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Radionuclide content in surface and groundwater transformed into breakthrough curves. A Chernobyl fallout study in an forested area in Northern Sweden

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SGAB, Uppsala

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RADIONUCLIDE CONTENT IN SURFACE AND GROUNDWATER TRANSFORMED INTO BREAKTHROUGH CURVES. A CHERNOBYL FALLOUT STUDY IN AN FORESTED AREA IN NORTHERN SWEDEN

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RADIONUCLIDE CONTENT IN SURFACE AND GROUNDWATER TRANSFORMED INTO BREAKTHROUGH CURVES. A CHERNOBYL FALLOUT STUDY IN AN FORESTED AREA IN NORTHERN SWEDEN.

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ABSTRACT

Large areas of Sweden was covered by the radioactive fallout from Chernobyl in 1986. This event started a study of migration and sorption behavior of the radionuclides in a small forested catchment area in northern Sweden. Within this study, over a period of three years, radionuclide breakthrough were modelled from data obtained from groundwater sampling in an artesian borehole with packed-off sections. Also the creek that drains the studied catchment area and a shallow well were sampled to study the radionuclide concentration. The content of the radionuclides in the water samples leads to the conclusion that Chernobyl radionuclides have penetrated down to large depths (> 100m) and that a large outflow of radionuclides from the studied catchment area took place within two months after fallout.

A computer based non-linear regression method makes it possible to determine transport parameters out of the obtained radionuclide breakthroughs in the borehole. The artesian borehole (length: 705m) is divided into three packed-off sections, 28-96m, 97-106m and 107- m. The breakthrough curves for section 97-106m shows that Ruthenium-106 is deviating from Cobalt-60 and Cesium-137 in terms of velocity. The Ruthenium peak concentration arrives 263 days after deposition. For Cesium and Cobalt the arrival is 516 and 599 days respectively. In terms of dispersivity Cobalt is the deviating nuclide due to its broad peak. The drawn-out peak can probably be ascribed to the different chemical behavior of Cobalt compared to the other analyzed radionuclides. The transport of the radionuclides from ground surface to the artesian borehole is performed in fissured crystalline rock. The distance has been approximated to about 300m. Radionuclide concentration in surface water as stagnant well water and creek water are also discussed.

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1. INTRODUCTION

Large areas of Sweden was covered by the radioactive fallout from Chernobyl in 1986. This event started a study of migration and sorption behavior of radionuclides in a small forested catchment area in northern Sweden. The main task within the project is to calculate the redistribution of radionuclides within the Orrmyrberget catchment basin at Gideå (Figure 1). A large effort is made to collect data needed for the redistribution modelling. The data collection is made by sampling and "in situ" measurements of/on materials like; water, sediment, soil, surface vegetation and surface contamination. Hydrological and meteorological conditions are also monitored (Ittner 1991). This report will focus on the radionuclide content in water sampled 1986 to 1988 within the Gideå site.

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2. THE GIDEÅ STUDY SITE

2.1 SITE CHARACTERIZATION

The geology within the study site consists of crystalline precambrian bedrock and of quaternary soils. The totally dominating rock type is migmatite. The migmatite is an old sediment (2000 Ma), transformed by the svecocarelian orogeny (1800 Ma) to a medium grained massive rock, grey in color. Some dolerite dikes are also cutting trough the bedrock within the study site. The geology and tectonics for the Gideå area is presented in Ahlbom et al 1983, Albino et al 1982 and in Gustafsson et al 1987.

The soils within the study site are quaternary. Main soil types within the study site are peat, till, sand and silt (Ittner et al 1991b).

The study site, Orrmyrberget catchment, is a small trough shaped catchment basin with an area of 0.74 km^2. The terrain is relatively flat, forested and with many small mires an situated below the highest coastline. The highest altitudes are strongly wave–washed and distinct shingle lines can clearly bee seen, especially in the eastern part of the area. Downwards the wave washed altitudes, on the side of the basin, till is found. The till surface is wave–washed. In the bottom of the catchment basin out–washed silt and sand deposits are found. These are partly covered with peat.

2.2 DEEP GROUNDWATER

Adjacent to Orrmyrberget catchment the GI2 area is situated (Figure 2) A well characterized core borehole (KGI02) is available for this study. This artesian borehole is 705 m deep and its declination to the horizontal plane is 60 degrees towards N – W. The borehole is intersecting one of the two major fracture zones in the area (Figure 3). KGI02 has been packed-off at two levels so that three sections are available for measurements. The three sections used are 28 - 96, 97 - 106 and 107 - 705 m below ground level. As can be seen in Figure 4 the water in the 97 - 106 m packed-off section is different compared to the rest of the borehole water. The inflowing water can be characterized as surface water due to its low temperature and low salinity in contrast to the rest of the borehole water.

The artesian properties of the borehole makes it possible to take samples at ground surface without any technical equipment except for the continuously installed borehole packers. The up-flowing water also prevents contamination of samples due to that it prevents surface water to flow down. The artesian pressure level in KGI02 is 4.87 m above ground surface (Stenberg 1983).

The inflow to the drillhole KGI02 sections can be separated into different types. The inflow to the packed-off section 97 - 106 m can be distinctly separated from the rest of the drillhole due to the large inflow of surface water in an relatively short part of the total drillhole length. This inflow have been characterized as "fast" fracture flow in a limited number of fractures. The inflow at the top section, 28 - 96 m, can probably be described as a more diffuse inflow in many small fractures. Here the nearest distance to the surface from the borehole section have been estimated to be about 50 - 100 m, compared with the 300 m estimated for borehole section 97 - 106. The section 107 - 705 m have roughly been estimated to be more than 300 m (Figure 5).

2.3 SURFACE/NEAR-SURFACE WATER

The radionuclide content have been measured in surface and near-surface water (shallow groundwater). In the central part of the study area a well with stagnant water is situated (Figure 6). The well is about three meters deep and one meter in diameter and it is dug in sand and gravel. No water have been taken out of the well for six or seven years except for the sampling in this study. Sampling and measurement of the radionuclide content in this stagnant water volume have been performed about twice per year since autumn 1986.

The seasonal fluctuations of the water level in the well are not recorded. However, since monthly measurements of groundwater level in borehole HGI20 are performed, the fluctuations in the well can be estimated. HGI20 are situated about 500 m to the north of the well. In an earlier study in 1986 it is shown that the groundwater fluctuations in the boreholes within the area coincide (Gustafsson et al 1987).

