-}, NO^{2-}, SO_4^{2-}, HCO_3^{2-}, dissolved CO_2, H_2S and O_2, pH, chemical oxygen demand C.O.D., and redox potential. Altogether, 109 analyses from Sob-1, and 72 from Sob-2 have been gathered untill the present. Since the year 1997, in 79 water samples from Sob-1, and in 10 samples from Sob-2 the abundances of the following trace elements were determined: Li, Be, B, Sc, V, Cr, Co, Ni, Cu, Zn, Ga, As, Se, Rb, Sr, Y, Zr, Nb, Mo, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, Th, and U.

2.2 Chemical composition of abstracted water

The water abstracted from the both wells is very similar in chemical composition (Table 1). The cationic facies is characterised by the dominance of sodium, and the anionic facies by bicarbonate. Both ions contribute to about 90% of total dissolved ions. The water from Sob-1 has somewhat higher average of the total dissolved ions (3189 mg/l) than Sob-2 (2736 mg/l), and it also contains appreciably higher amounts of undissolved CO_2 gas. At the beginning of exploitation, the concentrations of total dissolved ions were the highest ever recorded, and amounted to 4223 mg/l in Sob-1, and to 3358 mg/l in Sob-2.

Immediately after the wells started with operation, total dissolved solids begun to decrease. This trend can be observed in Figure 1 which shows the relation between Na^+ and HCO_3^-. The majority of data lie close to the line which connects the starting values and the lowest observed values. The line extrapolation crosses the nil point in the diagram, and can be regarded as a dissolution pattern (Mazor, 1991). After five years of production, the amounts of total dissolved ions contemporaneously increased, but started to vary, particularly in the Sob-1 well. In the past three years, a significant shift from the dissolution line has been observed (values dispersed right from the line) indicating that more complex processes control the chemistry of abstracted water.

A plot of pressure and temperature measurements in the Sob-1 well (Fig. 2) is a wave-like curve. Every 70 minutes the pressure suddenly decreases for about 1 bar, and then, it increases to the original value. When the pressure decreases, the temperature increases for about 2°C, and it decreases again when the pressure recovers.

The increase in temperature is accompanied by an increase in conductivity, pH, salinity, and concentration of almost all ions and trace elements. Figure 3 (a, b and c) shows the changes in time for Na^+ and HCO_3^-, observed in the Sob-1 well in November 1997, September 1998 and April 1999. In the Sob-2 well, the amount of total dissolved ions strongly depends on the flow rates. Figure 3 d shows very low and poorly changing concentrations of the Na^+ and HCO_3^- ions, which were observed in September 1998 at a low flow rate (3.2 l/sec). At the higher flow rate of 8.7 l/sec (Fig. 3 e), the concentrations were much higher for both ions and show similar changes in time as in Sob-1.

Ammonium, calcium, potassium, sulphate, chloride, fluoride and bromide ions, and almost all trace elements show very similar increase in concentration with the increase in temperature. For most of them, the increase is nearly contemporaneous with the increase in concentrations of sodium and bicarbonate, but the intensity may be very disproportional. For example: when the concentration of sodium increases twice, the concentration of calcium may increase for three to four times, copper for over seven times, cerium for over fortyfour times and lanthanum for over hundred times. Figure 4 shows the changes in the abundances for cesium, Figure 5 for boron and Figure 6 for the sum of yttrium and rare earth elements.

3. DISCUSSION

The water, abstracted from Sob-1 and Sob-2 is composed or mixed water originating from Termal I and the underlying aquifers. The water from the underlying aquifers belongs to the same hydrogeochemical facies as the water from Termal I, but contains more dissolved solids and CO_2. When the wells started with production, and also, many years later, the differences and their importance were unknown.

Lower Pliocene aquifers contain high amounts of CO_2 and for this reason, they are overpressurised. At the beginning of the well operation, inflow measurements in both wells indicated that the proportion of water from the aquifers underlying Termal I amounted to 40% of the total abstracted water mixture. This is the reason for their high mineralisation in the beginnig of exploitation, which has never been reached again.

