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## GEOCHEMICAL BALANCE OF THE SALGADO RIVER BASIN

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## ABSTRACT

In this work, the Salgado River basin (Bahia State, Brazil) was studied from the point of view of present climatic and geochemical conditions: inappropriate agricultural exploitation, irregular rainfall and high evaporation rate have driven this region to a state of unbalanced geochemical conditions. The water of the Salgado River showed high concentration of the total dissolved salts (1.57 g/l). The mean chemical composition of the rocks of the river basin was measured and their weathering rate was found to be 0.02 mm/yr. Among the most important cations sodium is certainly most abundant in rain water, superficial and deep water whereas calcium is found to be the most abundant cation among those measured in rocks.

## INTRODUCTION

Studies in superficial Geochemistry have been important due to their ability to solve general problems in Geophysics: dissolved and suspended matter of natural continental water have been investigated to know the nature and composition of the matter transported by rivers to the ocean (Gibbs, 1972; Subramanian, 1978), or to estimate the geochemical balance as a whole (Barth, 1961). Such studies are also used to determine the weathering rate of rocks (Johnson et al, 1968; Tardy, 1969; Moreira-Nordemann, 1980) or to solve problems in Hydrology (Goldschmidt et al., 1967; Osmond et al., 1974; Osmond and Cowart, 1976 etc ...).

In the present work, we studied the natural conditions of the Salgado River basin, located in the "Sertão" of the Bahia State in Brazil, as a function of climatic and present geochemical conditions, to investigate the high concentrations of salts in the surface waters.

"Bahian Sertão" is a part of the so-called "Caatinga" zone which covers an area of 500,000 km<sup>2</sup>. This region is characterized by a humid to semi-arid climate, being submitted to drought, high-temperature and irregular rainfall, and it presents a scarce vegetation resistant to drought. Most part of the tributaries of the rivers flowing in the region are of intermittent nature, shrinking to a ravine in time of dry weather. The high concentration of dissolved salts in water, which is relatively frequent, gave this river the name of Salgado River ("salgado" means "salty"). This name is common for many rivers and lakes in this region and in similar regions in Brazil.

## DESCRIPTION OF THE BASIN

The Salgado River basin extends over an area of 688 Km<sup>2</sup> in Bahia State

in northeastern Brazil. It is located between  $11.8^{\circ}$  and  $12.2^{\circ}$  South latitude and  $38.8^{\circ}$  and  $39.0^{\circ}$  West longitude, 130 km far from the Atlantic Ocean coast (Fig. 1).

This basin is included in the Brazilian undifferentiated pre-cambrian shield, with a tectonic shear zone near the fault where cretaceous sediments have accumulated. However the Salgado River basin does not present indication of detrital formation, once such a formation was observed only over an area of  $10 \text{ km}^2$  in the central part of the basin, which represents less than 2% of its area. This region was extensively studied and described by Tricart and da Silva (1968).

The rocks in the Salgado River basin are cataclastic metamorphism rocks, of regional metamorphism of migmatitic facies, with dominance of gneiss: quartz gneiss, hornblend gneiss, biotite gneiss, granitized gneiss with occurrence of amphibolites, cataclasites and quartzites.

Soils in the region are thin and do not reach 3 m thick. The clay is montmorillonite with concentration between 8 to 20% in surface and between 10 to 30% in depth. The exchange capacity of the mineral fraction less than  $2 \mu\text{m}$  is between 50 and 60% at the surface and may reach 100% in depth. The absorbing complex is saturated from 80 to 100%, the exchangeable bases vary from 7 to 25 mE%.

The surface horizons are generally dry or weakly humiferous. This structure is polyedric fragmentary to granular. Even in the surface horizons residues of mother-rock may be seen. The disadvantage of these soils is their low content of organic matter. Manioc (manihot esculenta), corn (zea mais) and tobacco (nicotiana tabacum) are cultivated there. Natural vegetation is xerophilic: mandacaru (cereus mandacaru), xique-xique (pilocerus cetosus) etc..., shrubby and drought resistant.

From the topographic point of view, the region is a great plain, at an altitude of 352 m at the source of the river and 246 m at the confluence point with the Pojuca River of which the Salgado River is a tributary. The Taboas, Pedra Nova and Porcos brooks, of intermittent nature are tributaries of the Salgado River (Fig. 2).

The Salgado River flow is  $5.05 \times 10^{10}$  l/yr ( $1.6 \text{ m}^3/\text{s}$ ) at its confluence point with the Pojuca River. This value was calculated from 2,568 observations made by DNAEE (National Department of Water and Electric Energy) from 1963 to 1971, 45% of which represent a flow lower than  $0.02 \text{ m}^3/\text{s}$ . Due to the irregularity of the flow it is difficult to perform more precise measurements so we had to use the available data. The temperature of the river water varies between  $24.5^\circ$  and  $29.5^\circ\text{C}$ , the pH varies between 6.9 and 7.8.

The mean rainfall in the region is 992.5 mm/yr at Irarã, obtained from measurements made during 50 years by DNOCS (National Department of Works against Drought) and are representative of the basin, once the IBGE (Brazilian Institute of Geography and Statistics) considers the whole basin as being included in the same "microhomogeneous" region. At Feira de Santana, south of the basin, the rainfall is 837.3 mm/yr and at Serrinha, north of the basin, it is 855.8 mm/yr (Andrea, 1963; DNOCS).

#### METHOD

Surface water samples (10 to 20 l) were collected and acidified at the place of collection Fazenda Mocambinho (Fig. 2), at the same place where the DNAEE set up the rules for flow measurements. Other samples were collected the same way, along the course of the river and in a lake and in some wells of the area.

Rain water samples were collected and analyzed during two years

(1972-1974] by Ribeiro Filho(1975) who studied concentrations of sodium, calcium, potassium and magnesium in rain water at several places in the Bahia State. For the Salgado River basin we used measurements at Serrinha, at the north of the basin. Owing to the similarity of the rainfall from the north to the south of the basin and to the parallelism of the basin shape with the Atlantic coast (Fig.1), we consider the rain water samples collected at Serrinha as representative of the basin.

The rain collector is made of an acrylic hemisphere of  $0.165 \text{ m}^2$  of area, the surface of it being covered by a double thickness surgical gauze, the collecting area being at 1 m above the ground level. A polyethylene tube at the bottom of the hemisphere allowed the rain water collected to flow into a 11 liters bottle made of the same plastic. The outside of the bottle was covered by an aluminum sheet to reduce evaporation and algae development due to the illumination effect of the sun.

Rock and soil sampling were performed in the whole basin, taking in account the geological context, the several kinds of rocks and their abundance or spatial representativity. Soils profiles were also analyzed in the region.

