

**ENVIRONMENTAL ISOTOPE- AND HYDROCHEMICAL INVESTIGATION
OF BAURU- AND BOTUCATU GROUNDWATERS, PARANA BASIN, BRAZIL**

(report covering 1989 and 1990)

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1. Introduction

A combined hydrogeochemical and environmental isotope investigation is being carried out in the Bauru- and Botucatu groundwaters. Based on former isotope data, the $^2\text{H}/^{18}\text{O}$ -, ^3H -, ^{13}C -, ^{14}C - and $^3\text{He}/^4\text{He}$ -contents of representative groundwaters out from the Bauru- and Botucatu-aquifer are now investigated to reveal a possible interaction of the groundwater systems and to correlate ^{14}C -groundwater residence times with groundwater "ages" derived from other isotope methods.

The area of investigation includes the southwestern part of the State of Sao Paulo and the northern Parana and follows a profile between the border of the Parana Basin to its central part. In the east it covers the city of Analandia and in the west it reaches the city of Presidente Epitacio, including the Londrina region.

Continuing former isotope investigations and in the context of a more detailed isotope investigation, groundwaters were selected in view of different drilling and casing depths to represent Bauru- and Botucatu groundwaters.

In 1989 and 1990, two groundwater sampling campaigns followed a trajectory from Sao Paulo to the city of Epitacio. Sampling drilling cuts from the new drilled well in Pres. Prudente first time enabled to check for $\delta^{13}\text{C}$ -contents and geochemical composition of this aquifer. Beside the aspect, that $\delta^{13}\text{C}$ -rock data are essential for evaluating carbon isotope hydrochemistry of the inorganic carbon dissolved in groundwater, geochemical data are of interest when interpreting hydrochemical contents of the groundwaters.

Results of hydrogeochemical- and isotope analyses obtained in the 1989 and 1990 campaigns are given in chapter 10 and a first interpretation of these new data is presented in this report.

2. Geological and hydrogeological situation of the Parana-Basin

The main aquifers in the brazilian part of the Parana Basin are the Bauru-, the Serra Geral- and the Botucatu-Pirambaia aquifer systems.

2.1 The Bauru Aquifer

The Bauru aquifer system covers 104 000 km² in the State of Sao Paulo. It is an unconfined aquifer which is formed from cretaceous sandstones. The average thickness of this aquifer is around 100m but increases towards the central part of the area of investigation.

The Bauru aquifer can be subdivided into four formations: Marilia, Adamantina, Santo Anastacio and Caiua. Because the Caiua is the most effective aquifer, its exploitation through wells with depth between 40m and 200m is intensive. In parallel to this, and due to industrial resp. agricultural activities on its surface, the aquifer is also vulnerable to pollutant input. In consequence to the use of fertilizers in agriculture, NO₃-contents up to 50 mg/l are found in Bauru-groundwaters. Beside fertilization, also different industrial activities represent a source for Cr-, Ba-, Hg- and Cd-contamination of Bauru-groundwaters.

2.2 The Serra Geral Basalt

The Serra Geral Basalt is a fractured aquifer system with very inhomogenous hydraulic characteristics. In the area of investigation only few wells are exploiting this aquifer, as its groundwater yield is not very high. In the first sampling campaign two samples of drilling cuts could be obtained and a geochemical analysis (performed at University of Göttingen, FRG) revealed the Serra Geral Basalt being a U- and Th-low, SiO₂-dominated and carbonate-low basalt with FeO₃- and Al₂O₃-contents of 5 and 10 % (weight-%) (comp. tab.2).

2.3 The Botucatu Aquifer

The most important aquifer system of the Parana Basin is the Botucatu- (Piramboia) sandstone. It covers around 800 000 km² on Brazilian territory and, from the North to the South, belongs to the states Mato Grosso do Sul, Minas Gerais, Sao Paulo, Parana, Santa Catarina and Rio Grande do Sul.

The Botucatu aquifer system is constituted by the two sedimentary formations Piramboia and Botucatu. The Piramboia formation consists of fluvial sandstones. In contrast to the Piramboia, the Botucatu formation consists of sandstones of eolic origin. The Piramboia and the Botucatu formations are intercalated between the Permian layers of the Passadois Group and the basalt flows of the Serra Geral Formation.

The Botucatu-aquifer is unconfined at the borders of the basin. The unconfined part is only some 10% of its area. The Botucatu aquifer is confined from the basalt flows of the Serra Geral Formation. The thickness of the covering basalt may reach about 2000 m in the center of the Parana-Basin. Hydrogeological studies revealed groundwater recharge rates up to $160 \times 10^9 \text{ m}^3/\text{year}$ for Botucatu-groundwaters.

