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Caldas Novas hot springs, State of Goiás

Remarkable occurrence of thermal waters
not related to magmatism

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The thermal waters of the southern Goiás State region represents one of the largest occurrences of hot groundwater without association with volcanism or other magmatism phenomenon. The heating is processed by geothermic energy, represented by the temperature rising with the gradual increasing of depth. In such way, the rainwaters infiltrate through the soil and through faulted and fractured rocks, reach up to 1,000 meters depths and get temperatures at least 50ºC higher than the annual average at the surface. After heated the waters migrate towards surface by fractures systems forming thermal springs (as exemplified by the Quente river springs). The chemical composition of the waters, the types of rocks, the relief pattern and the groundwater flow systems allow to distinguish three aquifers systems in the area: Porous Aquifer, Araxá Aquifer System and Paranoá Aquifer System. The chemical composition of the waters and the groundwater flow patterns show that there is a mixture of waters from several aquifers systems. In the last decades, the water levels of the thermal aquifer systems were submitted to fast lowering due to the overexploitation by tubular wells. The maintenance of the groundwater reservoirs requests management practices, including limitation of pumping rates, researches on environmental purposes to aim basic information for the general public, projects for artificial recharge of the aquifers and some others.
Keywords: Thermal water, aquifers, recharge, Caldas Novas.

INTRODUCTION

This contribution shows the results of the geological mapping of the Caldas Novas thermal waters region in the State of Goiás, Brazil, and includes data obtained on academic works with students of the University of Brasilia and the Technical University of Berlin.

The area is located in the southeast of Goiás State, including the city of Caldas Novas and the neighborhood of the Caldas Ridge (Fig. 1). The Pousada do Rio Quente Resort, with several hot springs (Fig. 2) and the Água Quente little town, both in the west flank of the mountain, the state highways GO213 (to the north), GO139 (to the east) and GO507 (to the west) can be mentioned as local geographical references. The accesses starting from Brasilia and Goiânia are made by federal and state highways, according to the map of the Fig. 3.

The area considered for the present study includes the Dome of Caldas and the adjacent lowlands. The Dome of Caldas, also called by Caldas Ridge or the Structural Dome of Caldas, is an isolated topographical elevation in the southeast Goiás State region, which reaches altitude up to 1,000 meters, although regional topography is about 600 meters.

The objective of this work is to present the area of the thermal waters of the state of Goiás as a Hydrogeological Site of central Brazil, which is very important to be preserved.

The Caldas Novas region represents one of the largest occurrences of thermal water in the world not associated to magmatism. The mechanism of heating of the waters is still unknown by the great public and many believe that the waters are warmed due to interaction with a volcano or due to the contact with igneous rocks in depth.

Hot waters are important for the local economy, once they feed the high tourist potential in the form of hotels and resorts. The increasing of the exploration of those waters has caused the dropping of the groundwater levels, leading to the springs dryness and risk of an economical collapse. Recently, the drilling of new deep wells is being controlled and initiatives for management of the aquifers are been programmed.