Concentrations of sodium, calcium, potassium and magnesium were determined in rain water and in surface water by atomic absorption spectrometry, and by the same technique in rocks and soils after convenient chemical attack. This attack was performed by repeated dissolution and evaporation to dryness by  $\text{HF}+\text{HCl}+\text{HNO}_3$  mixture. Analytical precision is generally better than 5% for rainfall and river water and better than 7% for rock and soils samples.

The determination of the total dissolved salts concentrations, in the samples of clear river water, were determined by the gravimetric method as described by Rodier (1971). A volume of 100 ml is heated in a porcelain crucible in a water bath to dryness and then dried in a heater at  $110^\circ\text{C}$

during four hours and cooled during 15 minutes in a desiccator before weighing. This process gives a precision of about 1% on the salt concentration but it must be reminded that some systematic error may not be eliminated due to hygroscopic properties of the evaporated salts, to interstitial or cristalization water remaining after drying at 110°C.

Uranium concentration was measured in all kinds of samples by alpha-ray spectrometry, after convenient chemical treatment, as previously described (Moreira-Nordemann, 1980).

## RESULTS

### Salt concentration

Table I presents the concentration of total dissolved salts (cations and anions together) for five different flows between April and December 1973. We have to emphasize that, due to frequent drought and irregularity of the rainfall and of the river flow itself, it was possible to obtain only these samples, although we used an inhabitant of the nearest farm to collect samples at different flow rates. The same table presents also the flow rates, the date of sampling and the statistical weight of each flow rate (this statistical weight  $P_i$  is the number of cases for which this flow rate was measured, during the eight years of twice-a-day measurements). From these data we calculated the mean value of the concentration of dissolved salts in the river water, using the following formula:

$$\bar{E} = \frac{\sum_i (E_i d_i P_i)}{\sum_i (d_i P_i)} \quad (1)$$

Where  $E_i$  is the salt concentration for the  $i$ -th measurement;  $d_i$  is the flow rate corresponding to the  $i$ -th sample;  $P_i$  is the statistical weight for the same measurement.

By this way we obtained a mean value of 1.57 g/l for the concentration



of salts dissolved in the river water. Of course, in these measurements the soluble part of the atmospheric falls out (cations and anions), coming from rain water and not trapped on its way to the river is included.

This mean value of salt concentration, multiplied by the mean flow of the river and divided by the area of the basin, allows us to calculate that  $115 \text{ t/km}^2/\text{yr}$  of salts are evacuated from the basin.

These values may be considered as very high when compared to those obtained in other river basins in Brazil. In the Amazon River basin, Gibbs (1972) found only  $52.9 \text{ mg/l}$  of salts in the river water, and Livingstone 1963 (in Gibbs 1972) found  $114 \text{ mg/l}$  in Parana River and  $54 \text{ mg/l}$  in Orinoco River. In the Preto River basin, in the South of Bahia State, also in northeastern Brazil, we found only  $42.7 \text{ mg/l}$  corresponding to an evacuation of  $16 \text{ t/km}^2/\text{yr}$  by the basin (Moreira-Nordemann, 1977).

Mean concentrations of dissolved salts varying from  $1.5$  to  $17 \text{ g/l}$  were found by Mazar et al. (1969) in mineral water of Kikar-Noit in Israel, although the climatic conditions and the geological context differ completely from those of the Salgado River basin.

Table I, presents also the dissolved salt concentration for flow-rates lower than  $0.02 \text{ m}^3/\text{s}$ , which correspond to the most frequent flows measured, in 45% of the cases. It may be seen that the salt concentrations are much lower when the samples were taken during long periods of drought (S16, S2, S19), than when they were taken during or after rainfall (S10, S13) which clearly shows a strong drainage in the region only in case of heavy rainfall.

Table II presents the concentrations of salts measured in a tributary (Taboas River), in a lake (Salito Lake) and in the high Salgado River, all of these being located in the higher part of the basin, and in the medium course of the river (Tiquaruçu). It is possible to note that the

salt concentrations are higher and higher as one comes nearer to the source of the river. Already in the mid course of the river (Tiquaruçu), the salt concentration is higher than in the lower course (Mocambinho), although the couple of samples were taken on the same day. We did not find any lithological difference able to justify such results (the geographical distribution of the various kinds of rocks are shown on Table X).

The sample SS3 from an artificial well, and the sample SS2 were taken in a pond, both places being located in the lower basin (Mocambinho). The salt concentrations were found to be rather high for both samples. However, the river water salt concentration values were found to be higher than them.

#### Sodium, calcium, potassium and magnesium measurements

Table II presents the mean values for these four elements in rain water. These results were obtained during two years of sampling. Sodium is without any doubt the most important element, and this is obvious, due to the vicinity to seashore of the basin and its origin being mainly oceanic (Eriksson, 1959; Blanchard, 1963; Ribeiro Filho, 1975). The concentrations in these elements vary very much, as it may be seen in Table III, where are shown the results of measurements made between March and November 1973. Between 1972 and 1974, corresponding to the two-year interval of measurements (Ribeiro Filho, 1975), the sodium, the calcium, the potassium and the magnesium concentrations were found to vary between 3.28 and 0.04, between 1.37 and 0.01, between 1.56 and 0.05 and between 0.53 and 0.01 respectively. Also, the ratios Ca/Na, K/Na and Mg/Na are varying, although the last ones vary less.

In Table IV, the mean chemical composition of the rocks of the basin is presented. This result shows that, between the four cations measured,

calcium is the most abundant, the other elements, sodium, magnesium and potassium are less abundant.

Table II shows the main cations concentrations for the Salgado River water, for all flow-rates, including the lowest ones, and also for the river course, a well and a lake of the region.

In the river water, sodium is without any doubt the most important element, followed by magnesium, calcium and potassium. High sodium concentrations are explained not only by its high concentration in rain water, but also because it is a very mobile ion, frequently found with such high concentrations in river flowing in hot climate countries (Gibbs, 1972). When it is fixed in deep horizons of soils (Demolon, 1960), it is always less strongly bound and for this reason easily lixiviated. Magnesium is also easily soluble and the concentrations obtained in the river water show that this element is easily lixiviated. Furthermore, the comparison of the results contained in Table II and III shows that, for measurement corresponding to the same day of sampling, sodium and magnesium concentrations in the river water are quite proportional to those obtained in rain water, which is obvious, due to the presence of these elements in rain water.

For calcium and potassium, the results are different: although being a less abundant element in rocks and in rain water, potassium shows very low concentrations in surface waters and high concentrations in the soil horizons, as shown in Table XI which presents the potassium concentrations as they were measured by gamma-ray spectroscopy. Also calcium, being the most abundant cation in the rocks of the basin, is the second most abundant element in rain water and seems to be retained by soils and rocks, and not easily lixiviated by running water.