The recharge of the aquifer is mainly due to infiltration of rain water in the outcrop areas. From the border of the basin towards its central part, groundwater flow direction follows the direction of the diving of the geological units. The Botucatu aquifer is exploited through wells with depths between 150 m and some 3000 m and exploitation pumping rates range from $100 \text{ m}^3/\text{h}$ to $1000 \text{ m}^3/\text{h}$.

In consequence to the flow rates and drilling depths, Botucatu groundwaters in the central part of the Parana Basin are geothermal and represent an important geothermal potential.

In view of the fact that the Bauru- and Botucatu aquifers, from its hydrogeochemical and bacteriological status, are suited for the population's, the industry's and the agriculture's water-supply, a combined hydrogeochemical and environmental isotope investigation is carried out to evaluate possible interaction of the groundwater systems on the basis of environmental isotope methods.

3. Isotope methods used for groundwater investigation

In this project the application of different isotope methods will be performed to cover the groundwater-ages and to check for deep reaching groundwater-mixing systems. As could be seen even from ^{14}C -data in geothermal groundwater in Pres. Prudente, recent water-input into a deep and geothermal groundwater mixing system could be found and apparently is due to deep reaching fractures in the Serra Geral Basalt and to overexploitation of this well.

As initial contents of ^{14}C can vary within a wide range in the aquifers investigated, a separate attempt to evaluate C-isotope evolution on the basis of ^{13}C -data is made: beside measuring ^{13}C -contents in the dissolved inorganic carbon (DIC) of the groundwater, a more detailed approach to C-isotope evolution must include the ^{13}C -contents in the aquifer materials. Consequently we started to measure ^{13}C -contents in drilling cuts from different depths of Pres. Prudente 2.

As ^{14}C -dating of geothermal groundwaters fails even when correcting with ^{13}C -contents in DIC and host-rock, enforced C-solution and enforced C-isotope exchange between the dissolved inorganic carbon and the carbon in the host-rock takes place and ^{14}C -data consequently only can serve as rough indicators for recent water input. To date these groundwaters, samples were taken for $^3\text{He}/^4\text{He}$ - and ^4He -excess-measurements. It is also foreseen in this context to use noble gas methods to determine recharge-paleotemperatures of the very old groundwaters.

In the following chapters a short description of the different isotope methods will be given.

3.1. ^2H - and ^{18}O -contents in groundwaters

The measurement of ^2H - and ^{18}O -contents in groundwater reveals its meteoric/non-meteoric origin and, in cases of changing recharge climate (paleotemperatures), ^2H - and ^{18}O -data can give hints to very old groundwaters (paleo-effect). When applying the noble gas method to reveal recharge temperatures, these " ^2H -/ ^{18}O -paleogroundwaters" would be of special interest.

3.2. ^{14}C - and ^{13}C -contents in groundwater

The ^{14}C -method to determine mean residence times of groundwater covers the dating range between some 2000 and 30 000 years. Because the ^{14}C -content is determined in the inorganic carbon dissolved in groundwater, the initial ^{14}C -content of the system groundwater/aquifer must be evaluated using the "Chemical Mixing-" and/or the "C-Isotope Exchange Model". Both models simulate the geochemical evolution of the ^{14}C -content following the groundwater pathway from the infiltration- or recharge area to the sampling site.

The models correct for the C-isotope interaction -and depletion of the ^{14}C -signal- between the DIC in the groundwater and the C-component of the rock matrix. The rock carbonate -as one component of C-isotope evolution of DIC in groundwater- is free from ^{14}C but shows typical ^{13}C -contents.

As the ^{13}C -content in atmospheric CO_2 is near some $-24 \delta\text{-o/oo } ^{13}\text{C}$ vs. an international standard (PDB), the ^{13}C -content of DIC approaches the ^{13}C -content of the rock. Depending on the formation of the C-component of the rock, the ^{13}C -content can vary in the range $+0.5 \delta\text{-o/oo } ^{13}\text{C}$ for e.g. limestones and $-6 \delta\text{-o/oo } ^{13}\text{C}$ in those aquifers, where the C-content in rock is due to secondary C-deposition.

It is apparent, that -if both C-components are known with respect to their ^{13}C -content- the ^{13}C -content in DIC offers a scale to evaluate the C-isotopic evolution of the groundwater system considered.