Besides sampling and measurements of radionuclide content in the well water, radionuclide content in the creek discharging the area, Orrmyrberget catchment, have been studied. The sampling is performed twice every year since 1986. Results from these samplings are available up till 1988. Monthly measurements of the discharging flow rate have been performed. The discharge rates vary between about 0.1 l/s at low summer flow to about 35 l/s at high flow in the spring. Higher flow rate are presumed, since the measurements are performed only during one day every month. (Ittner 1991c)

3. RADIONUCLIDE CONTENT

The measurements of radionuclide concentration are made in laboratory with an HPGe detector. The gamma spectras have been evaluated and some gamma emitting nuclides were found in low concentrations. Every measurement corresponds to a relatively large volume of water that have been concentrated with a distilling apparatus. In the samples were the lowest concentration of radionuclides were expected a volume of 250 l were sampled and used for measurement after reducing the volume down to 0.5 l. (Carbol et al 1989)

The results show an uneven pattern with spread concentration peaks with time. In the deep groundwater sampled from the three sections in KGI02 low radionuclide concentrations are found. In these borehole waters Co–60, Ru–106 and Cs–137 are found. The results are shown in Figures 7, 8 and 9. The results of the shallow groundwater/surface water show both higher concentrations and also more than three radionuclides. The radionuclides found in the well are; Cobalt–60, Ruthenium–106, Silver–110m, Cesium–134 and Cesium–137. In the creek Antimony–125 found as well. The results from the Surface/shallow groundwater measurements are presented in Figures 10 and 11.

4. DISCUSSION

As sampling and analysis of radionuclides in this case is costly and time consuming only a limited number of measurements are available. In an attempt to enhance the practical possibilities of interpreting these spars data, inverse modelling by non–linear regression was used.

This one–dimensional non–linear regression method makes it possible to estimate transport parameters out of the obtained breakthrough curves. Breakthroughs are estimated for the packed–off section 96 – 107 m in KGI02 for the radionuclides Co–60, Ru–106 and Cs–137 that is shown in Figures 12, 13, 14 and Table 1.

The different radionuclides found and their concentration in borehole KGI02 have variations within the samplings made during 1986 – 1988. The interpretations of these varying concentrations can be summarized as the fallout can be regarded as a large–scale tracer test were the tracers enters the ground water system as a non–point temporary source over the entire region. The packed–off section 96 – 107 m in KGI02 was selected for this interpretation of this set of spars data as the transport to this borehole section is assumed to follow one main transport path. The reason for this assumption is the temperature and saline plots from the drillhole investigation that shows one main inflow. The inflow to the sections above and under have no major large inflow which leads to the conclusion that the inflow to the rest of the borehole is more diffuse and distributed.

The limited number of data points makes it hard to interpret the shape of the breakthrough curve. Since the packed–off sections inflow have been interpreted to have one major inflow path a description with a simple one–dimensional flow path as shown in Figures 12, 13, 14 above have been made.

The Ruthenium peak concentration arrives 263 days after deposition. For Cesium and Cobalt the arrival is 516 and 599 days respectively. In terms of dispersivity Cobalt is the deviating nuclide due to its broad peak. The drawn-out peak can probably be ascribed to the different chemical behavior of Cobalt compared to the other analyzed radionuclides.

The artesian pressure level for borehole KGI02 was in 1982 measured to be 4.87 m above ground level. The entrance to the groundwater system, discussed in this paper, must then be at 109 – 124 m a.s.l. The area were the fallout nuclides are assumed to have entered the groundwater system is to the north-west in the surrounding to where Zone II passes. This is an area where the ground surface is bare rock or has a wery thin soil cover. The difference of starting the migration on/in an bare rock area compared to an area with soil cover must have an influence the chemical form of the radionuclides and their ability to migrate further down into the groundwater in soil or rock.

5. ACKNOWLEDGEMENTS

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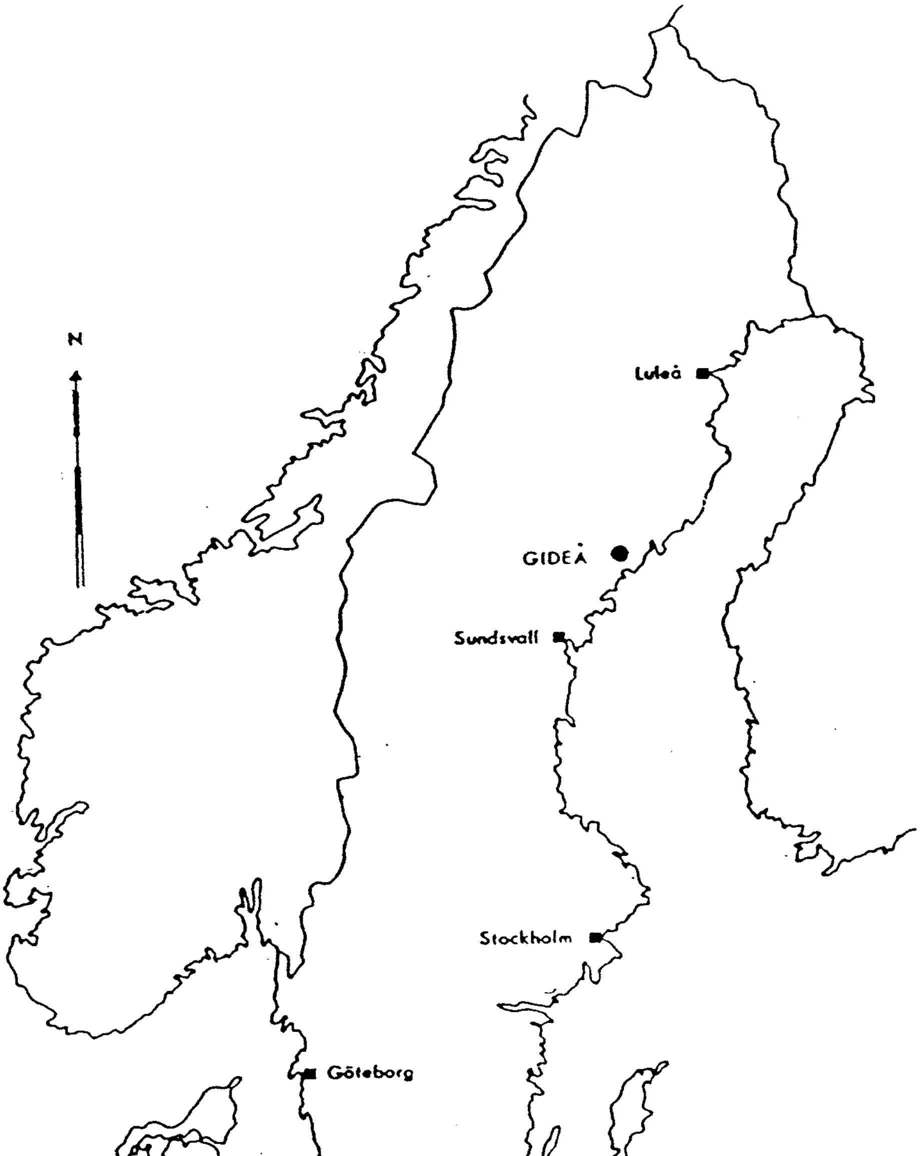

Figure 1 Key map to the Gideå study site.