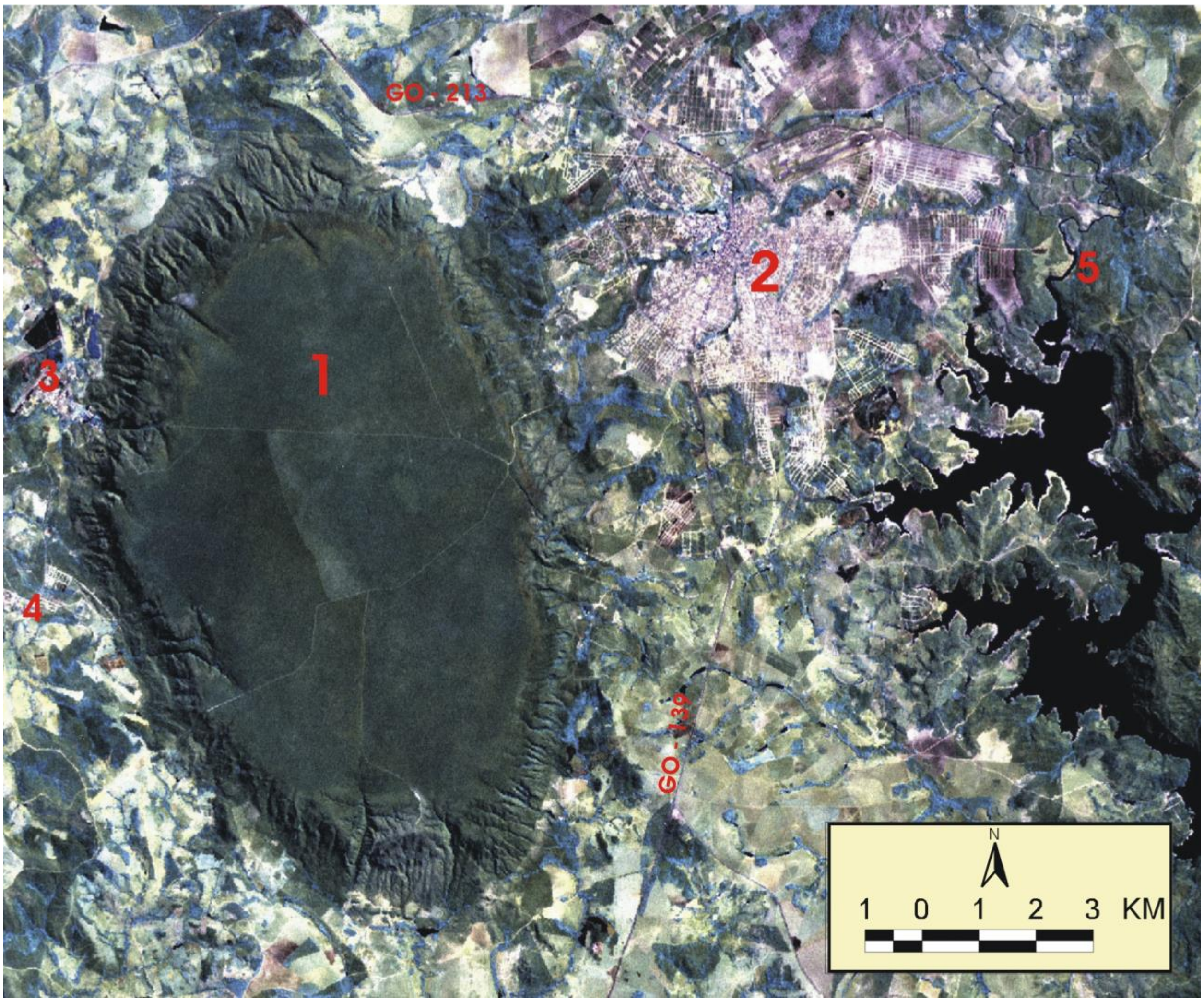


Figure 1 – Satellite image (RGB 345 from June 2001), showing the main geographical references of the region: 1 Caldas Ridge, 2 – Caldas Novas Town, 3 – Rio Quente Resort, 4 – Rio Quente Town and 5 – Corumbá Dam.

Figure 2 – Thermal spring observed in open fracture developed on massive quartzite.

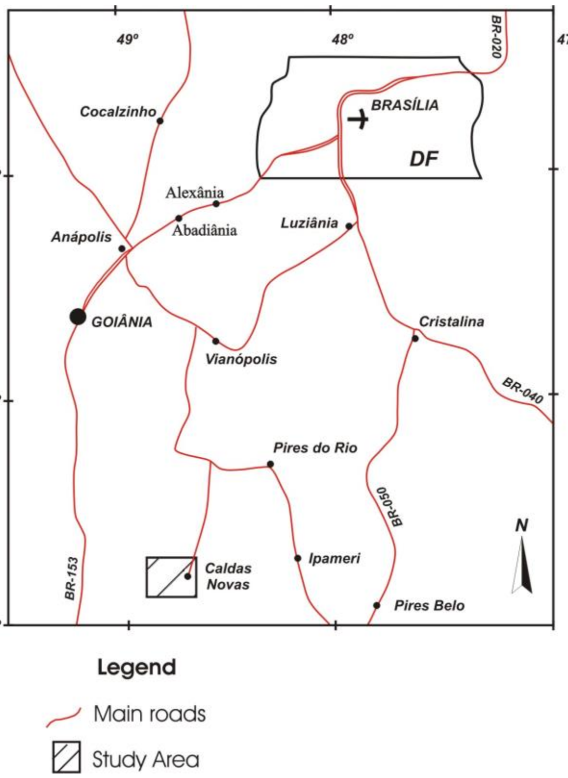


Figure 3 – Location map of the site.

SITE DESCRIPTION

Geology

In the area of Caldas Novas there are rocks correlated to the Paranoá and Araxá groups, and subordinated occurrences of conglomerate attributed to the Abaeté Group (Fig. 4).

PARANOÁ GROUP - MESO/NEOPROTEROZOIC

In the Dome of Caldas the Paranoá Group was divided in four lithostratigraphic units, from the base to the top: Ortoquartzite, Clay Quartzite, Metarrithmite and Pelitic-Carbonated Unit.

Ortoquartzite - composed essentially by white fine to medium quartzite, intensely silicified and usually intensely fractured, that outcrops in great rocky pavements. This unit is just exposed along the borders of the range, once at the center of the plateau a thick soil covers the rocks. The continuity of this unit towards the central portion of the Dome is based on data from five piezometers installed along the east-west road.

Microscopic analyses of these rocks show the presence of rounded and angular grains arranged in tangential contacts, showing modifications in function of tectonic superimposed events. Quartz grains varies from 0.2 to 1.3 mm sizes, and they are commonly recovered by a film of iron oxides and clay minerals. Rare feldspar grains are observed, usually intensely altered (transformed in a mass of white fine mica).

Some samples are intensely crystallized, showing interpenetrating grains and multiple junctions of grains, due to the fact that low-grade metamorphism has obliterated the primary features.