3.3. $^3\text{He}/^4\text{He}$ -contents in groundwater

The $^3\text{He}/^4\text{He}$ -isotope ratio is 1.4×10^{-6} in the atmosphere of the southern and the northern hemisphere. Beside the solution of atmospheric He, which copies this $^3\text{He}/^4\text{He}$ -ratio into surface waters, ^3He is also produced through the decay of ^3H in the groundwater. The $^3\text{He}/^4\text{He}$ -ratio therefore is correlated to the total amount of ^3H which decayed in the groundwater.

Due to the decay of radioisotopes from natural decay series (U- and Th-series), ^3He and ^4He are also produced in the earth's crust. This He-source typically shows $^3\text{He}/^4\text{He}$ -ratios in the range between 1×10^{-8} and 1×10^{-7} .

In contrast to these He-sources, the mantle helium component is characterized by a $^3\text{He}/^4\text{He}$ -ratio of more than 1×10^{-5} .

It is evident, that $^3\text{He}/^4\text{He}$ -data of groundwaters depend on the He-flux from the He-sources into the groundwater and also reflect the He-isotope production within the aquifer-material. Depending on the local situation, $^3\text{He}/^4\text{He}$ -data in groundwater may be used as indicators for the origin of groundwater once e.g. U- and Th-contents in the aquifer material favorate this He-source.

3.4. ^4He -excess data for groundwater investigations

If the $^3\text{He}/^4\text{He}$ -ratio is not influenced from a mantle helium component, the order of magnitude of very high groundwater "ages" may be given with the ^4He -excess method. These data are based on the assumption, that only locally produced helium is contributing to the He-excess. Because of He-components that originate from lower aquifer layers, He-"ages" of groundwater often only give a rough approximation to groundwater ages.

4. Sampling and analytical methods

Since 1989 groundwater samples have been collected for hydrochemical and for isotope analyses. These samples were taken from free-flowing and from pumped wells exploiting the Bauru, the Serra Geral and the Botucatu-Piramboia aquifer systems in both the unconfined and the confined areas. As drilling cuts could be obtained from the well in Presidente Prudente 2, geochemical investigations and the measurement of the U-, Th- and ^{13}C -content could be performed in samples from the Serra Geral Basalt. To detail the ^{13}C -isotope contents, a depth profile of the ^{13}C -contents will be measured covering the Bauru-, the Serra Geral- and the Botucatu-layers. This depth-profile is of special interest in view of the ^{13}C -isotope evolution of the groundwaters considered and details the calculation of the initial ^{14}C -content when dating these groundwaters.

4.1 Geochemical and isotope data in the core-samples from the well Presidente Prudente 2

Rock samples investigated for their ^{13}C -isotope contents and for their geochemical composition originate from the well Pres. Prudente 2. They correspond to the lower layer of the Serra Geral Basalt which covers the Botucatu.

When compared to mean geochemical contents of basalt, Al_2O_3 -, FeO -, Na_2O - and K_2O -contents of the Serra Geral Basalt fit the mean values for basalts as e.g. given in literature. Referring to the SiO_2 - and Fe_2O_3 -contents, the Serra Geral Basalt shows slightly elevated contents, whereas its K-, CaO- and MgO-contents are comparatively low. Low CaCO_3 - and MgO-contents would cause weak mineralisation and e.g. low Ca- and Mg-contents of groundwaters percolating the Serra Geral Basalts.

As turned out from very low U- and Th-contents in the Serra Geral Basalt, this aquifer can not be regarded as a dominating source for $^3\text{He}/^4\text{He}$ - or ^{222}Rn -production.

The ^{13}C -contents measured in these rock samples refer to carbonates from non-marine origin. As both ^{13}C -contents give the $\delta^{13}\text{C}_{\text{ROCK}}$ -component, an experimental value -as a main parameter for the C-isotopic evolution in the Serra Geral- already could be determined.

4.2. ^2H - and ^{18}O -data of Bauru and Botucatu groundwaters

Isotope data of groundwaters are given in tab.(4). In fig. (1) the ^2H - and ^{18}O -contents of the groundwaters are plotted together with the mean global meteoric water line (GMWL) $\delta^2\text{H} = 8 \delta^{18}\text{O} + 10$ (o/oo).

As all ^2H - and ^{18}O -contents of the groundwaters follow the meteoric precipitation line, all groundwaters -and even the groundwaters from the very deep wells- are of meteoric origin and recharged through precipitation.