These results are in agreement with those obtained in the Preto River basin (Moreira-Nordemann, 1977), in a humid tropical climate region also located in the Bahia State: there, sodium and magnesium were easily lixiviated by surface running water when calcium and potassium were retained. It is necessary then to recall that calcium and potassium (among the four cations measured) are preferentially integrated by the biomass. Graustein (1975) has shown that due to fixation of calcium, potassium and magnesium in alive or dead vegetal tissue, they may present concentrations higher than those corresponding to the annual turnover of these elements in running waters. Johnson et al. (1968) have shown that external factors modifying the vegetal equilibrium of a region give rise to variations of potassium concentrations in waters.

The analysis of anions in six samples have shown that chlorine is the most abundant anion (45.2%) with  $\text{CO}_3\text{H}^-$  (11.8%),  $\text{SO}_4^{2-}$  (5.4%) and  $\text{CO}_3^{2-}$  (2.8%).

#### Sodium, calcium, potassium and magnesium concentrations in the river salts

Results contained in Table II allow us to calculate the Na, Ca, K and Mg concentrations in the salts recovered from the evaporation of the river waters. For practical reasons, these measurements have not been performed directly, and Table V presents the results of the calculations made according to the following way: the element concentration in salt is equal to the ratio of element concentration in water and salt concentration in water. From the results contained in this table, it is evident that the salts dissolved in the river do not present the same composition for all the samples. From the standard deviation compared to the mean concentration (for all samples of river water), it may be seen that calcium (34%) and potassium (62%) concentrations vary much more than sodium (20%) and magnesium (14%) concentrations do. In a simple way, we may notice that the two

elements with highest concentrations in the salts vary less than those with lower concentrations. But this also shows clearly that sodium and magnesium concentrations do not vary so much as calcium and potassium do; these two elements, strongly involved in biological processes, present high variations in their concentrations. So it is possible to think that the surface water, even of underground origin during drought periods, bears the mark of the biological activity besides high concentrations, due at least to an important part of evaporation. In any case downward and upward movements of the water take place and its residence time in the underground water table is probably short. This is confirmed by the well known fact that, in these regions, pumping too much fresh water from wells turns the water salty within a few months.

#### Chemical weathering of rocks

The weathering rate of the rocks of the basin was determined bearing in mind two main purposes: first of all, the matter was to know if the high concentrations of salts in the surface waters were due to a strong dissolution of rocks; secondly, it was to know the value of the weathering rate of rocks in a region with hot climate and high frequency of drought.

We used the uranium method already used for another northeastern Brazilian basin (Moreira-Nordemann, 1980) and which gave very good results: uranium, used as a natural tracer, offers the advantage of not being present in rain water, turning the rain water contribution correction unnecessary, and so eliminating important causes of errors. Another advantage of this method is that, uranium being partially soluble (as the other elements are also) permits, through its radioactive natural properties, to determine a coefficient  $k$  of solution, which is characteristic of each region, once

it is obtained by measuring the activity ratio  $AR=U234/U238$  of the samples of the region.

The quantity of weathered matter  $W$ , per unit of area and per unit of time, may be determined as follows.

$$W = E_E D/E_R S, \quad (2)$$

and the mean thickness of weathered rock  $V$  per unit of time is

$$V = W/\rho k, \quad (3)$$

where  $E_E$  is the mean uranium concentration in the river water;  $D$  is the mean flow rate of the river;  $k$  is the solubility coefficient for uranium;  $E_R$  is the mean uranium concentration in rocks;  $\rho$  is the mean density of rocks (specific mass) and  $S$  is the area of the basin.

The coefficient  $k$  is determined by the formula:

$$k = (A_R - A_S)/(A_E - A_S), \quad (4)$$

where  $A_R$ ,  $A_E$  and  $A_S$  are the mean activity ratios  $U234/U238$  in rocks, waters and in weathered rock respectively.

Table VI shows the mean values obtained for the Salgado River basin, which were used to evaluate the weathering rate of rocks in the region. These values are also discussed in the appendix of this paper.

From these data and after applying the above formulas, we obtained a value of 0.02 mm/yr for the weathering rate in the Salgado River basin, which corresponds to 62 tons of soluble matter per year and per square kilometer.

This result shows clearly that the chemical weathering rate in the Salgado River regions is not very high, even being in a hot climate area. The value obtained corresponds to 60% of the value obtained (100 t/km<sup>2</sup>/yr) in the humid tropical climate region of the Preto River using the same

method (Moreira-Nordemann, 1980], and it is only slightly lower than the highest ones determined by Johnson et al. (1968), for the New-Hampshire region:  $80 \text{ t/km}^2/\text{yr}$  and  $77 \text{ t/km}^2/\text{yr}$  using calcium and sodium respectively, as natural tracers of the weathering process.

#### Solid load in the river

We performed these measurements of solid particles transported in the river water. The results of these measurements are given in Table VII and allow a comparison between solution and erosion of rocks in the region. Dissolved matter in river water seems to be much more important than the transported solid load coming from surface mechanical weathering. It must be said, however, that these measurements report only fine particles suspended in the river water, measured by decanting, filtering, drying and weighing. We did not consider big particles deposited at the bottom of the river bed, and we did not perform solid load measurements at various depths.

#### DISCUSSION

As seen before, the Salgado River waters are exceedingly rich in salts; the weathering rate of rocks, determined by the uranium method and equal to  $62 \text{ t/km}^2/\text{yr}$ , shows that the excess of salt in surface water is not due to a high dissolution of the rocks of the basin.

Measurements of concentrations in the river water show that chlorine is the most important anion whereas sodium is, between all cations, the one with the highest concentration.

Sodium is a very mobile cation, easily lixiviated and, for this reason, it has been widely used with good results, as a natural tracer for geochemical balance determinations (Johnson et al., 1968; Tardy, 1969;

Moreira-Nordemann, 1977]. So we can make an attempt to determine a geochemical balance and to estimate the excess of sodium liberated in the basin water. Admitting a mean value of 20% for the sodium concentration in dissolved salts (1.57 g/l), we obtain a concentration of 0.3 g/l of sodium in the water. Multiplying it by the mean flow rate of the river and dividing it by the basin area (Table VI) we obtain  $22 \text{ t/km}^2/\text{yr}$  for the sodium evacuated from the basin. Assuming a mean concentration of 3% for the sodium in the basin rocks (which corresponds to 3.96 of  $\text{Na}_2\text{O}$  in rocks as given in Table IV), and a solution rate of sodium from rocks of  $62 \text{ t/km}^2/\text{yr}$ , we see that the sodium contribution due to weathering is only 9% of the total sodium evacuated from the basin. Furthermore, assuming a mean value of 0.61 mg/l for sodium concentration in rain water (Table II), multiplying it by the total rainfall over the basin, and dividing it by the area of the basin (Table VI), we find that the atmospheric contribution in sodium is only 3% of the total sodium evacuated by the basin. Even taking into account the important evaporation in the region (the total rainfall over the basin represents 13 times the total flow of water from the basin), which implies a concentration of the elements present in the rainfall and liberated by rocks, we are obliged to conclude that another source of sodium exists in the basin.