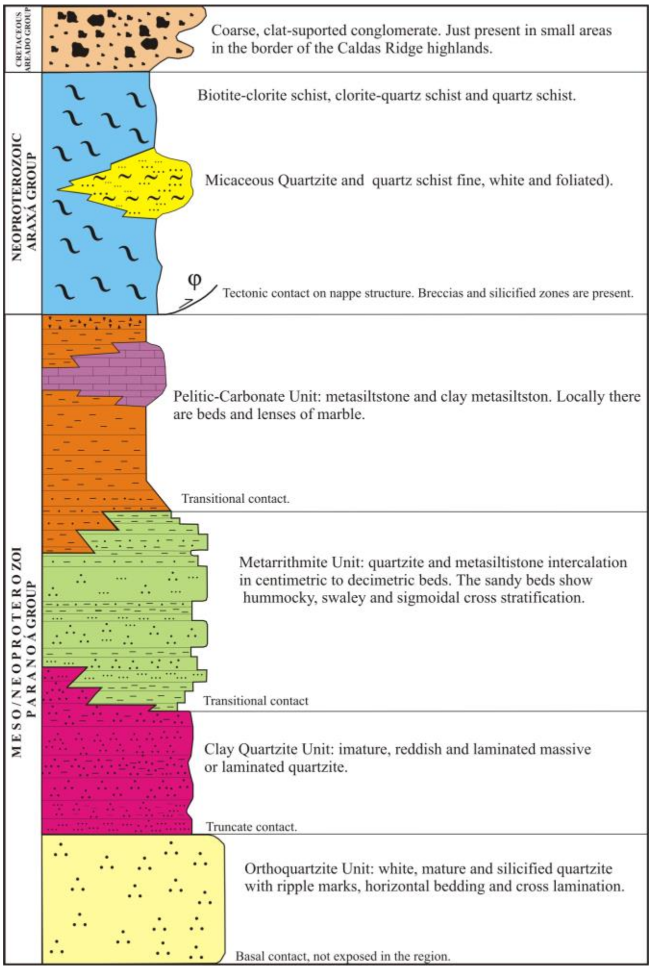


Figure 4 – Stratigraphy of the thermal water region in the southern portion of Goiás State, Brazil.

The intense silicification is responsible for the partial elimination of the sedimentary structures. However, it is still possible to observe the presence of symmetrical and asymmetrical ripple marks, crossed laminations, crossed bedding, horizontal bedding and mud flakes towards the top. The high textural and mineralogical maturity, allied to the lithologic homogeneity and the sedimentary structures allow to interpret this unit in a shallow marine waters depositional context, probably dominated by waves (typical tidal structures have not been found yet), which promoted the reworking responsible to the mineralogical and textural maturity.

Clay Quartzite - it is represented by fine clay bearing quartzite, reddish and mineralogically immature, locally substituted by laminated pelitic bedding. The silicification is variable, from absent to intense. The characteristic red color observed in outcrops is not considered as a primary color, once it is related to the oxidation of the clorite. The maximum thickness of this unit is 80 meters, however lateral variation of facies is responsible for the total absence of this unit in the northeast portion of the dome.

The observed sedimentary structures are horizontal lamination, crossed and wavy bedding.

Metarrithmite - it is characterized by a sequence of fine to medium quartzite, feldspar rich, white and pink, intercalated by levels of pelitic material (metasiltstone), frequently rich in white detrital mica. In the Rio Quente Resort area this unit is especially well exposed on natural slopes or artificial cuts, thick successions of this unit can be found.

Quartzite layers and banks present sedimentary structures such are: hummocky cross stratification, sigmoidal bedding, wavy marks, horizontal lamination, small crossed bedding, climbing ripples, and frequently layers with plane base and wavy top.

Microscope observation shows that the quartzite levels are represented by impure sandstone with up to 25% of feldspar and lithic fragments, badly sorted.

This unit was deposited on an open continental shelf environment dominated by storm episodes, charactering deposition under traction and suspension processes.

Pelitic-carbonated Unit - it corresponds to the upper succession of the Paranoá Group in the area. It is composed by a thick sequence of massive to laminated metasiltstone. The main structures observed in this unit are horizontal lamination and bedding. The red coloration is typical of this unit, which includes facies with pink, reddish to white tones.

There are fine marbles with sacaroidal texture, banded and rich in fin, prismatic mafic minerals that occur as restricted lenses. These marbles are white to pink, and always present small biotite crystals and isolated turmaline in the crystalline carbonate mass. The turmaline grains are scattered and they happen in lower frequency.

The presence of biotite associated to the marbles in the area does not mean that the Paranoá Group was submitted to regional metamorphism conditions of the biotite zone. It seems that it occurred just locally, close to the tectonic contact between the Pelitic-Carbonated Unit and the Araxá Group. In this situation, as these rocks are more reagent, local higher pressure and temperature conditions caused the crystallization of the biotite. In the remaining parts of the Paranoá Group stratigraphy, the mineralogy indicates low metamorphic grade conditions, close to the limit of the clorite zone diagenesis.

Through deep wells drills in the surrounding of the Caldas Novas city, it was possible to identify facies of marbles up to 100 meters thickness.

Breccia - A tectonic breccia lies on the top of the mable unit. Two thin sections of breccias were analyzed, one sample of surface and another collected from the drilling of a tubular well. Both show the same general characteristics, presenting badly sorted angular fragments (from a few millimeters up to 3 cm), of variable nature (mainly quartzite, metasiltstone and quartz) and intensely silicified. The largest difference between them is the fact that the samples collected at surface present silica and oxide cement, while the subsurface sample contains carbonate and oxide, besides subordinated silica cement.

In weathered outcrops, the alteration pattern shows boxwork textures that suggest probable sulfetation. This rock type materializes the plan of the regional thrust in which the Araxá Group slips over the Paranoá Group sequence.This rock type is locally substituted by quartz veins, intensely fractured or even by pelitic silicified rocks.

ARAXÁ GROUP – NEOPROTEROZOIC

It corresponds to the whole area distributed at the neighborhood of the Caldas Range. The outstanding highlands, present in the regional landscape (like the Matinha Ridge), also belong to this unit. It is represented by monotonous sequences of greenschist facies, including muscovite-quartz-biotite schist, muscovite-biotite schist and muscovite-biotite-garnet schist. The muscovite and the biotite bearing schists are the most common types, which show lepidoblastic texture. The garnet bearing types show snowball texture.