For the recharge area of the Bauru aquifer, which is close to the recharge area of both the Serra Geral Basalt and the Botucatu-Pirambaia aquifer system, a four-years mean value of $-6.0 \delta\text{-o/oo } ^{18}\text{O}$ was measured in precipitation from MARTINEZ. ^{18}O -contents measured in groundwaters from the Bauru and Botucatu aquifer vary within -9.8 and $-6.3 \delta\text{-o/oo}$. Groundwater samples from the unconfined aquifers show more positive ^{18}O -contents which may be an indication for recent groundwater contribution. In contrast to this, the ^{18}O -contents of those groundwaters, which represent the confined Botucatu-Pirambaia aquifer are more depleted.

The ^2H -contents of Bauru- and Botucatu groundwaters lie within the range -43 and $-67 \delta\text{-o/oo } ^2\text{H}$. With the exception of the geothermal groundwaters in Pres. Prudente and Pres. Epitacio, and with the exception of the groundwaters from Avare well 7 and from Pratania, the groundwater samples representing the confined Botucatu aquifer show more negative ^2H -contents (see fig.1). Through direct comparison it can be deduced, that groundwater from wells in Avare show differing ^2H - and ^{18}O -contents. A possible explanation could be a different admixture of surface-near groundwaters to the deep Botucatu-groundwater sampled in well 7.

The ^2H - and ^{18}O -contents in groundwaters from Areiopolis P5, from Avare well 5 and 6 indicate a tendency, that groundwaters from confined Botucatu show more negative values. The ^2H - and ^{18}O -contents from thermal groundwaters in Pres. Prudente and Pres. Epitacio do not fit this picture. In the case of the groundwater in Pres. Prudente, ^2H -, ^{18}O - and ^{14}C -data however support the assumption, that recent groundwater is admixed due to a pumping rate as high as $1000\text{m}^3/\text{h}$.

4.3. ^3H -contents in Bauru- and Botucatu groundwaters

Due to the very low content of ^3H in rain of the southern hemisphere, the ^3H -content -even in recent groundwaters- is in the range of 5 TU. Measurements of the ^3H -content in Bauru-/Botucatu groundwaters is therefore only tried in the Avare-system, to reveal a very recent groundwater component. As ^3H -contents below 1 TU were measured in these groundwaters, a contribution of very recent water exceeding 30 % can be excluded in the groundwater from well Avare P7.

4.4. ^{13}C - and ^{14}C -contents of Bauru and Botucatu groundwaters

^{13}C - and ^{14}C -results measured in groundwaters DIC are listed in tab. (2) and cover the range from -5.2 and -18.9 ‰ ^{13}C resp. 8 to 100 pmc. Unfortunately the results of samples 26, 27, 41, 43 and 44 are missing but a few facts already can be stated.

As the ^{13}C -content in thermal waters from Pres. Prudente reaches -6 resp. -7 ‰ ^{13}C , a direct comparison with -4 to -6 ‰ ^{13}C -as measured in rock material of the Serra Geral Basalt- reveals that C-isotopic evolution in DIC approximates -6 resp. -7 ‰ ^{13}C .

It can be deduced from the ^{14}C -content in the geothermal groundwater from Pres. Prudente, that surface near groundwaters are admixed to the Botucatu groundwater. This may be due to a high pumping rate and/or to a bad casing.

An admixture of surface-near groundwater does not affect the isotopic signature of the ^{13}C -content in DIC, because of the different "signal to background ratios" between ^{14}C and ^{13}C .

Apparent from ^{13}C - and ^{14}C -contents in groundwaters from Avare P5 and from Areiopolis P5, no admixture of surface near groundwater to the Botucatu-groundwater takes place in these wells. Mean residence times of these groundwaters correspondingly are high and will be evaluated using the Isotope Exchange Model to calculate the initial content of ^{14}C .

Groundwater from Aparecida de Sao Manoel P2 represents groundwater from the unconfined Serra Geral Basalt and its intertraps. The ^{14}C -content shows 104.00 ± 5.0 pmc and -fitting with expectation- indicates a very recent groundwater.