In 1968, SUDENE (Superintendência do Desenvolvimento do Nordeste) performed a hidrogeologic study in a  $1800 \text{ km}^2$  zone (Anjos and Bastos, 1968) around the city of Feira de Santana, Bahia State (Fig. 1). The most important area of this region is covered by sandy-clay sediments laying over the crystalline shield, mainly made of gneiss, the rest being constituted of the crystalline shield itself outcropping. Chemical analyses of well water, lake river waters were made. Some of the results of this study are reproduced in Table VIII.



As the lower part of the Salgado River basin is included in this region, we may compare the results Anjos and Bastos (1968) obtained with those produced in this paper.

Measurements of salinity were made for 95 wells of the region. Among them, 53 (i.e., 56%) show salinity greater than 200 mg/l and, only 3 wells have a salinity lower than 100 mg/l. After Anjos and Bastos (1968), the salinity is higher when the wells are bored in the crystalline shield than when the water comes merely from sedimentary Barreiras formation aquifers.

We could also verify from the map showing the location of the wells (Anjos and Bastos, 1968) that among the wells with highest salinity, five ones are located close to the Pojuca River (18 FSA, 55 FSA, 70 FSA, 107 FSA and 77 FSA), which exhibits also high salt concentrations: 10.96 g/l according to the same authors' data. The 84 FSA well is located in the region of Jurema Lake and Ovo da Ema Lake, both of high salinity (518 mg/l and 1218 mg/l according the same study). The 107 FSA well is known as the source of São Julião mineral water.

As it was shown for the same region in a geochemical study of underground water (Cruz and Melo, 1968) the movement of water in near surface cracks and permeable medium, in relation with relief feature, plays an important role on the salinity of surface waters and their chemical composition.

From these measurements, we may see that not only the salinity is high, but also are the concentrations of  $\text{Na}^+$  and  $\text{Cl}^-$ ; this result has already been met in the whole Salgado River basin. In the same way, the ratio  $\text{Na/salts}$  varies between 0.11 and 0.28, whereas it varies from 0.13 and 0.24 for the Salgado River water.

The activity ratio  $U^{234}/U^{238}$  in the river waters varies only slightly (20%) in the samples taken (see Appendix A, Table IX), which indicate a relative homogeneousness of the waters when considering their origin, and characterize the waters from the hydrological point of view.

These results and the observations we shall emit about pluviometric conditions in the region lead to conclude that surface waters are fed, for the most important part of the time, by underground deposits of water. The evaporation existing at the surface lead to enhance this effect, in relation to the salinity of the waters.

Rainfalls in the region are truly abundant, given the fact that the mean over 50 years of measurements is 992 mm/yr. But what really characterizes drought is the irregularity of rainfalls versus times; during March 1969, the precipitation was 427 mm of water, of which 195 mm on the 7th and 119 mm on the 15th, which means that 74% of the mont rainfall precipitated only during two days. During November 1970, we may note that 210 mm of rainfall only in 5 days. The results are not rare but repeat frequently, especially during drought. Fig.3 shows us an example the levels of the rule used for flow measurements and the rainfall for February 1969. Fig. 4 shows the monthly measurements of the same data for 1967. The river response was quite quick; drought in the region does not mean absence of rainfall, but a great irregularity of its rate.

The rivers and lakes feedback in the region is mainly pluvial, during rainfall season; when it ceases, the surface waters level lowers quicker than that of underground waters, due to evaporation, and underground water table tends to support rivers and lakes.

Linked to these factors, other ones contribute to the ecological disequilibrium of the region: the absence of vegetal cover helps erosion, increases the albedo and, as a consequence of this, decreases the rain-

fall rate (Charney et al., 1975; Potter et al., 1975). The tillage used, with the custom of burning soils after the outcrop, leaving the bare soil till being sown after the first rainfall. Furthermore, tobacco, corn and manioc cultivation, with little or no fertilizer, makes the soil poorer and poorer in organic matter and in mineral elements. All these factors tend an already under-used and semi-arid region to turn into a desert area.

### CONCLUSIONS

The weathering rate of the rocks of the Salgado River basin is 0.02mm/yr (62 metric t/km<sup>2</sup>/yr), which shows that 50.000 yr are necessary to weather 1 m of rocks in present conditions.

The uranium method proved to be satisfactory to determine such weathering rates, even in regions presenting important geochemical problems.

The measurements of total salts dissolved in water have shown the high salinity of the waters of the basin. Sodium and chlorine are the elements with the highest concentrations in these waters. Superficial streams in the region are practically fed by underground water during long duration drought, and by rain water during rainfall periods. The high salt concentrations of underground waters, associated with the high evaporation and irregular rainfall rates, give rise to the high salinity of surface waters. Due to these factors, fresh water storage should be done in this region in underground waterproof tanks to prevent fresh water from being contaminated in salt and from being evaporated at the surface. More adequate tillage methods and convenient irrigation should be used in the region, to allow long term feasible agricultural exploitation.

## APPENDIX

Determination of the weathering rate of rocks by the uranium method. Measurements of uranium concentrations and activity ratio U234/U238 in waters, rocks and soils of the basin.

### Uranium in water

Table IX shows the uranium concentrations, activities ratios U234/U238, and the corresponding flow rates. It presents also the results for other surface waters of the basin already mentioned. The highest uranium concentrations correspond to the highest salinities. For the highest flows, it may be seen that uranium is diluted by rainwater, which is obvious, for it does not contain uranium.

The variation of the activity ratios U234/U238 is 18% for flows greater than  $0.02 \text{ m}^3/\text{s}$ . This little variation is an indication of the homogeneity of the water of the region. Generally, the ratio U234/U238 is controlled by the composition of the rocks run through by waters (Osmond et al. 1974).

The mean uranium concentration in water equal to  $1.45 \text{ } \mu\text{g/l}$  was determined by formula (1) given in the beginning of this paper. Also the measured ratio U234/U238 in waters equal to 1.44 (Table VI) was calculated using the same formula, substituting the concentration  $E_i$  by the ratios, for the various flow rates.

### Uranium in rocks

In the high basin the most abundant rocks are anatexic granites with low uranium concentrations and biotite gneisses with higher uranium concentrations. This part is the greatest and cover 49% of the total area of the basin. In the mean basin (35% of the total area), near the geological fault of the Recôncavo graben, cataclastic metamorphism

rocks are the most abundant. From the geological point of view this region is the most heterogenous. In the lower basin (16% of the total area) there are also gneisses, but also amphibolites and anatexic granites (granitoid gneisses).