The foliation attitude of these schists is variable, in direction and dipping values. It suggests that the folding occurred after the displacement of the schist mass over the Paranoá Group.

Associated to schists there are also quartzite, micaceous quartzite and quartz schist, probably characterizing sandstone and impure sandstone. These quartzites are foliated and present a stronger fracturing pattern than that observed in schists.

Microscope observation shows that this unit presents typical mineral association of the greenschist facies in the clorite zone. The garnet observed is not stable, but is transformed to clorite by hydration, what indicates that this mineral is not part of the metamorphic paragenesis so that it is not in equilibrium with the pressure, temperature and fluids activity conditions.

Minerals from the epidote group, titanite, oxide and the zircon are the most common accessories found in all schist facies.

In association with schists and quartzites there are, in restricted areas, strips of metaultramafic rocks (tremolite schist and clorite-talc schist) and rock types interpreted as metavolcanic acid rocks of dacitic composition (Campos & Costa 1980 and Drake Jr. 1980).

AREADO GROUP, ABAETÉ FORMATION - LOWER CRETACEOUS

Locally, along the east and west borders of the plateau that composes the top of the Dome of Caldas, there is a conglomerate interpreted as the Abaeté Formation (Areado Group) of Cretaceous age. This correlation is based on:

- the lithologic similarity of the conglomerate at the high topographical position, as in the other areas out of the Sanfranciscana Basin, where this unit was defined (e.x. Água Fria Range/Minas Gerais State – Penha *et al.* 1998, Federal District - Campos *et al.* 1999, Bonfinópolis/MG - Barbosa 1997, and other occurrences);
- the presence of ventifacts (similar to that in the areas of the basin);
- the pattern of the outcrops;
- the same depositional system related to the sedimentation;
- the same topographical level in which these sediments are regionally distributed;
- the similarity of the content of heavy minerals (turmaline, zircon, garnet, opaque and metamorphic minerals).

The grain size of the conglomerate varies from fine to very fine, being commonly clast-supported and locally matrix-supported. Quartzite and quartz pebbles vary from badly to well sorted, and locally exhibit silica cements associated to iron oxide (amorphous silica in brown tones). These cements are represented by amorphous silica, fibrous silica and grains overgrowths, representing cements of precocious type, typical of red bed. The microscopic features of these cements, present in fine conglomerates, suggest that the climate to the time of the deposition was arid to semi-arid.

This unit shows paleogeography importance, once it is associated to the Gondwan regional surface, preserved in tectonic depressions controlled by small reject faults. This control type was already described by Campos *et al.* (1999), to explain the presence of the Abaeté Formation in the Federal District region, and by Barbosa (1997), who studied the Cretaceous conglomerate in the region of Bonfinópolis de Minas.

Deformational Context

Two tectonic events were responsible for the structuring and for the geomorphological aspect observed in the region. The two tectonic stiles can be related to the forming tectonic, of ductile-brittle nature attributed to the Brazilian Cycle and the modifier tectonic, of brittle nature related to the reactivation of the South American Platform. In the study area there were identified four families of planar and linear structures, which present a genetic relationship, developed during the first event. The second event was not responsible for the generation of structures, but just for the reactivation of planar structures previously generated.

The deformational events are separated by a great time interval and will be refereed as the E1 Event (Brazilian Cycle developed at the end of Neoproterozoic) and E2 Event (Waldenian Reactivation developed in the Cretaceous). The E1 Event holds four progressive deformational phases that can be partially synchronous (P1, P2, P3 and P4), while the E2 Event is considered as developed for a single phase (F5).

The structural elements are mostly concordant with a compressional EW deformation, towards the São Francisco Craton. The equatorial strain is responsible to the development of the asymmetrical dome (Fig. 5).

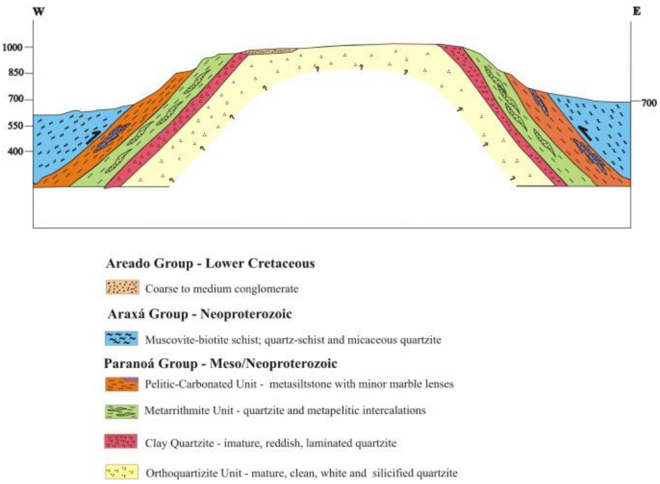


Figure 5 – Schematic geologic east-west cross section of the central portion of the Caldas Range.

The analysis of mineral lineation data shows that the Dome was structured after the tectonic placement of the Araxá Group over the Paranoá Group. The comparison with the Federal District region indicates that the Dome of Brasilia was already structured in the braquianticlinal style, when the Araxá Group thrust over the Paranoá Group. The basic difference is that the mineral lineation in the Caldas Novas region shows a centrifugal pattern, while in the Federal District the lineation present constant attitude, about the azimuth 270º (Freitas-Silva & Campos 1998).