The high pressures in the underlying aquifers decreased owing to the CO_2 release, and consequently, the proportion of waters from Termal I increased. The original waters from Termal I have much lower content of total dissolved ions than the abstracted mixture, averaging to 1400 mg/l. The amount of free CO_2 is very low, as well as the content of many trace elements. After five years of the well exploitation, the water from Termal I dominated in the abstracted water mixture.

By overexploitation of Termal I in the vicinity of the wells, the proportion of waters from the underlying aquifers increased. Particularly the composition of water mixtures from Sob-1 started to shift from the dissolution pattern. Abundances of some trace elements as cesium (Fig.6) and rare earth elements (Fig.7) indicate that the Sob-1 penetrates some deeper aquifers where these elements are particularly abundant. In the Sob-2 well, their concentrations are much lower even at the same or higher concentrations of the sodium and bicarbonate ions.

The water from Sob-1 well is used for heating of local apartment buildings and preparation of sanitary water. Dynamics of water exploitation influences hydrodynamical conditions in the aquifer, and they influence the extent and mode of water mixing. Rare earth elements are very useful in recognition of these processes.The changes in concentration, shown by the curve a in Figure 6 were observed in November 1997, when the demand for thermal water, used for heating, is high. Lowermost concentrations indicate very high proportion of the waters from Termal I. The concentration peak is very high, but narrow indicating immediate recovery of hydrodynamic pressures in Termal I. In September 1998, after the summer period when the water was used only for preparation of sanitary water, the lowest concentrations were higher than in November 1997, but the peak was very low. In April 1999, after the winter period of intensive exploitation, the concentrations of rare earth elements were very high, indicating large proportion of thermal waters from the aquifers underlying Termal I. The peaks were high and broad, indicating poor recovery of hydrodynamical pressures in Termal I in the vicinity of Sob-1.

4.CONCLUSIONS

Intensive exploitation of Sob-1 and Sob-2 is reflected in a very decreased yield of thermal water, in changing hydrodynamical pressures in the aquifer Termal I in the vicinity of both wells, and in changing chemical composition of abstracted water. A demand for more thermal water appeals for reinjection, which would be possible only into Termal I. Besides technical problems, related to reinjection into sandy sediments, the water from Sob-1 is not suitable owing to much higher content of total dissolved ions than the original water from Termal I. Reinjection may cause exolution of solids and cementation of interstitial pores, and consequent destruction of the aquifer.

The systems of thermal aquifers in the Mura basin are very complex, and their distinction on the basis of lithological characteristics very difficult. Their exploitation must be planned and designed carefully to enable safe production and successful reinjection. In the case of Sob-1 and Sob-2, only the aquifer Termal I should have been captured, and reinjection of thermally used water should have started at the same time as production.

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Table 1. Average composition of waters abstracted from the wells Sob-1 (109 samples) and Sob-2 (67 samples) with standard deviations σ_n. Twh is the temperature measured at the wellhead.

Ions (mg/l)	Sob-1	Sob-2
NH_4^+	5.6 ± 1.8	5.7 ± 1.9
Na^+	759 ± 154	719 ± 194
K^+	71 ± 32	44 ± 14
Ca^{2+}	32 ± 20	10 ± 2
Fe^{2+}	0.22 ± 0.13	0.20 ± 0.09
Mg^{2+}	8 ± 5	4 ± 1
Cl^-	149 ± 35	122 ± 8
Br^-	0.53 ± 0.42	0.56 ± 0.50
J^-	0.16 ± 0.13	0.17 ± 0.06
F^-	0.98 ± 0.29	0.98 ± 0.36
HCO_3^-	2130 ± 506	2020 ± 993
SO_4^{2-}	32 ± 19	<5
TDI	3189 ± 780	2736 ± 652
CO_2	550 ± 246	411 ± 214
pH	6.85 ± 0.39	7.03 ± 0.40
Twh	49.0 ± 1.0	47.6 ± 3.7