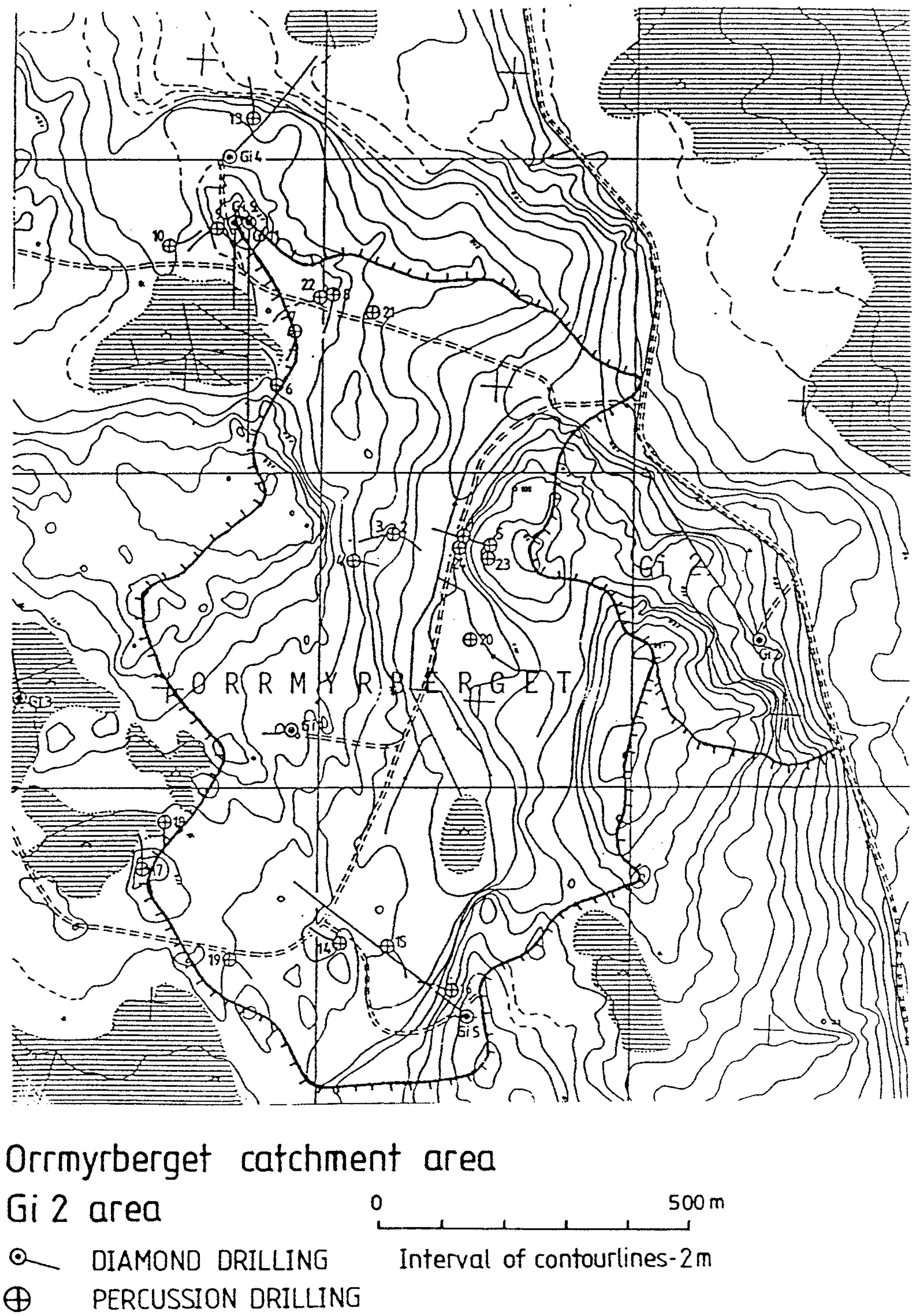

Figure 2 The Gideå study site with Orrmyrberget catchment and the Gi2 area.