The thickening of the Paranoá Group sedimentary stratigraphy, which could control the crustal uplift and the flexural accommodation of residual stress, might have influenced the behavior of the ductile-brittle deformation in the area. It is important to point out that *bouguer* anomalies (geophysical data) suggest that the Paranoá Group in the area should present thickness up to 1,000 meters (Haralyi & Hasui 1982).

The geological evolution of the area can be synthesized by the following historical moments:

- deposition of a thick sedimentary column in the Paranoá Basin, Mesoproterozoic to Neoproterozoic;
- deposition of the Araxá Group in more internal portions of the Brasilia Fold Belt, under continental shelf conditions, with turbidites associations of deeper waters, in Neoproterozoic;
- metamorphism of the Araxá Group and development of the nappe that puts this unit over the Paranoá Group, and structuring of the NW/SE axis of the Dome of Caldas during the Brazilian Cycle;
- uplift of the dome with the structuring of the EW axis and centrifugal pattern of the mineral lineation, in late stages of the Brazilian Cycle;
- fracturing/folding of the whole region (Araxá and Paranoá groups) in the Brazilian Orogeny final stages;
- normal reactivation of the planar structures by extensive tectonics, forming small rejects faults and enlarging the opening of existent fractures, during the Cretaceous;
- erosion of the schist, during the Cenozoic, and denudation of the region with the maintenance of the most resistant rocks (Paranoá Group), resulting in the relief observed at present.

Hydrogeology

This item intends to present the general aspects of the hydrogeology of the of Caldas Novas region, including the aquifers classification, the main water chemistry, the cause of the hydrothermalism and the main patterns of groundwater flow regimes.

In spite of the importance of the groundwater for the Caldas Novas region, that represents one of the largest occurrences of thermal waters of the world, there are few consistent studies on the aquifers classification and the causes of the hydrothermalism. Among the existent studies, can be mentioned: Campos & Costa (1980), Tröger *et al.* (1999), Haesbaert & Costa (2000) and Zschocke (2000), besides several technical reports.

AQUIFERS CLASSIFICATION

Based on chemical variations, conditions of circulation, temperature variation and rock types, three aquifers groups were generically defined as: Porous, Paranoá and Araxá Systems.

Porous Aquifer System

It corresponds to the so-called unconfined aquifers of Tröger *et al.* (2000). These aquifers are shallow and laterally continuous, of wide extension with saturated zone thickness very variable, and they show great hydrogeologic local importance. These aquifers carry out three important functions in the area, since they work as filters, favor the recharge of the deeper aquifers and regularize the base flow of the superficial streams in the periods of precipitation recession.

This system is divided in two different subsystems denominated P_I and P_{II}. The classification was based on physical characteristics of the soil coverage, including texture, thickness, lateral variation and associated geomorphological pattern relief. The P_I Subsystem is limited to the plateau of the Caldas Ridge, represented by the quartzite regolith with thickness varying from some meters to 64 meters. This coverage, composed by soils and saprolite, presents very high hydraulic conductivity values (varying from 10^{-5} to 10^{-4} m/s) as function of the sandy origin of the material, classified as latossoil with medium to sandy texture.

The relationship between the physical characteristics and the plan relief pattern with altitude up to 1,000 meters results in a situation of very efficient regional recharge. In this context, the volume of water kept by infiltration is very high, what limits the overland flow in the periods of maximum precipitation. As this subsystem presents great conductivity, it drains quickly by vertical leakage, and consequently the vadose zone is very thick and saturated zone is limited to the rock top.

The P_{II} Subsystem is represented by cambisoil in the border of the Caldas Range and by the clay soils derived from schist of the Araxá Group. In this case, the aquifers thickness and values of hydraulic conductivity are significantly lower than the P_I Subsystem. The relief in that area shows a pattern that limits the natural recharge by infiltration of rainwaters.

As the P_I Subsystem, P_{II} waters show very deep static levels and are placed in area of environmental preservation (Caldas Novas State Park), and are not exploited for any use. The P_{II} Subsystem is exploited from dug wells, either in rural areas or in the neighborhoods of the Caldas Novas city.

Cold waters characterize the porous aquifers, with temperatures close to the local annual averages and by low mineralization. The time of contact between the rainwaters and the geological material (soil or weathered rock) is restricted, what reduces the total amount of dissolved salts. The discharge of these aquifers is processed by small contact or depression springs and by the drainage into the underlying fractured aquifers.

Paranoá Aquifer System

This system is represented by free or confined, cold or hot waters, anisotropy and heterogeneous aquifers, where the laterally extension are controlled by the main regional lineaments. The Paranoá System is classified as a free aquifer where the areas of fractures are associated to rock outcrops of the Paranoá Group. In the Caldas Novas region it corresponds to the Dome of Caldas. On the other hand, when schist of the Araxá Group covers the fractured/fissured areas, these aquifers are classified as confined, and the schist is considered the confining aquitard. The Araxá Group can be considered as the confining layer, because even it is fractured, the density and the opening of the fractures are smaller than those observed in the Paranoá Group rocks. This feature is exclusively defined as function of the reology constrain of the rock types of two litostratigraphic units.

In the same way, the Paranoá System can be divided in cold and thermal aquifers. The first case is related to the fractured areas with descending water flow in depths up to 400 meters. Usually this situation is associated to the portions where the aquifers are classified as unconfined. The Paranoá Aquifer System should be considered thermal when it is associated to conditions of descending flows in depths deeper than 450 meters, or in any depth, when it maintains the ascending flow starting from open fractures in great depths.