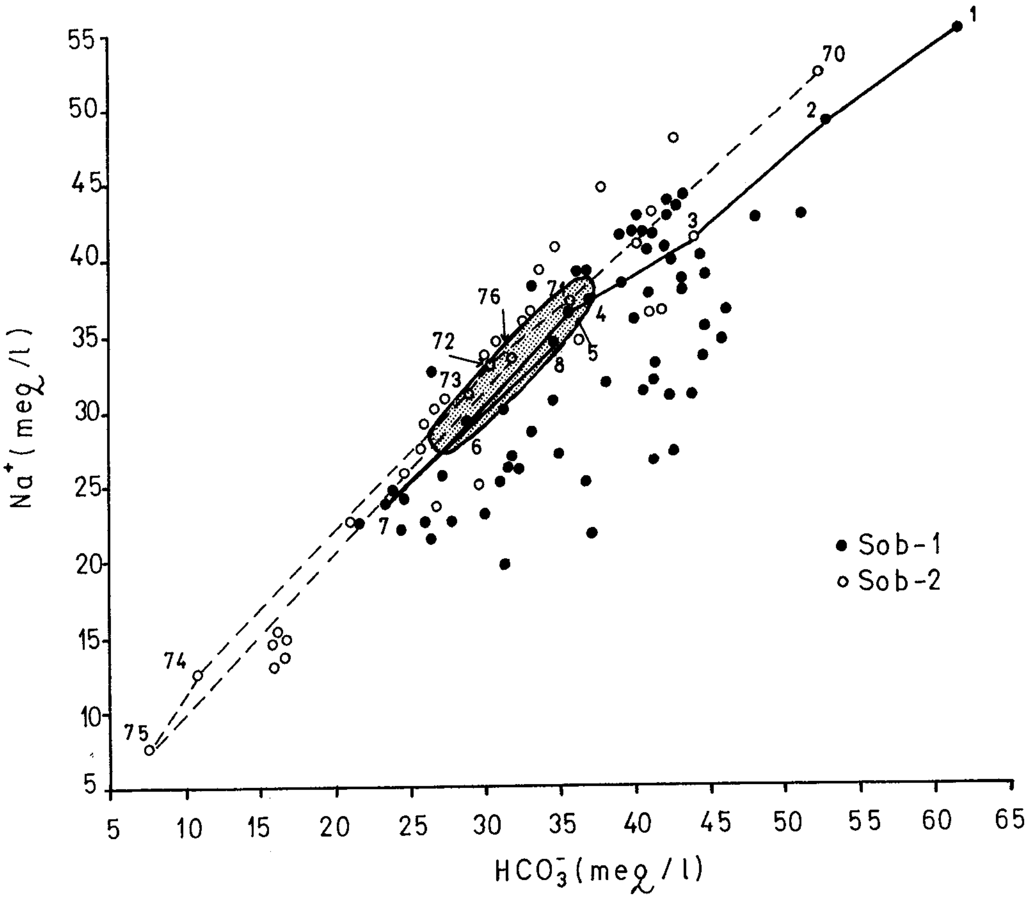

Fig. 1. Relation between Na$^+$ and HCO$_3^-$. Shaded area includes 39% of the data points for Sob-1, and 79% of the data points for Sob-2. Two lines connecting the samples 1-8 for Sob-1, and 70-76 for Sob-2, show the trend of a five-years lasting decrease in concentration, followed by a contemporaneous increase