4.5. $^3\text{He}/^4\text{He}$ - and He-excess data in deep groundwaters from Botucatu

$^3\text{He}/^4\text{He}$ -samples were taken from groundwater in Avare P5, in Presidente Prudente and in Pres. Eptacio. $^3\text{He}/^4\text{He}$ -ratios listed in tab.(4) show ratios in the range of 10^{-7} to 10^{-8} . Despite the low U- and Th-contents measured in the samples from Serra Geral Basalt, excess He- (given in 10^{-8} NmI He per gramm of water) can be stated in all groundwaters investigated. Referring to the thermal groundwaters in Pres. Prudente and Pres. Eptacio, a clear indication for an He-excess can be derived from $4000 - 11000 \cdot 10^{-8}$ NmI He per gramm of water. These results however can be influenced from outgassing due to very difficult sampling conditions.

5. Hydrochemical analyses of Bauru and Botucatu groundwaters

The hydrochemical data are listed in tab.(3). Because the Bauru and the Botucatu sandstone layers show low carbonate contents, their groundwaters are only weakly mineralised and e.g. HCO_3^- -contents below $200 \text{ mg HCO}_3^-/\text{l}$ were measured. Even in the geothermal groundwaters in Pres. Prudente and Pres. Eptacio HCO_3^- -contents do not exceed $510 \text{ mg HCO}_3^-/\text{l}$.

When compared to non-geothermal groundwaters in the Bauru and Botucatu-layers, geothermal groundwaters show elevated HCO_3^- -, Cl^- -, Na - and SO_4 -contents but are depleted in their Ca-contents. As the SO_4 -content does not correlate with the Ca- or Mg-contents of the groundwaters, SO_4 -contents are not due to Ca/MgSO_4 -solution. It is also evident, that Ca-contents in the thermal groundwaters are lower than in the other groundwaters investigated. CaCO_3 -contents in the deep layers of the Botucatu aquifer consequently are assumed to be lower than in the aquifer layers above.

When comparing the Ca/Mg-ratio of the groundwaters with the CaO- resp. MgO-contents as measured in the deeper layers of the Serra Geral Basalt (see tab.2), geothermal groundwaters fit a Ca/Mg-ratio between 1.5 and 2 whereas other groundwaters show slightly higher Ca-contents but same Ca-/Mg-ratios and may indicate aquifer-layers with Ca/Mg-ratios differing from the basalt. Referring to the Na- and Cl-contents in the geothermal groundwaters, the influence of NaCl-solution out from deeper aquifer layers, resp. the influence of a groundwater with higher Na- and Cl-contents is obvious and perhaps may fit the geochemical analyses which will be done on the Botucatu-drilling cuts.

6. Summary and Advances

During the first phase of the project, three field trips for sampling have been done. First hydrochemical parameters and environmental isotope-contents of groundwaters sampled in both campaigns are measured and results are listed in tabs. (3) and (4).

As samples of drilling cuts could be obtained from the well Pres. Prudente 2, first uranium-, thorium and ^{13}C -contents of rock material could be determined in the lower layers of the Serra Geral Basalt.

As the U- and Th-determinations in the basalt are of interest in view of applicating the He-isotope-method to date groundwater, the ^{13}C -content in rock material is necessary for evaluating the isotope evolution of ^{13}C and ^{14}C in the dissolved inorganic carbon (DIC) of the groundwaters investigated.

It can be seen from hydrogeochemical data, that all groundwaters -and even the geothermal ones- show only small mineralisation which is due to the low calcium-carbonate contents of the Bauru- and Botucatu-sandstone aquifers. As Na- and Cl-contents of the geothermal groundwaters out from the deep layers of the Botucatu are elevated, the influence of another aquifer resp. the admixture of a groundwater with higher Na- and Cl-contents can be assumed.

A first interpretation of isotope contents measured in the Bauru and Botucatu groundwaters reveals, that based on a ^{13}C -contents between -4 to -6 o/oo- $\delta^{13}\text{C}$, as measured in the rock material, -6 to -7 o/oo- $\delta^{13}\text{C}$ in the DIC of the Botucatu-groundwaters are the endpoint of ^{13}C -evolution between the systems DIC in groundwater and rock carbonate.

As can be deduced from ^{14}C - (^{13}C -) data, groundwaters in Avare P5 and Areiopolis represent Botucatu-groundwaters with high mean residence times. This conclusion is supported from ^2H - and ^{18}O -data of these groundwaters, when compared with the ^2H - and ^{18}O -contents of the recent groundwaters e.g. in Sao Manoel. The groundwater system in Avare will be of special interest, because ^2H - and ^{18}O -data support the opinion, that a groundwater mixing system is represented in wells 5, 6 and 7.