These aquifers are related to low mineralized waters, and, when thermal, the total dissolved solids can reach higher values when compared to the cold correspondent waters.

The Cold Paranoá Aquifer has its natural discharge controlled by fractured springs. In the Thermal Paranoá Aquifer the discharge is also represented by fractured springs, as well as by the Hot River and the water exploitation through tubular wells in operation in the area of Caldas Novas City (artificial discharge).

The recharge of this aquifer system processes mainly by infiltration on the plateau of the Caldas Range by leakage of the Porous P_I Subsystem and secondarily, by the infiltration of waters of the P_{II} Porous Subsystem.

In a general way, the Paranoá System Aquifer presents excellent conditions of circulation and high values of hydraulic conductivity and transmissivity, however these values are strongly anisotropic. These high values of dimensional parameters are due to the fact that the area of Caldas Novas was submitted to neotectonic processes related to the drift phase of the South-Atlantic evolution. In the area of Caldas Novas there are wells deeper than 900 meters with significant thermal waters entrances (temperatures to 55^o C).

Araxá Aquifer System

This system is represented by fractured, free, very heterogeneous and anisotropic cold or thermal aquifers, with restricted lateral extension controlled by the distribution of fractured areas.

The aquifers classified as cold are those whose fractured zone are recharged directly by the infiltration of rainwaters beginning from the Porous P_{II} Subsystem. In this case, it is considered the first hundreds meters of the schist column.

The deeper fractured zones, next to the tectonic contact among the Araxá and Paranoá groups and eventually, the larger fractured zones in smaller depths, compose the Thermal Araxá Aquifer of the Caldas Novas region. Ascending flow from the hot waters of the Paranoá Thermal Aquifer processes the recharge of these aquifers.

In the confinement conditions, the fractured zones that represent the Thermal Paranoá Aquifer System present high potenciometric head, once the recharge area is placed in high topography region (up to 1,000 meters). Because of this, when the warm waters find open fractures in the schist, they ascend and are mixed with the cold waters of the Araxá Aquifer, composing a group of hot waters, with intermediate temperatures between the Paranoá Thermal Aquifer waters and the Cold Araxá Aquifer waters.

The discharge of the Araxá Aquifer System (thermal and cold) is represented by the old thermal springs of the Caldas Novas region and the cold-water fracture springs, dispersed in the area. The tubular wells of the Caldas Novas area are artificial discharges of these aquifers.

According to the adopted model, the depth that separates the Araxá cold and thermal aquifers is very variable, and depends just on the opening of the fractures in the schists, which favor the ascent of the Thermal Paranoá Aquifer waters. Because of this, there are relatively shallow wells (with depths of few hundreds of meters) that provide hot waters and there are deeper wells, where hot waters are absent.

In chemical terms, these waters are the most mineralized in the area, what is direct related to the higher reactivity of the schist in comparison with the quartzite and pelitic rocks of the Paranoá Group. Schists present biotite, mucovite, clorite and carbonate, all of them reactive and soluble minerals.

Because of the few reliable data, the dimensional parameters for the Araxá Aquifer were not treated quantitatively. However, by analogy, with the values obtained for the Federal District area (Campos & Freitas-Silva 1998), these values are significantly smaller than those attributed to the Paranoá Aquifer System. This feature is owed to two factors: 1) the ductile behavior of the schist, which presents plastic character, with the fracturing closing in increasing depth, and 2) low angle of the foliation attitude, what difficult the infiltration of the waters from the Porous P_{II} System.

GROUNDWATER CIRCULATION PATTERN

The groundwater circulation pattern, here proposed, should be considered as preliminary, once it would be necessary a larger amount of data for its refinement. Among the principal data for definition of a more consistent model, those are important:

1) hydrologic information, main values of flows of the superficial streams;

2) ages of cold and thermal waters,

3) information on the local water budget, and

4) direct and indirect subsurface data (geophysical,) focusing to delimitate the main fractured areas at the plateau of the Caldas Ridge.

The Caldas Ridge carries out extreme importance to the thermal waters, because it is in the area that the largest volume of recharge of the hot waters is processed. That area is important to the Paranoá Aquifer, as well as to the Araxá Aquifer (by mixture). In this way the circulation model, that includes local and regional flow systems pattern, will be represented based on the tectonic outline of the plateau and on the data of the five piezometers located in the central portion of the Caldas Ridge.

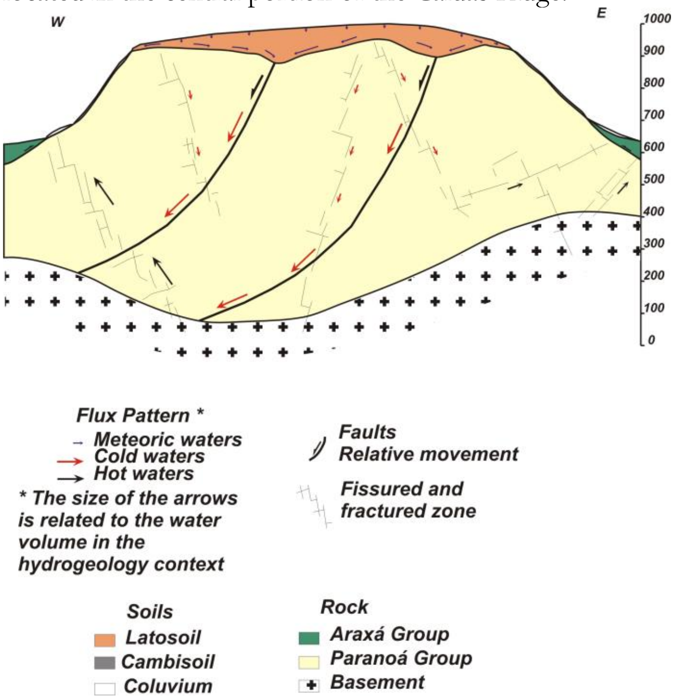


Figure 6 – Schematic section showing the hydrogeologic flow pattern present in the region of thermal waters of the southern portion of Goiás State.