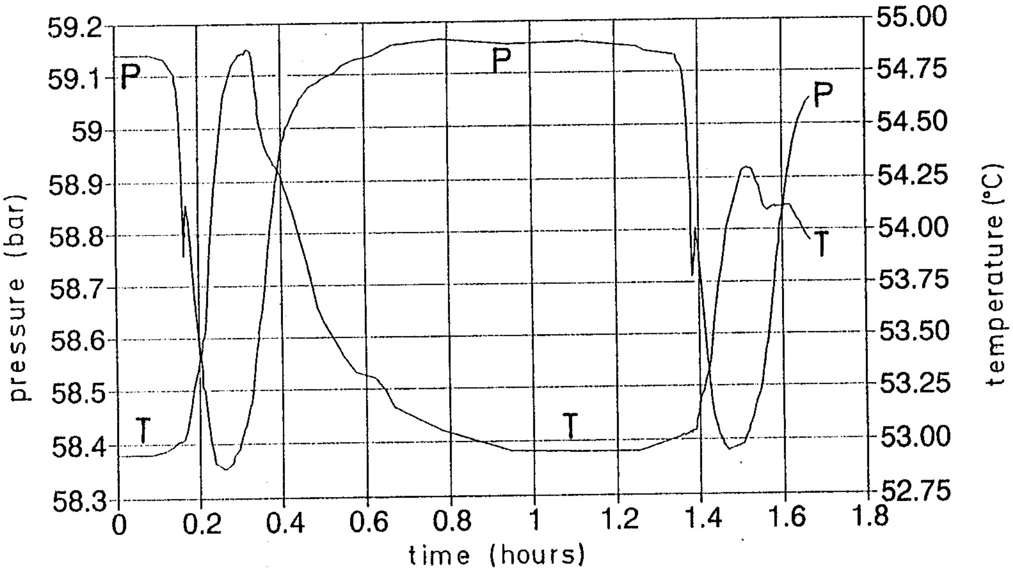

Fig. 2. Changes in hydrodynamic pressure and temperature, observed in Sob-1 at 600 meters of depth