The geothermal groundwater in Pres. Prudente represents the groundwaters from the deep layers of the Botucatu. The ^{14}C -content was supposed to be below the detection limit of 2 pmc due to enforced C-isotope solution and -exchange. Contradicting our opinion, the ^{14}C -content in this groundwater was 15 pmc. As contamination of the sample is improbable, the only explanation is the high exploitation-rate (up to 1000 m³/h) and/or an insufficient casing of this well, which concedes a young groundwater component to be admixed to the geothermal, old Botucatu groundwater.

First $^3\text{He}/^4\text{He}$ - and He-excess data are obtained in groundwaters from Avare, Pres. Prudente and Pres. Epitacio. As no significant $^3\text{He}/^4\text{He}$ -differences could be stated in the Botucatu groundwaters, a $^3\text{He}/^4\text{He}$ ratio in the range of $3 \cdot 10^{-8}$ is taken to represent deep Botucatu-groundwaters. Due to severe difficulties when sampling for He-excess data, only the order of magnitude of the He-excess in the geothermal groundwaters can be derived from data obtained. Nevertheless, a He-excess in the deep Botucatu layers could be stated and will be the subject of further investigation.

7. Future activities

Future investigations will cover a more detailed study of the groundwater systems in Avare and Areiopolis using ^{14}C - and He-isotope analyses. It is also intended to measure noble gas contents in these groundwaters (cooperation with M. Stute/Lamont University), to investigate recharge-paleotemperatures of these groundwaters and to compare with the noble-gas-data obtained from geothermal Botucatu-groundwaters.

To contribute to C-isotope evolution of groundwaters and to seek for a variation of the ^{13}C -content in the different aquifer-layers, a $^{13}\text{C}_{\text{Rock}}$ -depth-profile will be measured in drilling cuts from the well Pres. Prudente 2. These data will represent different layers of the Bauru-, the Serra Geral- and of the Botucatu/Piramboia Formation.

Concerning the deep Botucatu layers and its geothermal groundwaters, future isotope investigations should include ^{222}Rn -measurements and will include Ra- and $^3\text{He}/^4\text{He}$ -isotope investigations. In view of the low U- and Th-contents it is also intended to sample the deep Botucatu-groundwaters for a few $^{36}\text{Cl}/\text{Cl}$ -determinations. In the context of Ra- and Rn-data, which will be used to check for subsurface production of ^{36}Cl , an attempt to date the very old groundwater with the ^{36}Cl -isotope method will be undertaken.

8. 1990-1991 Timeschedule of the Bauru-/Botucatu-Project

November,	1990	IAEA-experts visit in Sao Paulo, field campain
June/August	1991	field trip for collecting further groundwater samples to determine ^3He - and ^4He -contents, to measure noble-gas recharge temperatures and to supply further ^{14}C -, ^{13}C -, ^2H - and ^{18}O -measurements of both groundwater systems
Okt./Nov.	1991	IAEA-experts visit intended for preliminary data treatment and data-interpretation.

9. Cooperating Institutions

Hydrochemical investigations were measured in the CEPAS laboratory of USP, Sao Paulo, Brazil.

The He-sampling device used for He-sampling was machined at the laboratory of CEPAS-USP-Sao Paulo, Brazil.

The University of Göttingen performed the geochemical analyses of the Serra Geral samples given in tab.(2).

The determination of the stable isotopes ^{18}O -, ^2H - and the ^{13}C -analyses were performed in the laboratory of CENA-USP-Piracicaba, Brazil.

The measurement of the specific activity of ^{14}C in DIC and the $^3\text{He}/^4\text{He}$ - as well as the ^3H -determinations were performed at the environmental isotope laboratory of IfH, GSF-Neuherberg, Germany.

Further samples for ^{14}C -measurements in groundwater will be analysed at the radiocarbon laboratory of CENA-USP - Piracicaba, Brazil.

10. Tables and figures

Tab. 1: Groundwaters sampled are given with reference to their type of aquifer and their aquifer layers.

sample	site/well	aquifer-layer	type
25	Avaré P-5	Botucatu Piramboia	confined
26	Avaré P-6	Botucatu-Piramboia	confined
27	Avaré P-7	Botucuta-Pirambóia	confined
28	Pres.Prud. P1	Botucatu-Pirambóia	confined
29	Pres. Eptácio	Botucatu-Pirambóia	confined
30	Pres.Prud. Pla Bauru		unconfined
40	Aparecida de Sao Manoel P-2	Serra Geral-Basalt	unconfined
41	Aparecida de Sao Manoel P-1	Serra Geral Basalt	unconfined
42	Areiópolis P-5	Botucatu	confined
43	Areiópolis P-1	Serra Geral Basalt	unconfined
44	Pratânia	Baru and Serra Geral-Basalt	unconfined
46	Pres.Prud. P2	Botucatu	confined