As a whole, gneisses are the most abundant (75%). Then after come amphibolites and anatexic granites (19%), cataclasites and quartzites (5%). The uranium concentrations in rocks are variable for these reasons, due to the lithologic heterogenousness of the region. The uranium concentrations in rocks are function of the kind and the fraction of various minerals existing in the rock. Some accessory minerals like zircon, biotite hornblend, etc ... are richer in uranium than other essential ones like quartz and feldspars (Leonova e Tautson, 1958; LeVan Tiet, 1975; Moreira-Nordemann, 1977). The mean uranium concentration in unweathered rocks of the basin is 4.50  $\mu\text{g/g}$ , this value has been calculated taking into account the representativity of each kind of rock.

#### Uranium in weathered rocks and soils

The behaviour of uranium in weathered rocks (Table X) and in soil profiles (Table XI), as in the thinner one as in the thicker one, is the same as already studied in other soils (Pliler and Adams, 1962; Hansen and Stout, 1968; Moreira-Nordemann and Sieffermann, 1979). The uranium able to be freed seems to be lixiviated at the beginning of the weathering process, as seen when comparing its concentrations in weathered and in unweathered rocks. It is evident that soils are much richer in uranium than the corresponding mother-rock. This result suggests that uranium is "concentrated" in soils. However, high uranium concentration in upper horizons of soils profiles may be easily explained when one remembers that one gram of soil comes from several grams of rocks. The difference

of density between rock and soil may exceed 50%, which shows the importance of losses of matter during weathering processes.

To compare element concentrations in rocks and in soils, we must usually use isovolumetric analysis (Millot and Bonifas, 1955). In the Salgado River basin we may not apply isovolumetric analysis because the rocks structure is not maintained, i.e.: after the weathering process in the lower part of the profile, the residue does not occupy a volume equal to that of rocks from which it originated.

However, by chance, we can determine the coefficient  $k$  of solubility of uranium for the region (see formula (4) ), and to find the weathering rate of rocks in the basin.

The activity ratio  $U^{234}/U^{238}$  in rocks is always close to one, within the margin of error due to measurement uncertainties ( Table X). In weathered rocks and deep horizons of soils, the lower value  $A = 0.73$  (Tables X and XI) corresponds to the higher level of mobilizations of uranium 234.

For this region, the coefficient  $k$  we determined is equal to 0.38 (see Table V). So, only 38% of the uranium is dissolved from rocks during weathering processes.

Table XI also shows potassium concentrations in soils, as determined by gamma-ray spectrometry. These measurements were previously discussed in this paper.

#### ACKNOWLEDGMENTS

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- Table I : Total salts concentrations in the Salgado River waters, flow rate of the river and statistical weight ( $P_i$ ) of measured flows.
- Table II : Na, Ca, K, Mg and total salt concentrations in Salgado River basin waters.
- Table III: Na, Ca, K and Mg in rain water, at Serrinha, from April to December 1973, after A. Ribeiro Filho (1975)
- Table IV : Mean composition (%) of the rocks of Salgado River basin.
- Table V : Na, Ca, K and Mg in the Salgado River dissolved salts.
- Table VI : General data in Salgado River basin and mean values used to determine the weathering rate of rocks (other data given in the Appendix).
- Table VII: Solid load and total dissolved salts in 3 samples of river water.
- Table VIII: Total dissolved salts and  $\text{Na}^+$  and  $\text{Cl}^-$  concentrations in wells of the Feira de Santana area, after Anjos and Bastos, (1968).
- Table IX : Uranium concentrations and  $\text{U}^{234}/\text{U}^{238}$  ratios in river water.
- Table X : Location, petrography, uranium concentration and activity ratio  $\text{U}^{234}/\text{U}^{238}$  in the several kinds of weathered and un weathered rocks of the Salgado River basin.
- Table XI : Uranium and potassium concentrations and  $\text{U}^{234}/\text{U}^{238}$  ratios in 2 soils profiles of Salgado River basin. Profiles of different depths and in mean basin. Uranium measurements by alpha-ray spectrometry and potassium measurements by gamma-ray spectrometry.

TABLE I

Sample	Flow rate (m <sup>3</sup> /s)	P <sub>i</sub>	Salt concentration (g/l)	Data of sampling (1973)
S6	0.02	300	3.13	30/06
S21	0.05	453	2.97	05/12
S18	0.18	209	4.93	23/11
S12	0.28	137	10.38	14/09
S20	10.00	60	0.73	01/12
S2	<0.02	1155	4.17	26/04
S10	<0.02		12.49	29/08
S13	<0.02		9.56	30/09
S16	<0.02		3.13	08/11
S19	<0.02		3.90	28/11
S22	<0.02		6.33	15/12



TABLE II

Sample Number	Flow Rate (m <sup>3</sup> /s)	Total Salt Concentration (g/l)	Na (mg/l)	Ca (mg/l)	K (mg/l)	Mg (mg/l)	Date of sampling (1973)
S2	<0.02	4.17	950	340	75	220	26/04
S10	<0.02	12.49	2976	605	55	1020	29/08
S13	<0.02	9.56	1240	417	65	569	30/09
S16	<0.02	3.13	640	173	40	220	08/11
S19	<0.02	3.90	710	217	17	281	28/11
S12	0.28	10.38	2350	607	50	850	14/09
SALITO	lake	20.20	3850	1250	-	1520	27/10
TABOAS	tributary	15.6	4131	645	68	1337	21/11
High							
R.S.	Near the spring	10.5	2830	545	-	839	27/10
TIQUARUÇU	Mean basin	6.21	1130	480	55	420	26/04
TIQUARUÇU	Mean basin	4.38	-	-	-	-	08/04
SS3	Well	0.19	53	2.63	5.15	2.63	15/12
SS2	Pond	0.25	17.2	3.36	4.70	7.24	07/09
RAIN* WATER	Mean Value	-	0.61	0.19	0.09	0.10	From May 1972 to June 1974

\* After Ribeiro Filho (1975)

TABLE III

Sample Number	Volume of the sample (ℓ)	Concentrations (mg/ℓ)				Date of Sampling (1973)
		Na	Ca	K	Mg	
18	8.06	.69	.29	.12	.11	26.04 - 01.06
19	4.17	.32	.05	.05	.04	01.06 - 04.06
20	9.71	.61	.13	.07	.07	04.06 - 23.06
21	4.28	.05	.02	.04	.01	23.06 - 28.06
22	8.15	1.30	.19	.09	.17	28.06 - 03.08
23	4.46	1.43	.22	.06	.20	03.08 - 30.08
24	8.21	.98	.16	.11	.14	30.08 - 01.10
25	2.38	.27	.05	.05	.04	01.10 - 03.10
26	1.22	3.11	.96	.34	.43	- 02.11
27	9.70	.45	.21	.08	.09	- 29.11
28	2.04	.23	.21	.06	.05	- 30.11