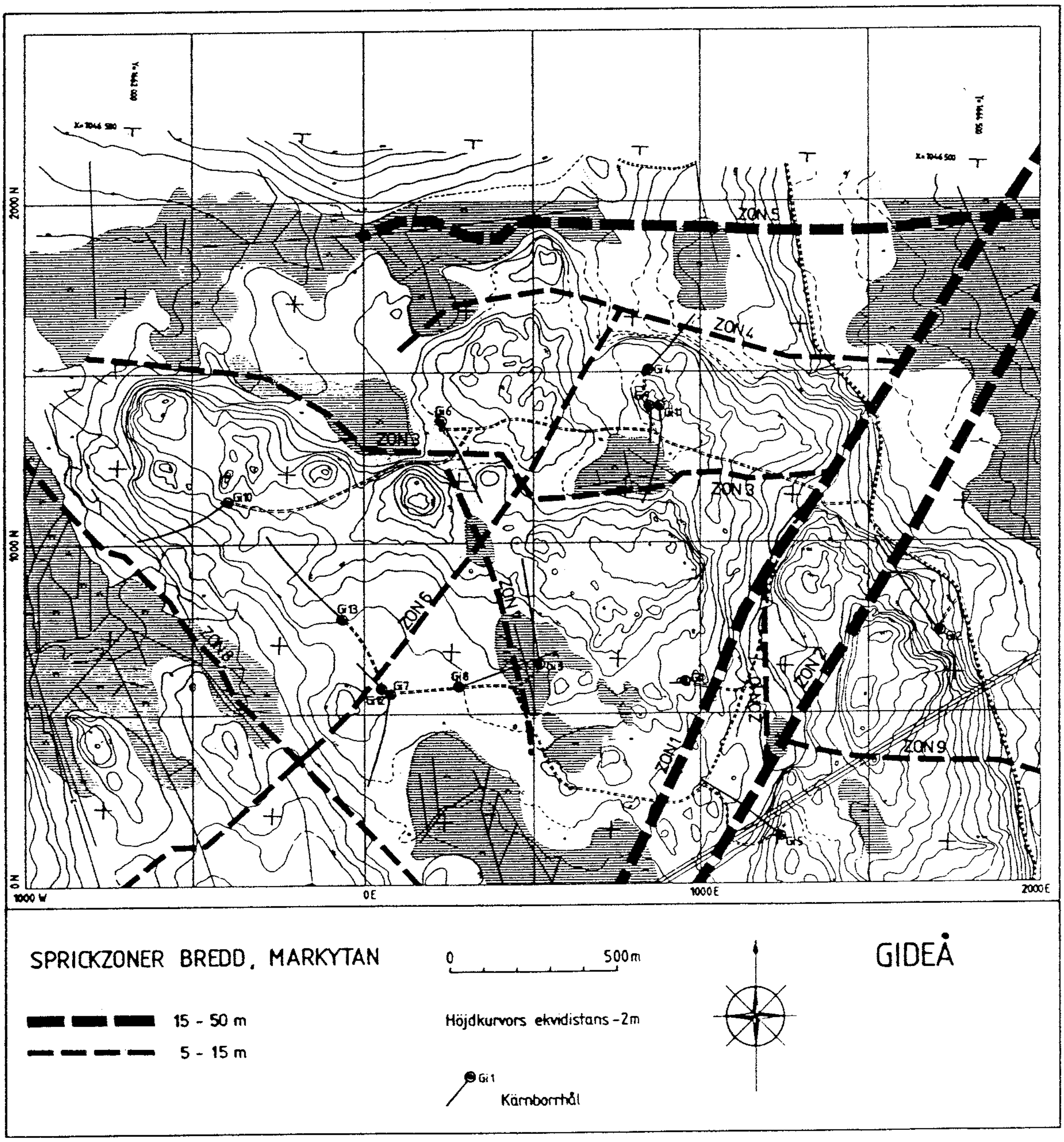

Figure 3 Major lineaments within the Gideå site. Orrmyrberget catchment is situated in the S – E part.

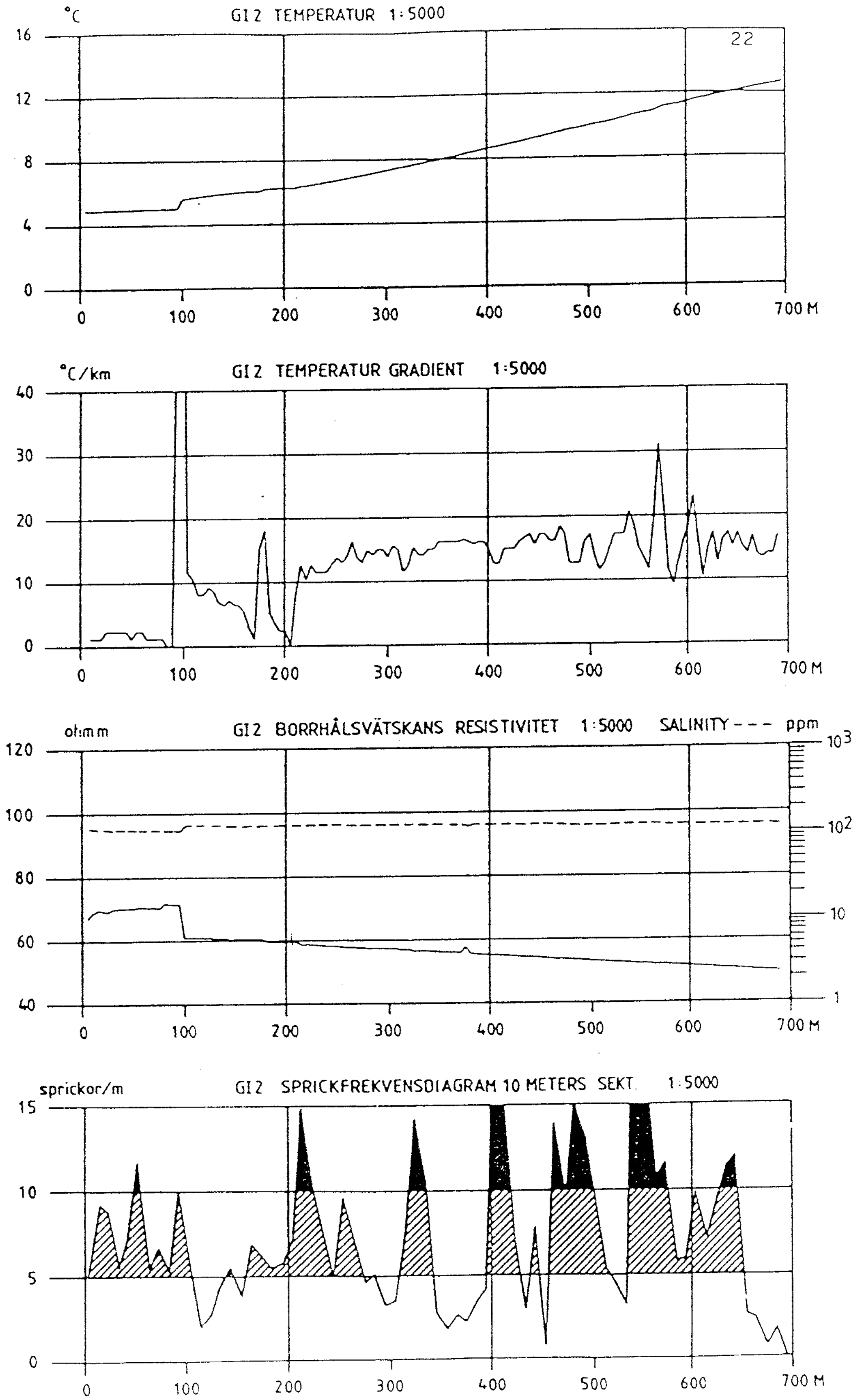

Figure 4 Borehole investigation of KGI02. (Stenberg 1983).