Table 2: Results of geochemical analyses of drilling cuts out from well Presidente Prudente 2. Samples represent Gerra seral Basalt at depths 1576 m and 1604 m. (Geochemical analyses from Univ. of Göttingen, Germany)

Element	Depth	
	1576 m	1604 m
U (mg/kg)	0.880	1.130
Th (mg/kg)	3.340	4.540
^{13}C -content (δ -o/oo)	-4.6	-6.7
K (%)	0.900	1.500
SiO ₂	61.400	55.100
Al ₂ O ₃	9.720	13.300
Fe ₂ O ₃	5.100	4.300
FeO	7.020	7.680
CaO	6.520	7.520
MgO	3.220	4.850
Na ₂ O	2.140	3.240
K ₂ O	1.300	1.970
Li ₂ O	0.005	0.003

Tab. 3: Results of hydrochemical analyses of Bauru- and Botucatu groundwaters.

Sample Nr.	Site and well	sampling date	HCO ₃ (mg/l)	Cl (mg/l)	NO ₃ (mg/l)	SO ₄ (mg/l)	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)
25	Avaré P-5	21.9.89	164.7	0.4	0.1	0.5	15.0	0.9	7.3	1.2
26	Avaré P-6	21.9.89	142.6	2.4	0.2	0.9	12.0	0.3	9.2	1.3
27	Avaré P-7	21.9.89	89.2	1.7	nd	1.3	7.0	0.5	12.3	2.3
28	Pres.Prud. P1	22.9.89	385.5	165.0	nd	109.3	230.0	2.1	4.7	1.8
29	Pres.Epitácio	23.9.89	506.3	59.7	nd	80.0	180.0	1.8	0.5	0.9
30	Pres.Prudente P-1a	22.9.89	65.2	1.5	0.2	2.5	0.6	0.3	2.9	1.4
40	Aparecida de Sao Manoel P-2	08.2.90	73.2	1.0	5.0	0.1	2.0	0.9	10.7	1.8
41	Aparecida de Sao Manoel P-1	08.02.90	54.2	1.0	4.8	0.1	2.0	0.9	10.9	1.9
42	Areiópolis P-5	09.02.90	134.2	0.1	0.7	nd	4.4	2.1	19.0	0.7
43	Areiópolis P-1	10.02.90	85.5	0.8	2.1	nd	6.6	0.9	11.3	1.4
44	Pratânia	11.02.90	97.6	1.8	9.0	0.1	2.9	1.7	14.7	2.9
46	Pres.Prud. P2	21.07.90	506.2	208.0	nd	88.0	295.0	3.4	2.4	0.9

nd = below detection limit

Tab. 4: Results of isotope analyses of Botucatu and Bauru groundwaters
 * indicates samples where the result is outstanding
 L indicates samples which are lost or were contaminated

Sample Nr.	Site and well	sampling date	Temp. (°C)	¹⁸ O (δ-o/oo)	² H (δ-o/oo)	¹³ C (δ-o/oo)	¹⁴ C (pmc ± 2σ)	³ He/ ⁴ He *10 ⁻⁶	⁴ He _{excess} *10 ⁻⁸ Nml/g
25	Avaré P-5	21.9.89	27.0	-8.61	-56.6	-12.7	7.6 ± 1.6	<0.04	46
26	Avaré P-6	21.9.89	26.5	-7.66	-51.2				
27	Avaré P-7	21.9.89	27.0	-7.37	-49.5				
28	Pres.Prud. P1	22.9.89	60.0	-6.52	-43.1	-6.34	15.0 ± 1.4	0.02	10500
29	Pres.Epitácio	23.9.89	72.0	-6.94	-48.6			<0.12 0.030	5000 4700
30	Pres.Prudente P-1a	22.9.89	22.0	*	*			0.05	25
40	Aparecida de Sao Manoel P-2	08.2.90	24.0	-7.01	-45.8	-18.9	104.0 ± 5.0		
41	Aparecida de Sao Manoel P-1	08.02.90	24.0	-6.92	-44.9				
42	Areiópolis P-5	09.02.90	28.5	-9.87	-67.1	-11.7	17.2 ± 5.0		
43	Areiópolis P-1	10.02.90	21.0	-6.84	-46.3				
44	Pratânia	11.02.90	22.5	-7.21	-46.4	*	L		
46	Pres.Prud. P2	21.07.90	70.0	-6.26	-43.8	-7.5	*	L	

Fig. (1): ^2H - and ^{18}O -contents of Bauru- and Botucatu groundwaters. The Global Mean Meteoric Water Line $\delta ^2\text{H} = 8 + \delta ^{18}\text{O} + 10$ (o/oo) is indicated.