TABLE IV

Oxide	Concentration (%)
SiO <sub>2</sub>	63.66
TiO <sub>2</sub>	0.71
Al <sub>2</sub> O <sub>3</sub>	14.31
Fe <sub>2</sub> O <sub>3</sub> §	6.58
MnO	0.04
MgO	2.59
CaO	5.07
Na <sub>2</sub> O	3.96
K <sub>2</sub> O	2.52
H <sub>2</sub> O	0.48
Total	99.92

§ Total iron expressed in Fe<sub>2</sub>O<sub>3</sub>

TABLE V

Sample Number	Salt Concentration (g/l)	Na (mg/g)	Ca (mg/g)	K (mg/g)	Mg (mg/g)
S2	4.2	228	82	18.0	53
S10	12.5	238	48	4.4	82
S13	9.6	130	44	6.8	60
S16	3.1	205	55	12.8	70
S19	3.9	182	56	4.4	72
S12	10.4	226	58	4.8	82
Mean $\pm$ Standard Deviation	7.3 $\pm$ 4.0	202 $\pm$ 40	57 $\pm$ 13	8.5 $\pm$ 5.6	70 $\pm$ 12
Salito	20.2	191	20	-	75
Táboas	15.6	265	41	4.4	86
High R.S.	10.5	270	52	-	80
Tiquaruçu	6.2	182	77	8.9	68
SS3	0.2	279	14	27.1	14
SS4	0.3	69	13	0.4	0.4

TABLE VI

Mean uranium content in river waters ( $E_E$ )	1.45 g/l
Mean uranium content in rocks ( $E_R$ )	4.50 g/l
Mean flow rate (D)	$5.05 \times 10^{10}$ l/yr
Surface of the basin (S)	$688.125 \text{ km}^2$
Coefficient of dissolution of uranium (k)	0.38
Mean U234/U238 activity ratio in waters ( $A_E$ )	1.44
Mean U234/U238 activity ratio in rocks ( $A_R$ )	1.00
Mean U234/U238 activity ratio in weathered rocks ( $A_S$ )	0.73
Mean density of the rocks ( $\rho$ )	$2.7 \text{ g/cm}^3$
Mean rain fall	$68,3 \times 10^{10}$ l/yr (992,5 mm/yr)

TABLE VII

Sample Number	Total salts concent- ration (mg/l)	Solid load (mg/l)	Flow rate (m <sup>3</sup> /s)
S20	730	95	10.0
S18	4930	440	0.18
S21	2970	453	0.05

TABLE VIII

Well	SALTS mg/ℓ	Na mg/ℓ	Cl mg/ℓ	Na/salts
1FSA	145.0	36.25	48.5	0.25
2FSA	121.0	25.05	29.0	0.21
3FSA	118.0	27.25	29.5	0.23
4FSA	128.0	27.55	36.5	0.22
6FSA	109.0	25.00	26.0	0.23
7FSA	136.0	27.50	28.0	0.20
8FSA	139.0	30.00	36.0	0.22
9FSA	243.0	27.50	23.0	0.11
10FSA	151.0	37.00	42.0	0.25
13FSA	138.0	25.75	21.0	0.19
13FSA	126.0	23.75	20.0	0.19
18FSA	730.0	227.50	360.0	0.31
24FSA	125.0	19.00	15.0	0.15
25FSA	123.0	34.00	33.0	0.28
27FSA	456.0	127.50	235.0	0.28
28FSA	123.0	34.00	33.0	0.28
34FSA	170.0	44.50	56.0	0.26
47FSA	160.0	34.00	60.0	0.21
55FSA	550.0	68.12	130.0	0.12
70FSA	1307.0	155.00	315.0	0.12
93FSA	145.0	22.75	35.0	0.16
107FSA	2748.0	210.00	1400.0	0.08
108FSA	137.0	36.25	55.0	0.26
109FSA	382.0	98.75	188.7	0.26
76FSA	695.0			
77FSA	3115.0			
84FSA	1356.0			
104FSA	940.0			
105FSA	985.0			
110FSA	3545.0			
111FSA	746.0			
112FSA	686.0			

TABLE IX

Sample	Flow rate (m <sup>3</sup> /s)	Pi	Salts (g / l)	Uranium* μg/l	U234/U238**	Date of sampling 1973
S6	0.02	300	3.13	6.80	1.41±0.02	30/06
S21	0.05	453	2.97	5.65	1.48±0.02	05/12
S18	0.18	209	4.93	7.44	1.45±0.02	23/11
S12	0.28	137	10.38	9.24	1.50±0.03	14/09
S20	10.00	60	0.73	0.36	1.53±0.03	01/12
S2	<0.02	1,155	4.17	4.60	1.37±0.04	26/04
S10	<0.02		12.49	7.30	1.51±0.02	29/08
Taboas	Tributary		15.60	13.61	1.47±0.02	21/11
High R.S.	Near the spring		10.5	15.90	1.42±0.02	27/10
Tiqua ruçu	Mean basin		6.21	6.50	1.45±0.03	26/04
Tiqua ruçu	Mean basin		4.38	6.53	1.47±0.03	08/04
SS3	Well		0.19	0.14	1.53±0.03	15/12
SS2	Pound		0.25	0.57	1.06±0.05	07/09
Sali to	Lake		20.20	12.37	1.54±0.02	27/10

\* Uncertainty ± 5% corresponding to 1σ .

\*\* Uncertainty corresponding to 1σ .



TABLE X

Sample Number	Location	Petrography	U* (pg/g)	** U234/U238
RS13	Mean basin	Augen gneiss	1.72	0.96 ± 0.01
RS13A	Mean basin	idem, weathered	1.92	0.97 ± 0.03
RS10	Mean and higher basin	Biotite gneiss	2.50	1.00 ± 0.01
RS10A	Mean and higher basin	idem, weathered	2.73	1.00 ± 0.02
RS2	Lower basin	Augen gneiss with hornblend	7.89	0.98 ± 0.03
RS2A	Lower basin	idem, weathered	6.05	0.73 ± 0.02
RS12	Mean basin	Biotite quartzite	1.92	1.02 ± 0.04
RS12A	Mean basin	idem, weathered	1.88	0.82 ± 0.05
RS11	Mean basin	Augen gneiss	5.86	1.01 ± 0.01
RS11A	Mean basin	idem, weathered	2.32	0.73 ± 0.03
RS4	Lower basin	Granitoid gneiss	0.80	1.02 ± 0.01
RS7	Lower basin	Amphibolite	2.63	0.99 ± 0.02
RS15	Mean basin	Cataclasite	0.70	0.97 ± 0.04
RS25	Higher basin	Biotite gneiss without muscovite	2.30	0.97 ± 0.02
RS33	Higher basin	Granitoid gneiss	0.78	1.00 ± 0.03