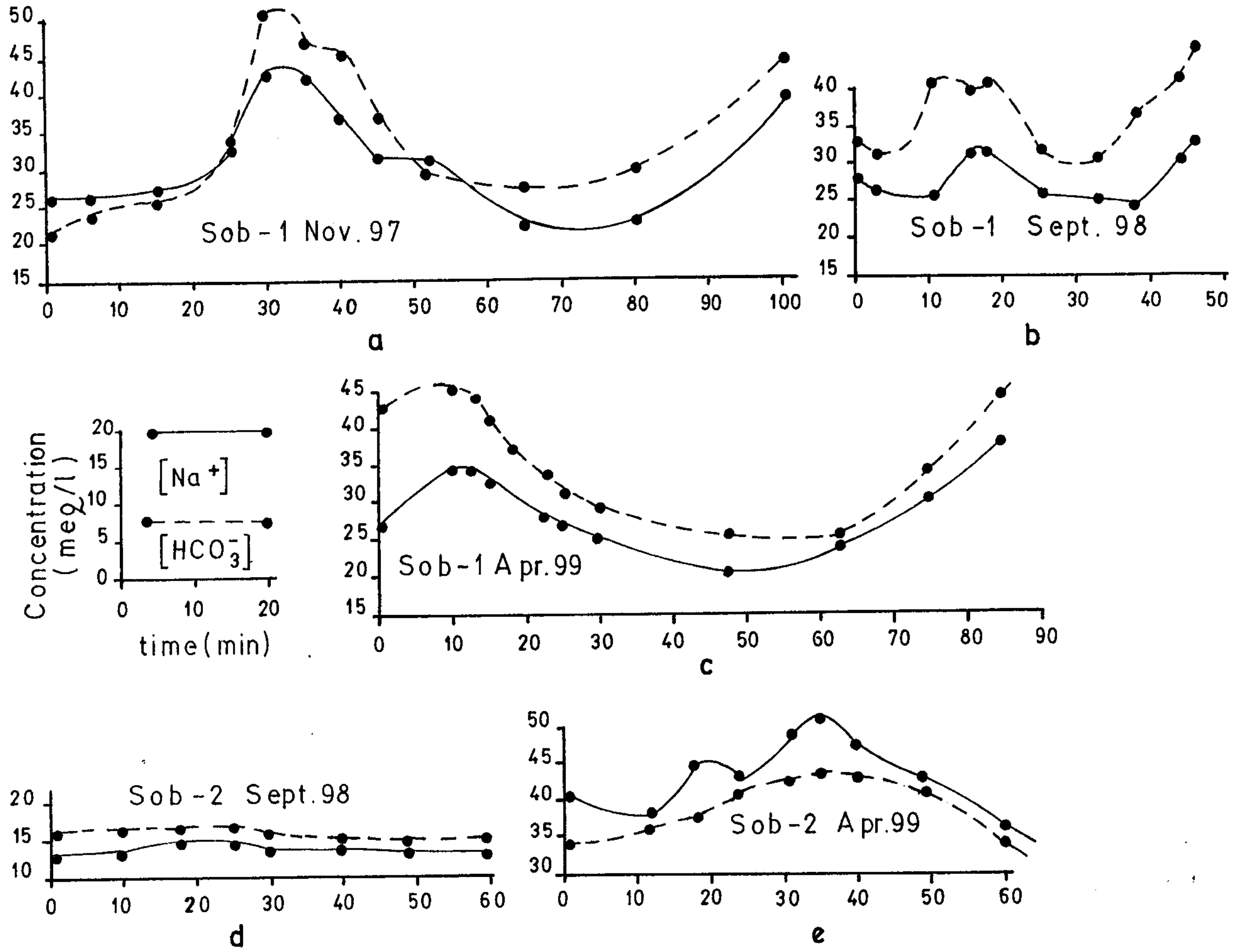

Fig. 3. Changes in concentration for Na^+ and HCO_3^-, observed in Sob-1 and Sob-2.