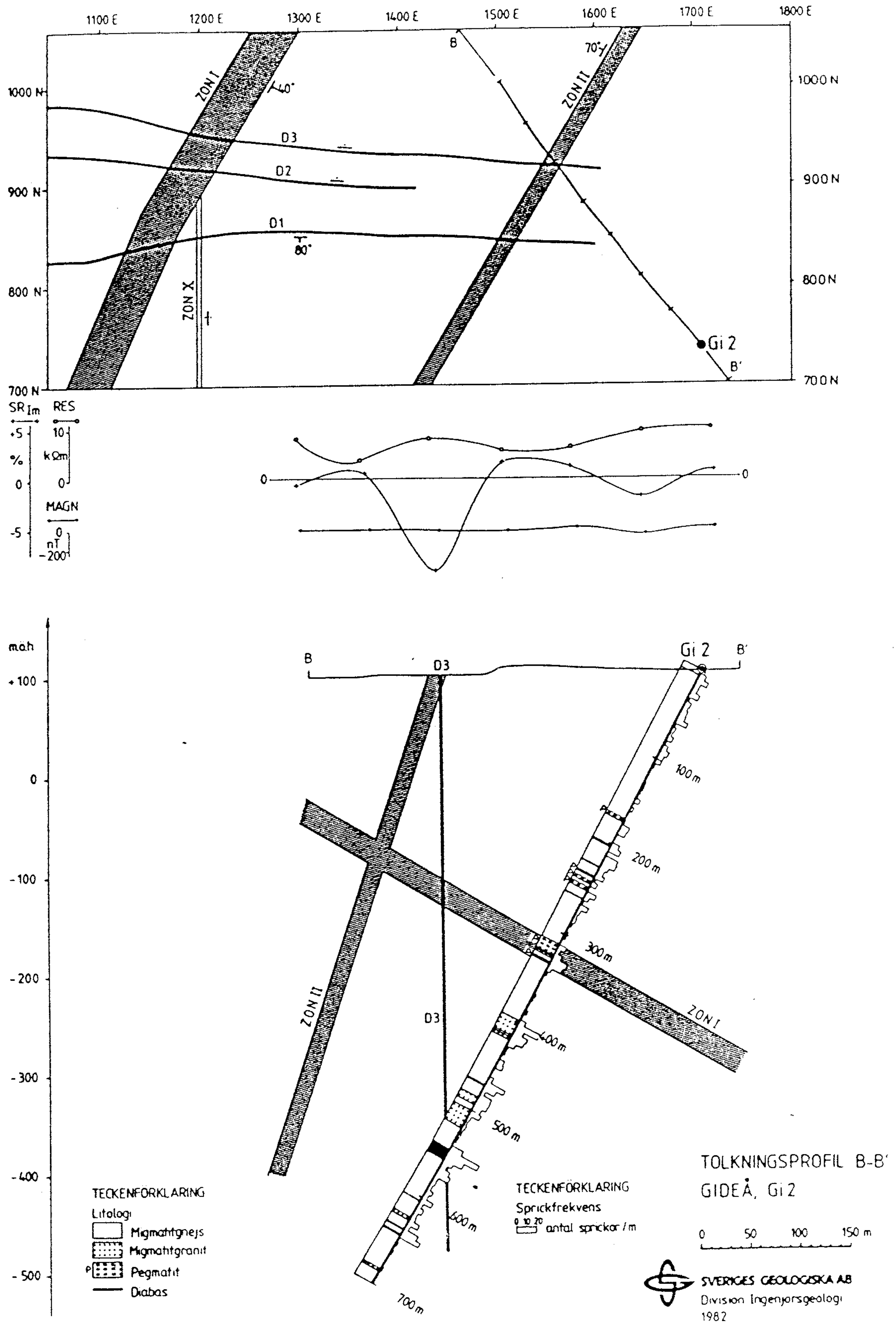

Figure 5 Interpreted vertical profile at borehole KGI02. (Stenberg 1983).

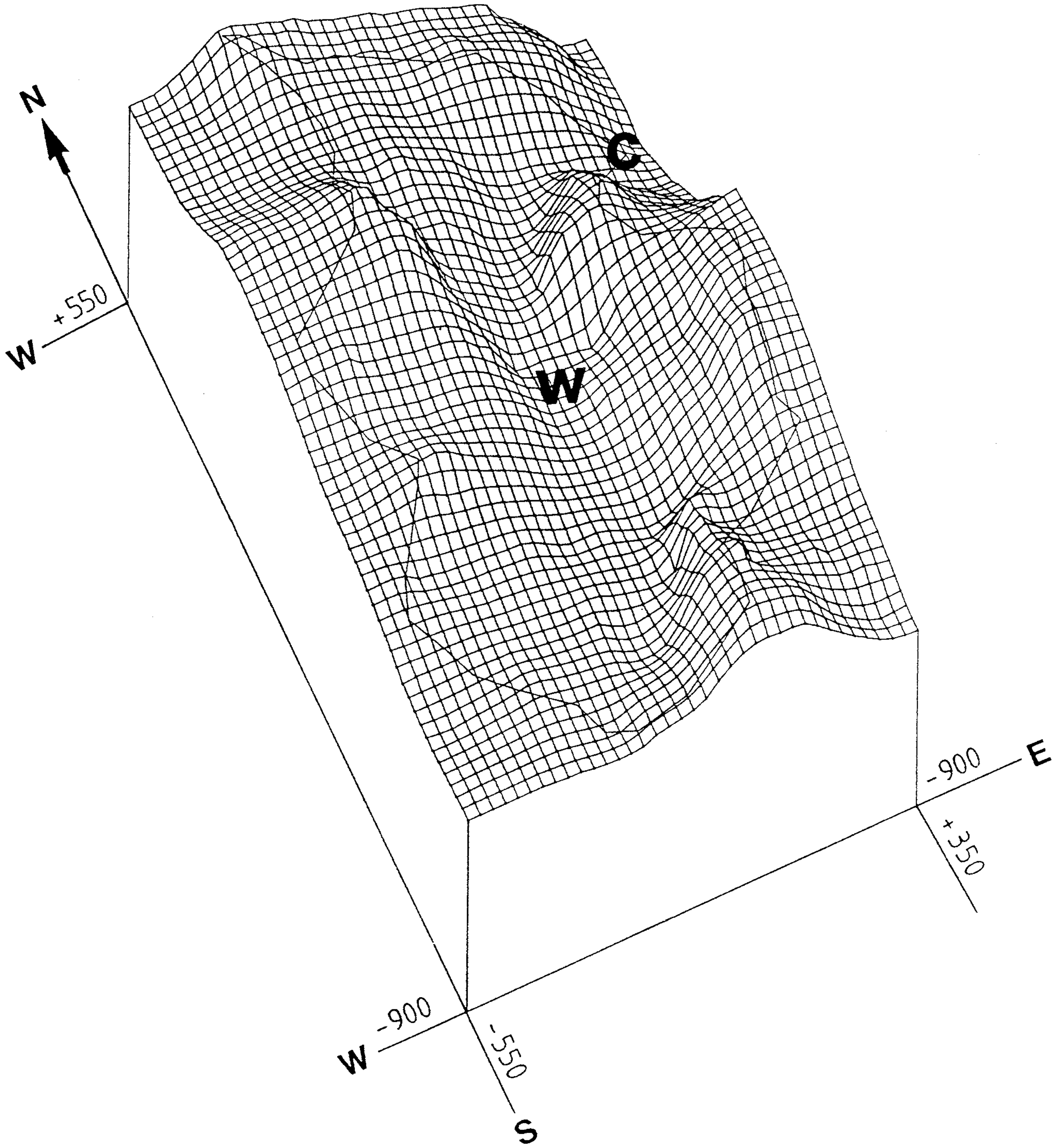

Figure 6 Sampling sites for the Well (W) and for the Creek (C).