As it can be evaluated by the regional lineaments that cross the Caldas Ridge, and by the breaches observed in subvertical flow plain, the mountain is split up by structures that present wide opening and vertical continuity. Under these structures (cataclastic areas related to Brazilian and/or Cretaceous faults) there is a strong decreasing of the potenciometric surface related to the Porous P_I Aquifer System, which is interpreted as a "natural depression cone", resulting from the efficient drainage of the shallow waters by local hydrogeologic flow systems.

Considering a geothermic degree of 30^{o}C for kilometer, which means an increase of 1^{o}C per each 33 meters of penetration in the crust, the hottest waters of the Thermal Paranoá Aquifer, with about 60^o C in the surface, so it would be necessary to keep it in contact with rocks up to 1,000 meters depths. Fig. 6 shows the schematic regional pattern of thermal waters circulation for the Paranoá and the Araxá aquifers systems.

Bouger anomalies data (regional gravimeter study) show that in the Caldas Novas region there is a crustal thickening of the Paranoá Group, what is possibly controlled by the anomaly subsidence in the Paranoá Basin at the time of its deposition. The heating of the water can be processed in function of the contact between the descending waters and Paranoá Group rocks, with minimum contact with the basement granitic rocks.

The presence of an intrusion (alkaline or granitic composition) in subsurface is totally discarded in function of the thermal waters chemical composition of the Paranoá Aquifer, which is characterized by low mineralization. In the case of an igneous intrusion as a source of heating for the hydrothermalism, the chemical composition of the waters should present much higher values of dissolved ion than the measured in water samples. The same would be expected for the case of contact with basement granite-gnaissic rocks.

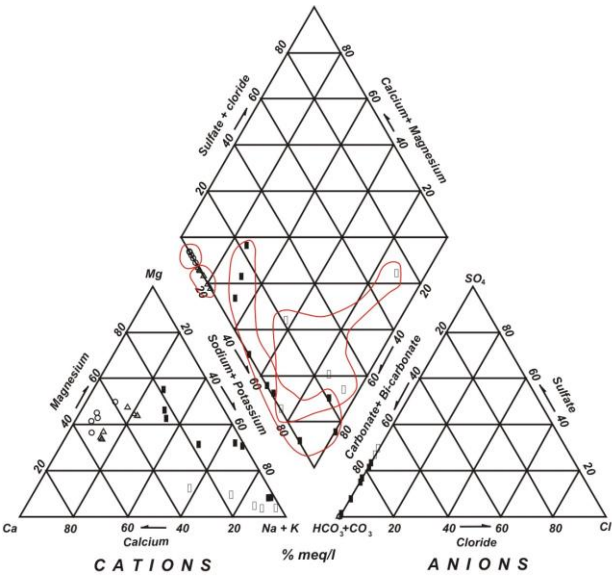
WATER CHEMISTRY

The study of the chemical quality of the waters was developed based on 25 analyses of waters from superficial streams and tubular wells (in thermal aquifers related to the Paranoá and the Araxá systems). Besides these analyses, data of 66 samples of hot waters from quartzite and schist (Zschocke 2000) were considered for the interpretations.

The silica, calcium, magnesium and carbonate are the chemical species that provide the largest distinction among the several types of waters.

According to the chemical content, four groups of waters were defined as waters from the cold springs, streams and Paranoá and Araxá aquifers systems (Fig. 7). The waters from cold springs and streams are important, because their chemical composition is close to the original composition of the waters that infiltrate and recharge the deep aquifers. The difference of the chemical composition among the waters of the Paranoá and Araxá aquifers is important since it is a parameter used for the differentiation of the groundwater reservoirs.

It is necessary to point out that the samples were collected at the end of the rainy period and an important contribution of the run off is responsible for the dilution of the waters from the springs and the superficial streams. On the other hand, the thermal waters from the Paranoá and the Araxá aquifers systems should not present chemical differences independently of the period of sample collecting.



Open Circles - Araxá Aquifer System
Open Triangles - Paranoá.Aquifer System
Close Squares - Streams water
Open Squares - Cold water springs

Figure 7 – Piper Diagram showing the several water types present in the region.

The waters from springs present the smallest values of total dissolved solids, and represent the waters with smaller total mineralization. These waters have close chemical composition to the rain precipitation waters. As the contact with the geological media (soil and rock) is minimum (local hydrogeologic flow), the ion content is very reduced.

As expected, the waters from streams present the largest chemical variations. It is due to the fact that these waters keep in contact with several types of rocks and they are susceptible to superficial contamination, mainly out of the limits of the Caldas State Park, where the human activity is more accentuated. In the Piper Diagram the largest chemical variation is indicated by the widest field resulted by the spread of the several analyses.

The thermal waters from the Paranoá Aquifer System present low total mineralization, with TDS varying from 17 to 43 mg/L; pH varying from 5,2 to 6,3; and values of silica varying from 12 to 17 mg/L. This weak mineralization is interpreted as function of the little reactivity of rock types that compose the reservoir. Quartzite and metasiltstone are low soluble and do not provide great ion concentration to the water that circulates through their fractures.