\* UNCERTAINTY ± 5% CORRESPONDING TO 1  $\sigma$

\*\* UNCERTAINTY CORRESPONDING TO 1  $\sigma$

TABLE XI

Sample	Depth (cm)	U* ( $\mu\text{g/g}$ )	U234/ U238 **	K ** (%)
RS16	0 - 20	3.06	$0.78 \pm 0.06$	$2.6 \pm 0.3$
RS17	20 - 40	3.82	$0.81 \pm 0.04$	$4.0 \pm 0.4$
RS18	40	3.32	$0.85 \pm 0.02$	$4.1 \pm 0.4$
RS11A	Weathered rock	2.32	$0.73 \pm 0.03$	$4.2 \pm 0.4$
RS11	bed rock	5.86	$1.01 \pm 0.01$	$4.2 \pm 0.4$
RS20	0 -100	2.53	$1.03 \pm 0.02$	$1.3 \pm 0.2$
RS21	100 -130	1.79	$1.00 \pm 0.05$	$1.3 \pm 0.2$
RS22	130 -190	3.31	$0.91 \pm 0.06$	$1.2 \pm 0.2$
RS23	190 -220	2.66	$0.95 \pm 0.03$	$1.1 \pm 0.2$
RS24	220 -240	2.70	$0.89 \pm 0.02$	$1.1 \pm 0.2$
RS12A	Weathered rock	1.88	$0.82 \pm 0.05$	$2.3 \pm 0.3$
RS12	bed rock	1.92	$1.02 \pm 0.04$	$2.2 \pm 0.2$
Clay from RS16 sample		1.51	$0.84 \pm 0.03$	-
Clay from RS17 sample		1.67	$0.92 \pm 0.02$	-

\* Uncertainty 5% corresponding to  $1\sigma$ .

\*\* Uncertainty corresponding to  $1\sigma$ .

# FIGURES CAPTIONS

Fig. 1 - Geochemical situation of the Salgado River basin

Fig. 2 - Detailed map of the Salgado River basin

Fig. 3 - Flow rate of Salgado River (expressed in height of the water level on the vertical rule at the point of measurement, Mocambinho) and rainfall (mm) at Irarã, during February 1969

—— rainfall

---- flow rate

Fig. 4 - Mean monthly rainfall and flow rate for the Salgado River basin during 1967, in the same units as in Fig. 3.