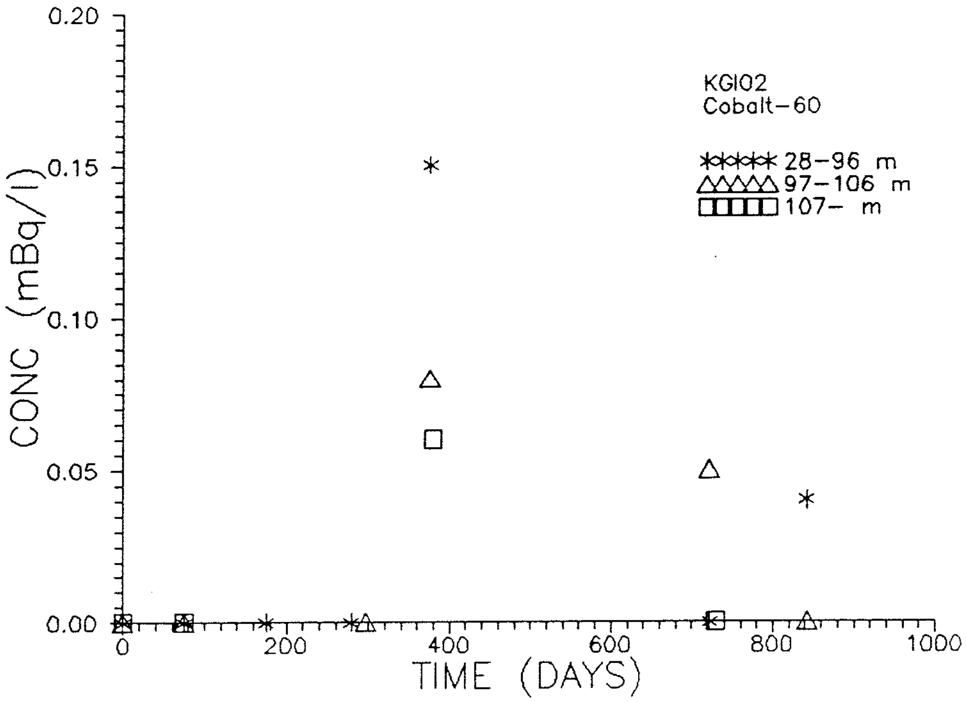

Figure 7 Measurements of Co-60 in KGI02. Time scale starting at 26 April 1986.

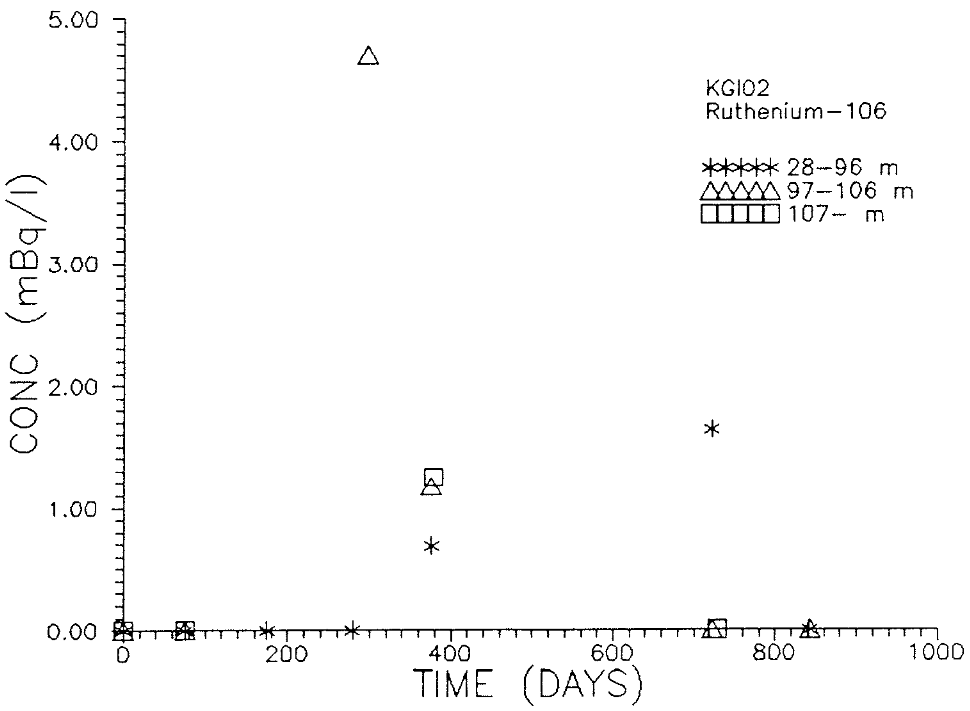

Figure 8 Measurements of Ru-106 in KGI02. Time scale starting at 26 April 1986.

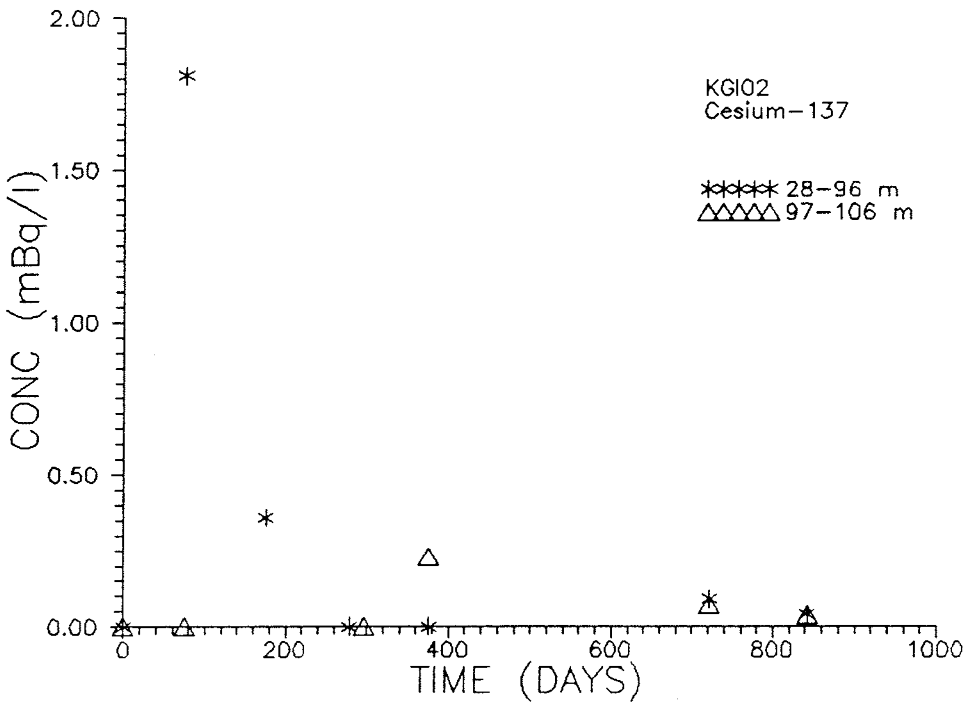

Figure 9 Measurements of Cs-137 in KGI02. Time scale starting at 26 April 1986.