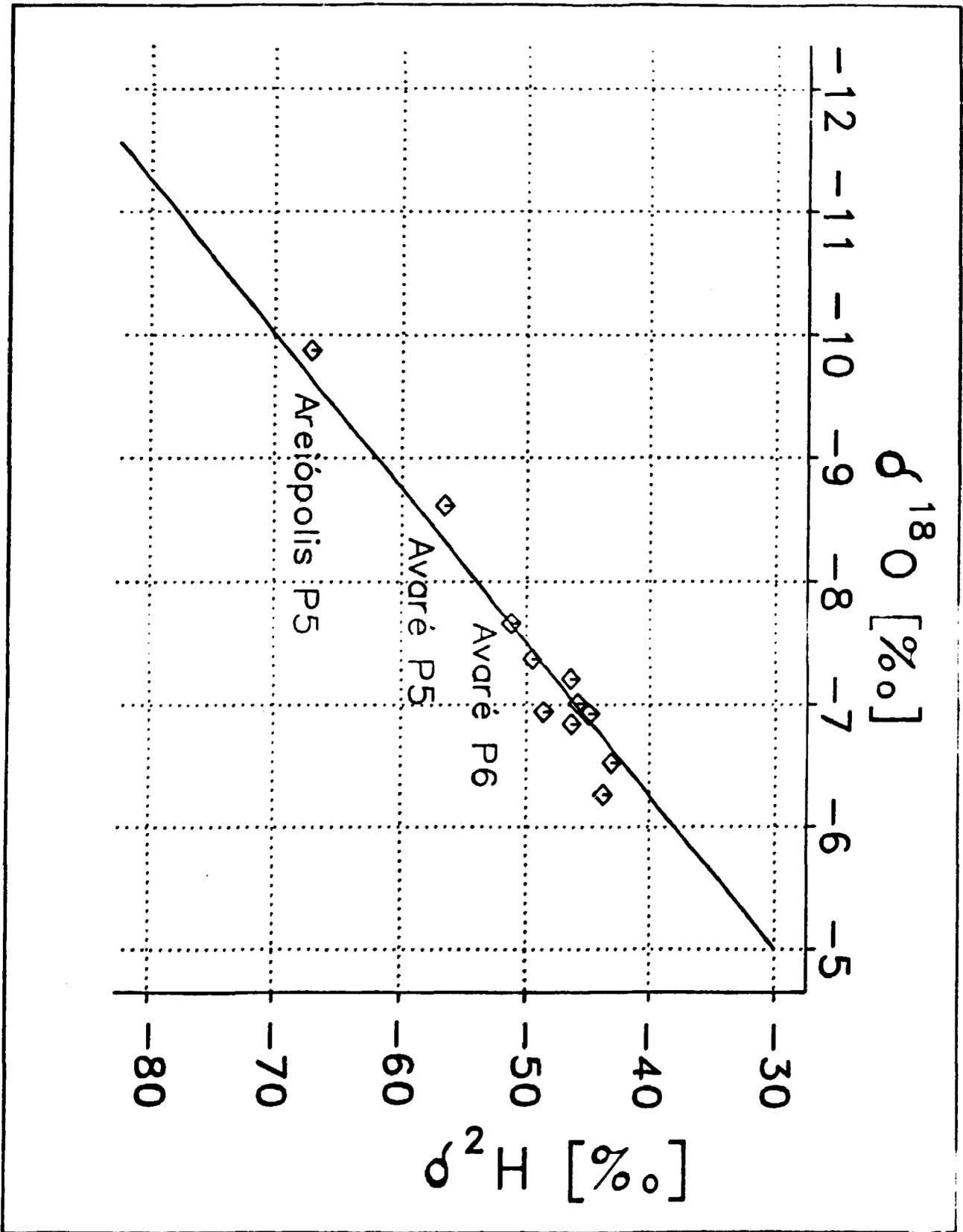


Fig. (2): Ca- and Mg-contents of Bauru- and Botucatu groundwaters. - To compare with the rock samples in a first approximation, a Ca-/Mg-ratio of 2 is indicated.