—— rainfall

---- flow rate

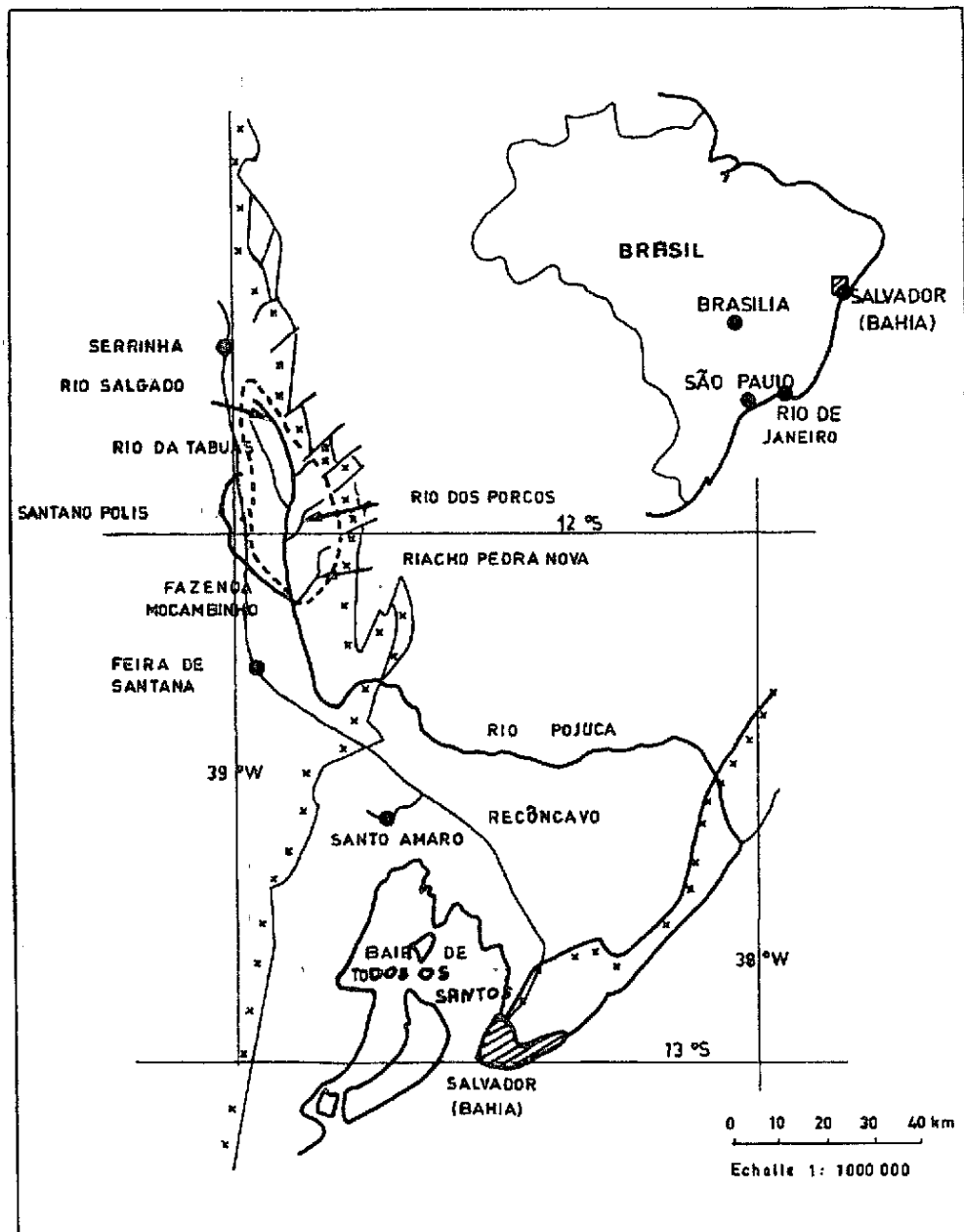


FIG. 1

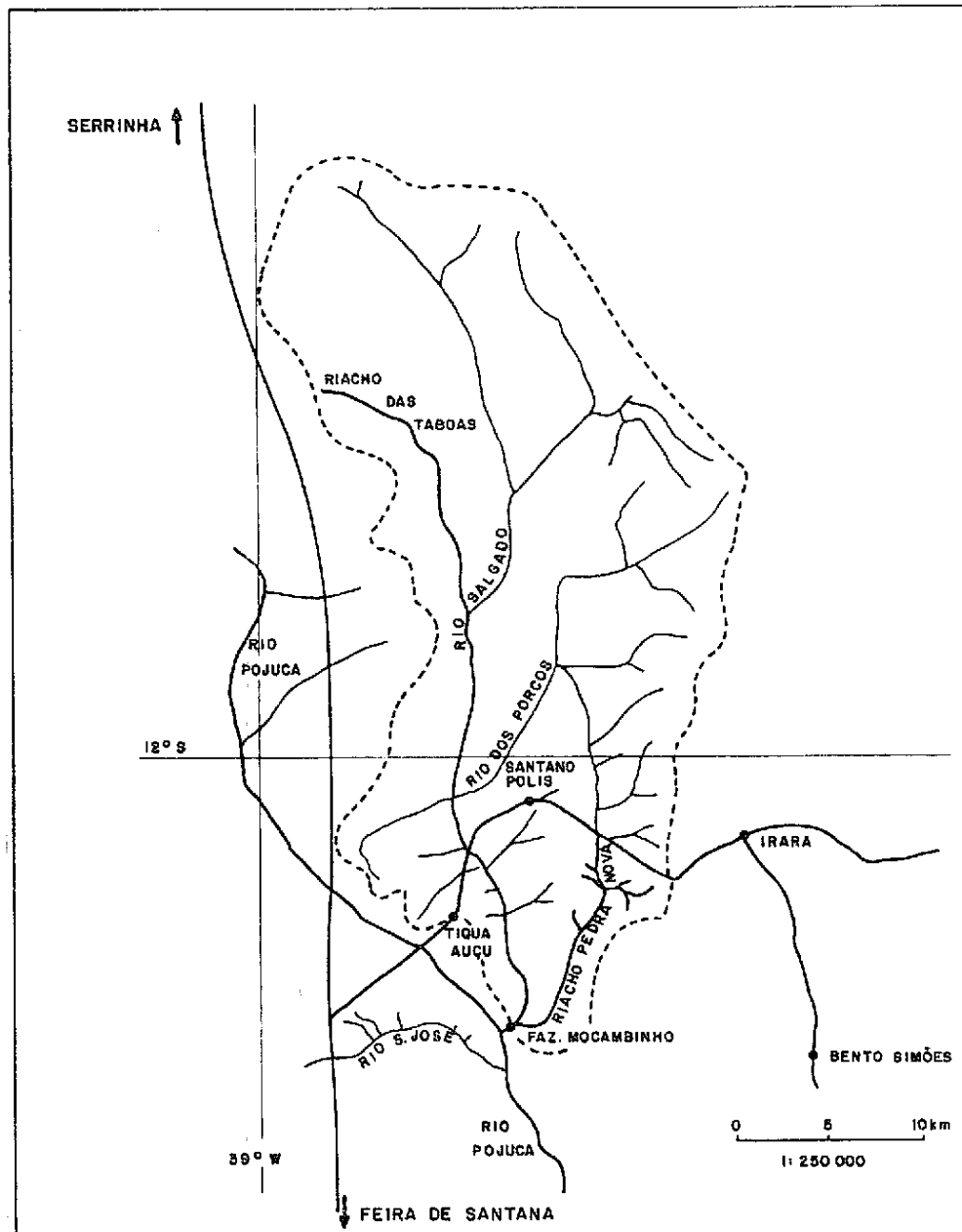


FIG. 2

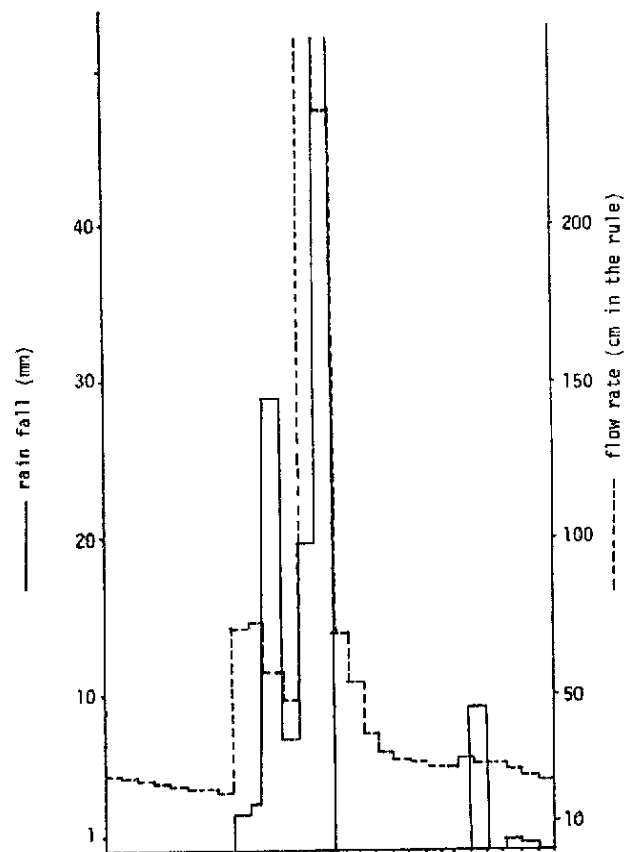


FIG. 3

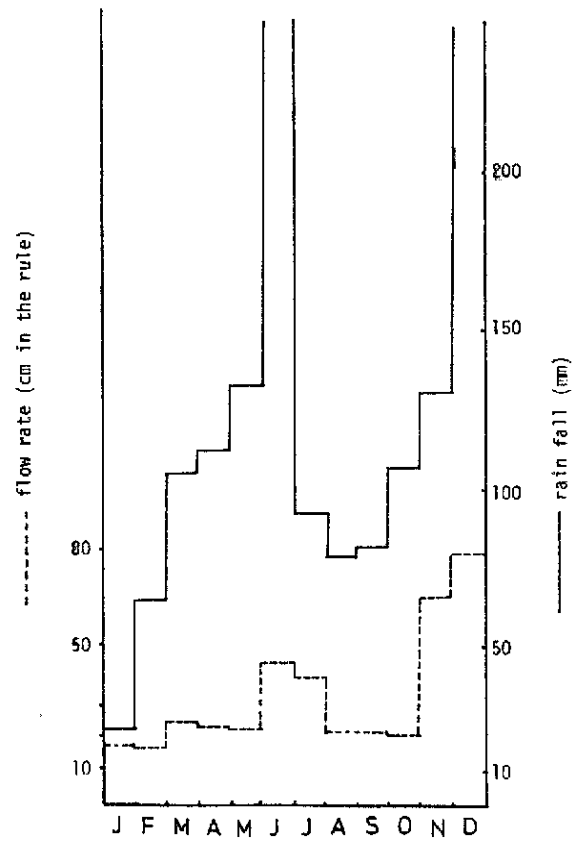


FIG. 4

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