Close to the contact with the Paranoá Group rocks, in the area of the breccia outcrops, or in situations where the marbles of the upper portion are present, there is the possibility of occurrence of high-mineralized waters. The sample of water from the well that supplies the administration of Caldas State Park is probably an example of this type of water. It could be inferred by the location of the well and by the analytical results of that water sample.

The group of the Araxá Aquifer System represents the groundwater with higher mineralization degree, with values of TDS that can overcome 70 mg/L; pH greater than 6,6 and in general larger than 7,0; values of silica varying from 6 to 12 mg/L and values of calcium and magnesium greater than the values observed in the waters from the Paranoá Aquifer System. The highest values of water mineralization of the Araxá Aquifer System were already expected, once it evolves the most reactive type of rocks that compose the groundwater reservoirs - schists with carbonate, mica, clorite and minerals of the epidote group.

Discussion

The general aspects of the water chemistry presented above allow some considerations concerning the genesis of the thermal aquifers in the area, as followed.

1 - The hot waters do not have relationship with igneous bodies in depth. In the case of the presence of a heating intrusive body at depth (as the case of Poços de Caldas, in the state of Minas Gerais), the waters would necessarily present high concentrations of total dissolved solids (in several ionic forms) and, consequently, must be more mineralized and show higher electric conductivity.

2 - The Araxá Aquifer hot waters show heating in function of mixtures with thermal waters of the Paranoá Aquifer in ascending flow.

3 - The largest chemical variability of the Araxá Aquifer waters, without direct relationship with the temperature, indicates that locally the waters of this aquifer system can be warmed by geothermic degree, without significant mixtures with hot waters of the Paranoá Aquifer.

4 - The heating of the waters is attributed to regional flow regimes and evolves waters that reach depths deeper than 1,000 meters, in an area where the geothermic degree is considered from 25 to 30^{o} C per kilometer.

5 - Neotectonic activity presents a fundamental importance in the context of the hot waters from the Araxá and the Paranoá aquifers. The expressive occurrence of hot waters in Caldas Novas region would not exist without the effective development of extensional events in the Cretaceous.

CONCLUSIONS

In the Caldas Novas region there are different rock types correlated to the Paranoá (Meso/Neoproterozoic), the Araxá (Neoproterozoic) and the Areado (Cretaceous) groups. This correlation is based on lithologic, sedimentologic, metamorphic and structural characteristics.

In the Paranoá Group it was possible to individualize four rock units, from the base to the top composed by: Ortoquartzite, Clay Quartzite, Metarrithmite and Pelitic-Carbonated Unit.

The Paranoá Group depositional context shows a marine transgressive cycle into the basin, where marine shallow waters facies passed progressively to a deep waters deposition dominated by storms (Metarrithmite Unit). The unit on the top is related to a marine regressive event responsible for the final stage of the deposition in the Paranoá Basin, in the studied area.

Varied schists, in a metamorphic context of the clorite zone, compose the Araxá Group.

Two tectonic events were recognized for the structuring observed in the area. The first event is related to the Brazilian Cycle when, in a schematic way, the area was under four deformation phases: D_1 - tectonic transport of the Araxá Group from the internal zones of the Brasilia Fold Belt; D_2 - folding with NNW/SSE main axis; D_3 - open folding with axes close to EW, and D_4 - fracturing and widespread faulting. The second event is associated the Waldenian reactivation (South-Atlantic rupture) processed during the Cretaceous, which was responsible for the reactivation of the brittle structures formed in the final stages of the first event.

Three aquifers systems in two different domains are discriminated in the area: the Porous, the Paranoá and the Araxá aquifers systems.

The Porous Aquifer System is subdivided in P_I and P_{II} subsystems, characterized by soils and saprolite coverages. The Paranoá Aquifer System corresponds to the fractured / fissured zones, and can be divided in Cold and Thermal aquifers. In the same way, the Araxá System is also divided in Cold and Thermal subsystems.

The heating of the waters is exclusively related to the geothermic gradient of the area, and the main recharge source is placed on the plateau of the Caldas Ridge.

Four groups of waters were characterized based on the chemical analyses of waters samples collected in streams and wells. Hot waters of the Paranoá Aquifer System present low mineralization, controlled by its silica content and the lowest values of K^+ and Na^+. The Araxá Thermal System waters present the highest values of total dissolved solids, pH values and percentiles of bicarbonate, Ca^{2+} and Mg^{2+}.

The neotectonics scenario was important for the characterization of the local hydrogeologic context and it is one of the main controls of the hydrothermalism observed in the Caldas Novas region.

Studies of rock chemistry can be useful for correlation between the several types of water and the context of groundwater circulation, with definition of regional and local regimes of hydrogeologic flow.

The development of geophysical studies for thick determination of the soils and saprolite is important for the best knowledge of the recharge mechanisms, mainly in the largest area of the plateau of the Caldas Range.

PRESERVATION MEASURES

As the Caldas Novas State Park area represents great importance in the processes of aquifers recharge, it is fundamental that it is maintained as an environmental preservation unit with restriction in use and human occupation.

To avoid the continuous lowering of the groundwater level of the thermal aquifers systems in the region, projects and studies seeking to the artificial recharge of those reservoirs should be developed.

The restriction of authorizations to construction of new wells and the limitation of the pumping rates at the existent wells are also initiatives to preserve this important Brazilian Geological Site.

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