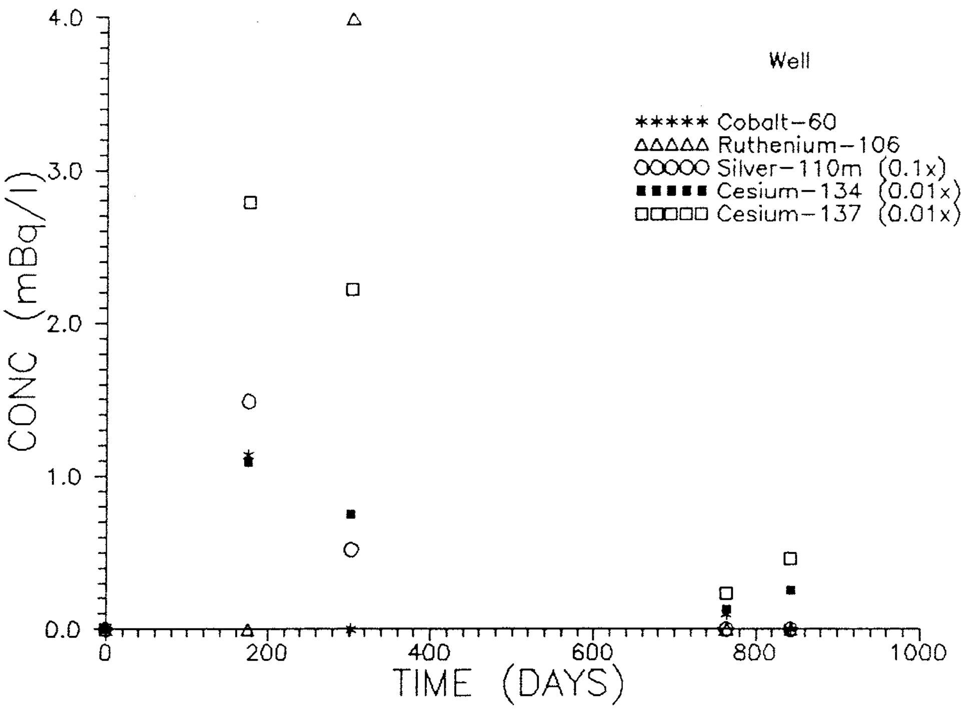

Figure 10 Measurements of radionuclides in the Well. Time scale starting at 26 April 1986.

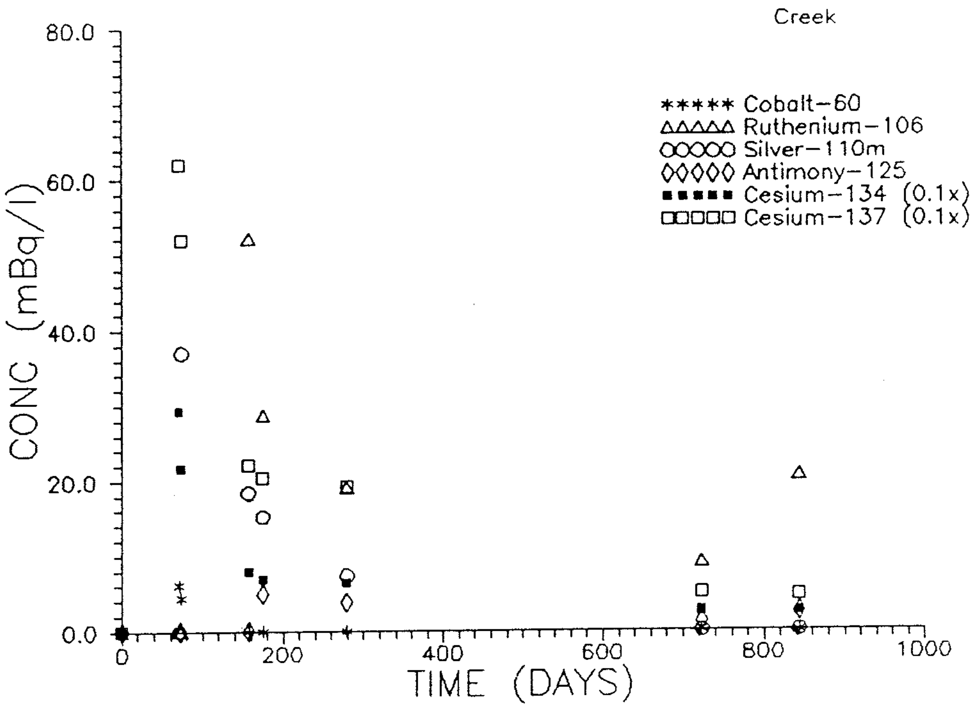

Figure 11 Measurements of radionuclides in the Creek discharging Orrmyrberget catchment. Time scale starting at 26 April 1986.

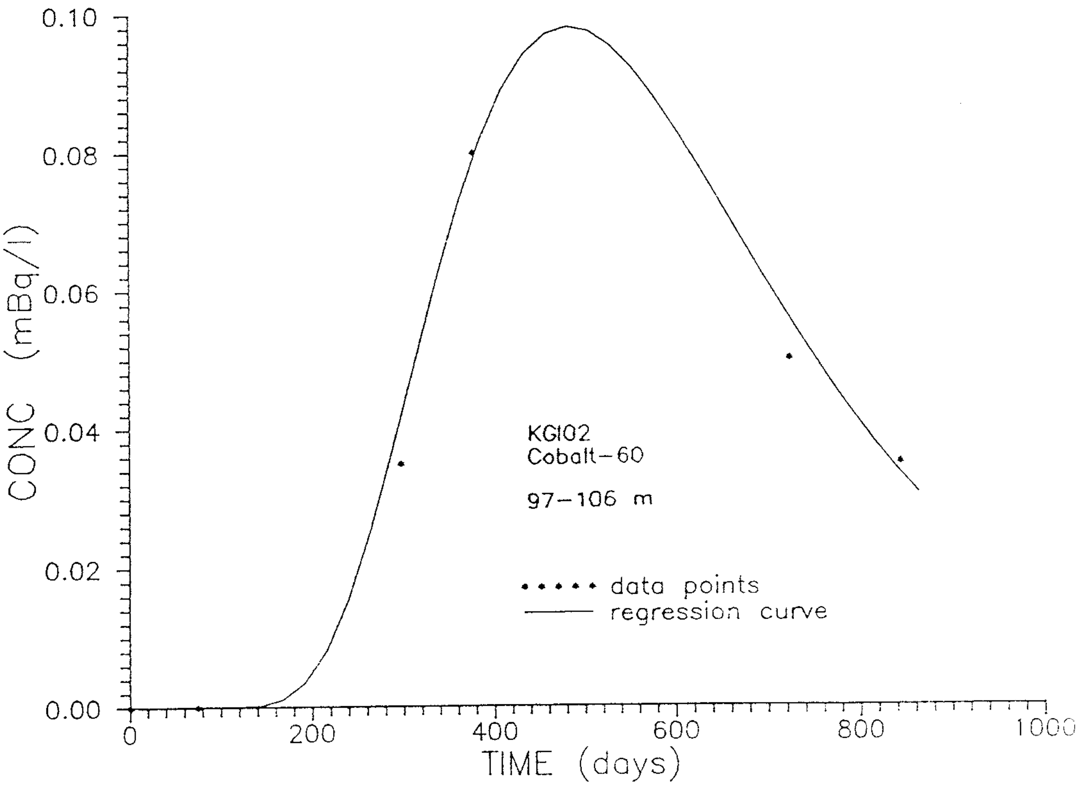

Figure 12 Interpretation of data for Co-60 in KGI02, section 97 - 106 m.