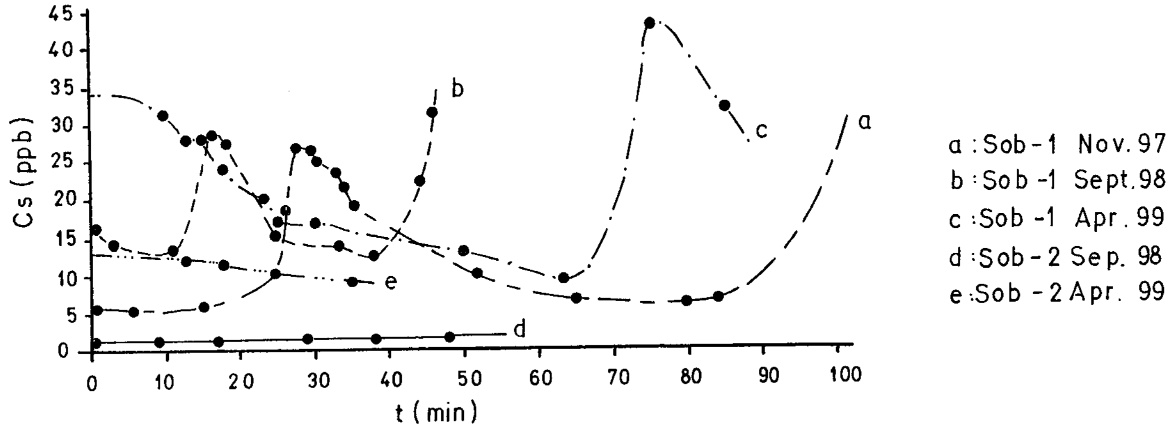

Fig. 4. Changes in concentration for cesium

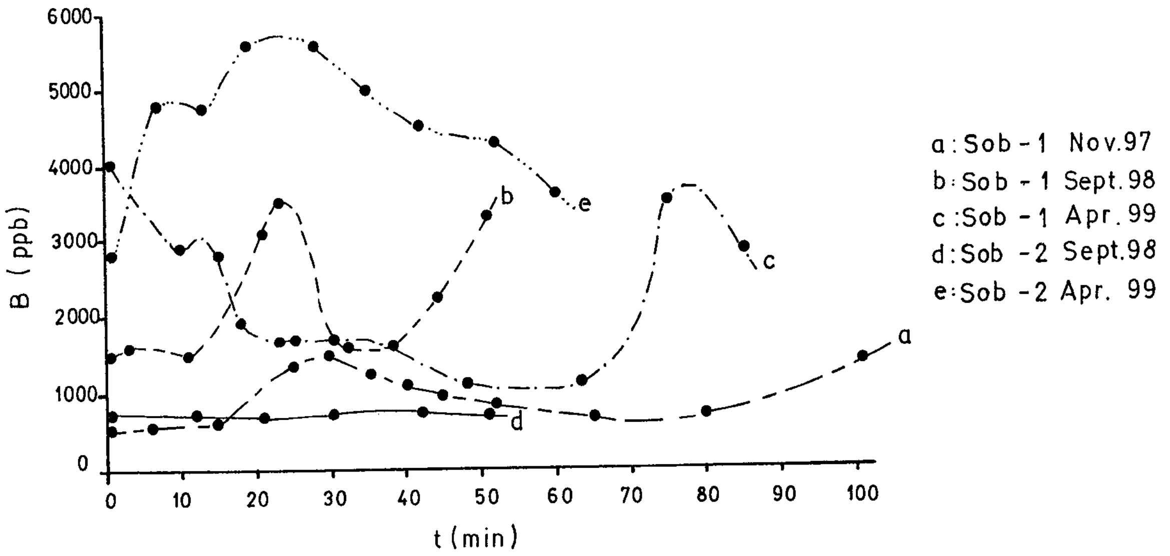

Fig. 5. Changes in concentration for boron

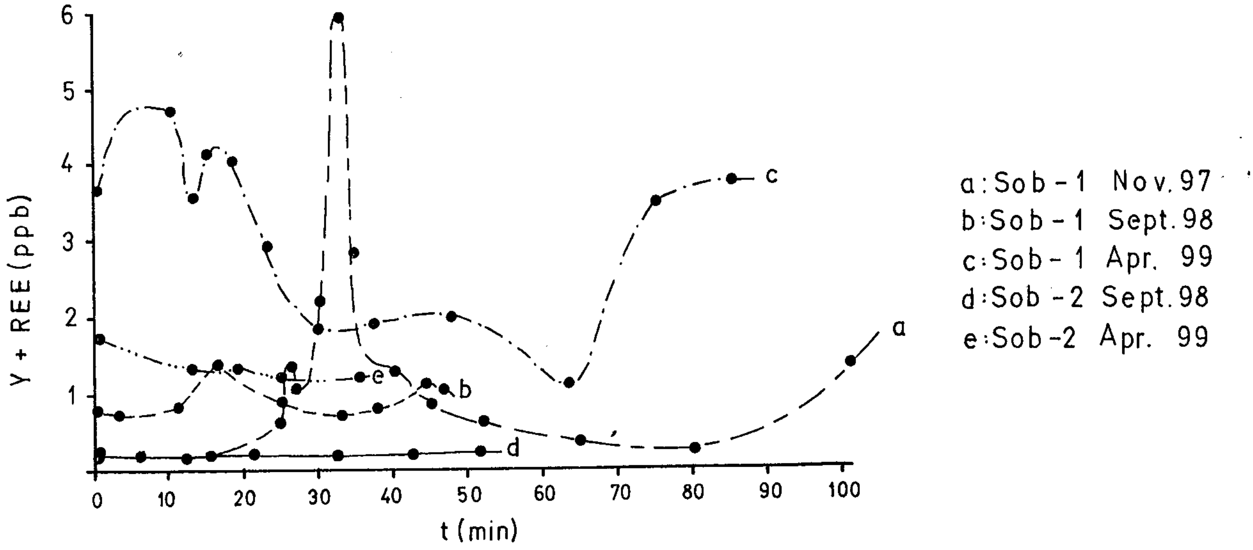

Fig. 6. Changes in concentration for yttrium and rare earth elements