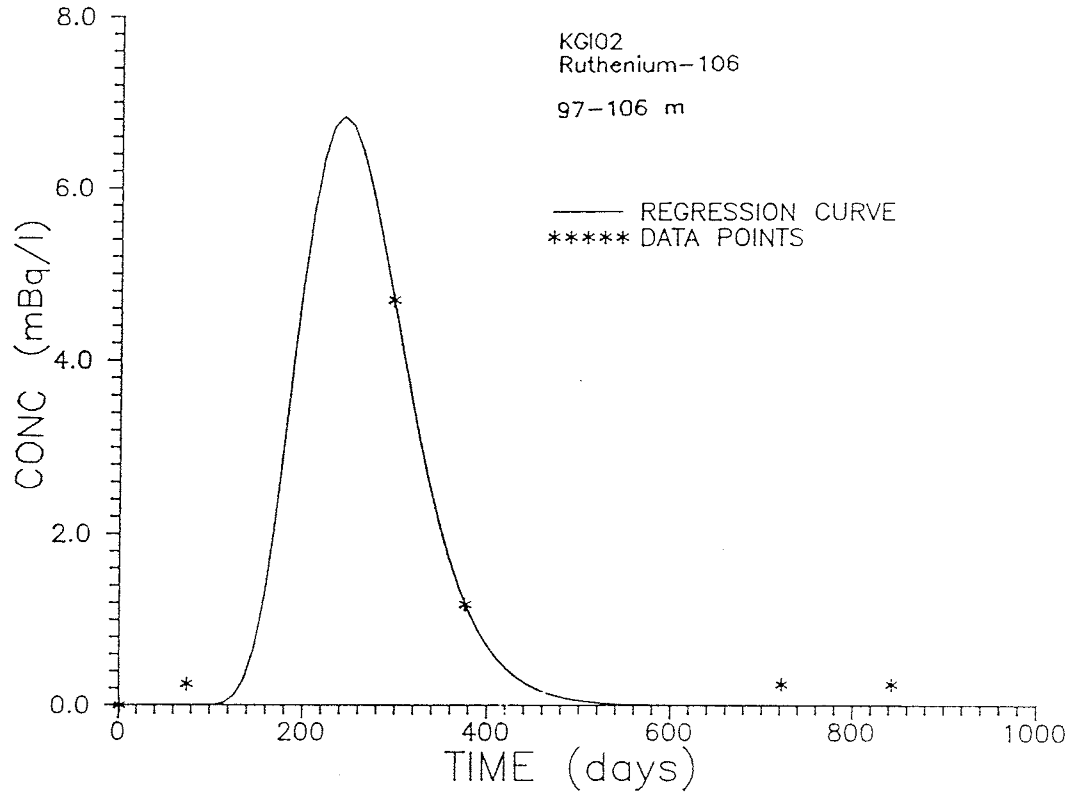

Figure 13 Interpretation of data for Ru-106 in KGI02, section 97 - 106 m.

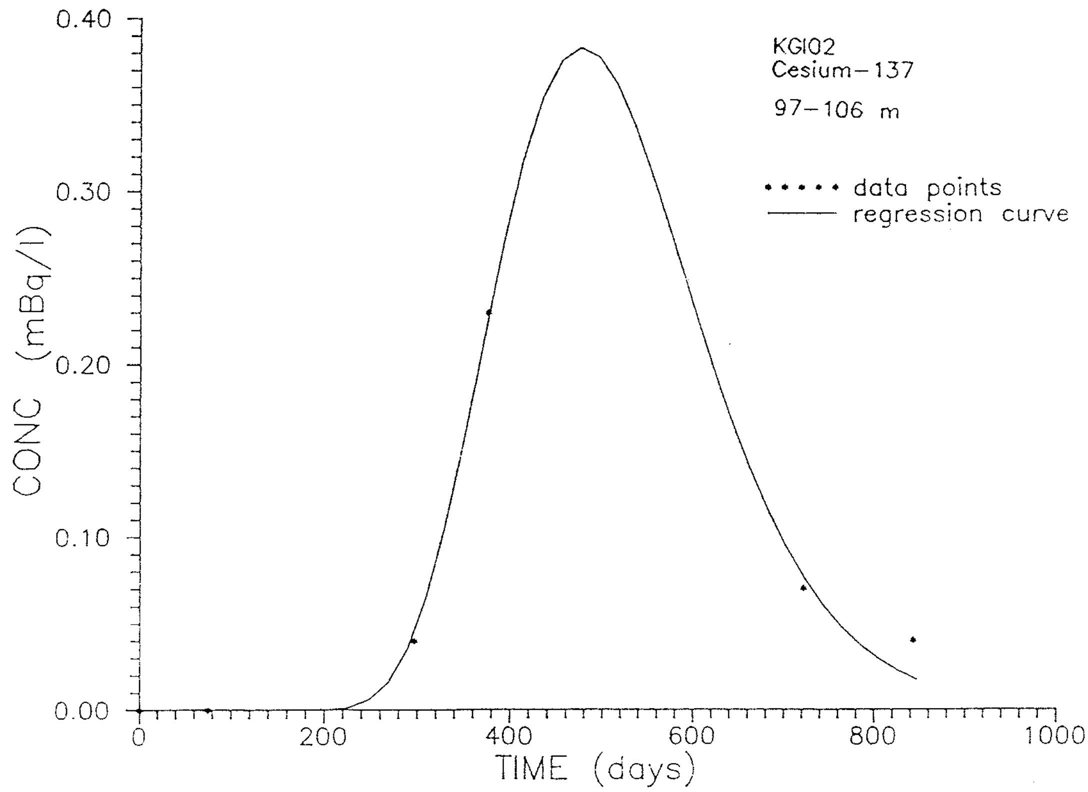

Figure 14 Interpretation of data for Cs-137 in KGI02, section 97 - 106 m.

Table 1 Estimated transport parameters out of interpreted data from Figures 12, 13 and 14.

Radionuclide breakthrough in KGI02, section 97–106 m. Non–linear regression method on measured breakthrough curves.

Route	Zon 1 and 2	to	KGI02, 97–106 m.
Radionuclide	Ru–106	Co–60	Cs–137
t_o (days)	263	599	516
D/v (m)	8	22	8

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