

**THE LAGOA REAL URANIUM PROVINCE,
BAHIA STATE, BRAZIL: SOME PETROGRAFIC
ASPECTS AND FLUID INCLUSION STUDIES**

K. Fuzikawa¹, J.V. Alves¹, P. Maruéjols², M. Cuñey², C. Kostolanyi², B. Poty²

1. Empresas Nucleares Brasileiras S/A. - NUCLEBRAS/EBHO.PM. Av. Uruguai, 531. 30310 Belo Horizonte, Brazil
2. Centre des Recherches sur la Géologie de l'Uranium - G.S. C.N.R.S., BP 23, Vandoeuvre-les-Nancy 54501 Cedex, France

ABSTRACT

The Lagoa Real Uranium Province in the central-southern Bahia State, consisting of six deposits and several prospects, has a reserve of near one hundred tons of U_3O_8 .

The main lithological unit in the area is the Lagoa Real Complex which is formed by coarse granites and gneisses derived from them. The unit overthrusts the Espinhaço metasediments to the west. The Complex is the host of albitites which may contain uraninite. The mineralization is mainly associated with pyroxene and garnet.

Petrographic and field relations indicate the overthrusting as the latest event, having left imprints in the orebodies and their hosts.

Fluid inclusion studies indicated fluids of different characteristics in the Espinhaço and the Lagoa Real Complex although they were similar in composition (carbonic and aqueous). The types of inclusions detected are in agreement with the geologic processes suggested for the area: emplacement of the São Timóteo granite at 1.72 Ga; albitization and uranium mineralization at ~ 1.4 Ga; and metamorphism at ~ 0.49 Ga.

The study is an example of fluid inclusion behaviour in a metamorphic process with very limited amount of fluids.

RESUMO

A Província Uranífera de Lagoa Real, centro-sul do Estado da Bahia, é formada por seis depósitos e vários indícios e contém uma reserva de quase uma centena de toneladas de U_3O_8 .

O Complexo de Lagoa Real, formado de granitos e seus ortoderivados, é a unidade litológica principal sendo ainda a encaixante dos albititos, uraníferos ou não. A uraninita associa-se principalmente aos máficos (piroxênio e granada). Essa unidade acha-se empurrada sobre os metassedimentos do Espinhaço, situados a oeste.

As relações petrográficas e de campo indicam que esse tectonismo que atingiu tanto o minério como suas encaixantes foi o evento mais tardio registrado na área.

O estudo de inclusões fluidas mostrou a ocorrência de fluidos de características diferentes nos metassedimentos do Supergrupo Espinhaço e nas rochas do Complexo de Lagoa Real, embora ambos apresentassem fluidos carbônicos e aquosos. Os tipos de inclusões presentes são concordantes com a seqüência de eventos sugerida para a região: intrusão do granito São Timóteo a 1,72 Ga; albitização e mineralização uranífera a $\sim 1,4$ Ga e metamorfismo a $\sim 0,49$ Ga.

O estudo constitui um exemplo do comportamento das inclusões fluidas num processo metamórfico escasso em fluidos.

INTRODUCTION

The Lagoa Real uranium province in the central-southern part of Bahia State (Fig. 1) presents uranium mineralization of grade in six deposits and several prospects. The global tonnage at present approaches a hundred tons of U_3O_8 (Villaça & Hashizume, 1982). Preliminary studies have been carried out by Fuzikawa (1980, 1982) and Alves & Fuzikawa (1984) but the interpretations were hindered by poor geologic knowledge of the area.

Geologic mapping (1:25000) of the Province (Costa *et al.*, 1985) and numerous studies by NUCLEBRÁS geologists (Geisel *et al.*, 1980; Fuzikawa *et al.*, 1982; Lobato *et al.*, 1982, 1985; Brito *et al.*, 1984; Ribeiro *et al.*, 1984; Lobato, 1985) brought conditions for a better sampling of different lithologic unities. The new fluid inclusion data obtained from them coupled with previous results and the petrological (Maruéjol *et al.*, 1987) and geochronological (Turpin *et al.*, 1988) studies permitted to evaluate the composition of the fluids, interpret their origin and the subsequent behaviour from the time prior to uranium mineralization to the late Brasiliano period.

GEOLOGICAL SETTING AND GENETICAL HYPOTHESES

The main stratigraphic unit of the Province is the Lagoa Real Complex (Costa *et al.*, 1985). This unit consists mainly of the São Timóteo granite (1.72 Ga; Turpin *et al.*, 1988) and the gneisses derived from it (Maruéjol *et al.*, 1987). The Complex crops out between the Archean migmatites to the E-SE and the Tertiary/Quaternary unconsolidated detritic-residual sediments to the NW and NE (Fig. 1). The typical São Timóteo granite is a blue-grayish, porphyritic (feldspar crystals in the few cm range) or coarse grained rock with amphibole and biotite as the most common mafic minerals. The gneisses present the same mineral assemblage with granoblastic texture. Shear zones of highly foliated and recrystallized rocks are present within undeformed granites.

Tabular to lensoid bodies, several meters thick, of albite or oligoclase dominant rocks occur within the Lagoa Real Complex. When these plagioclase contents average $\geq 70\%$ by volume approaching a more dioritic/tonalitic composition the rocks have been locally named albitites. These rocks may be differentiated from

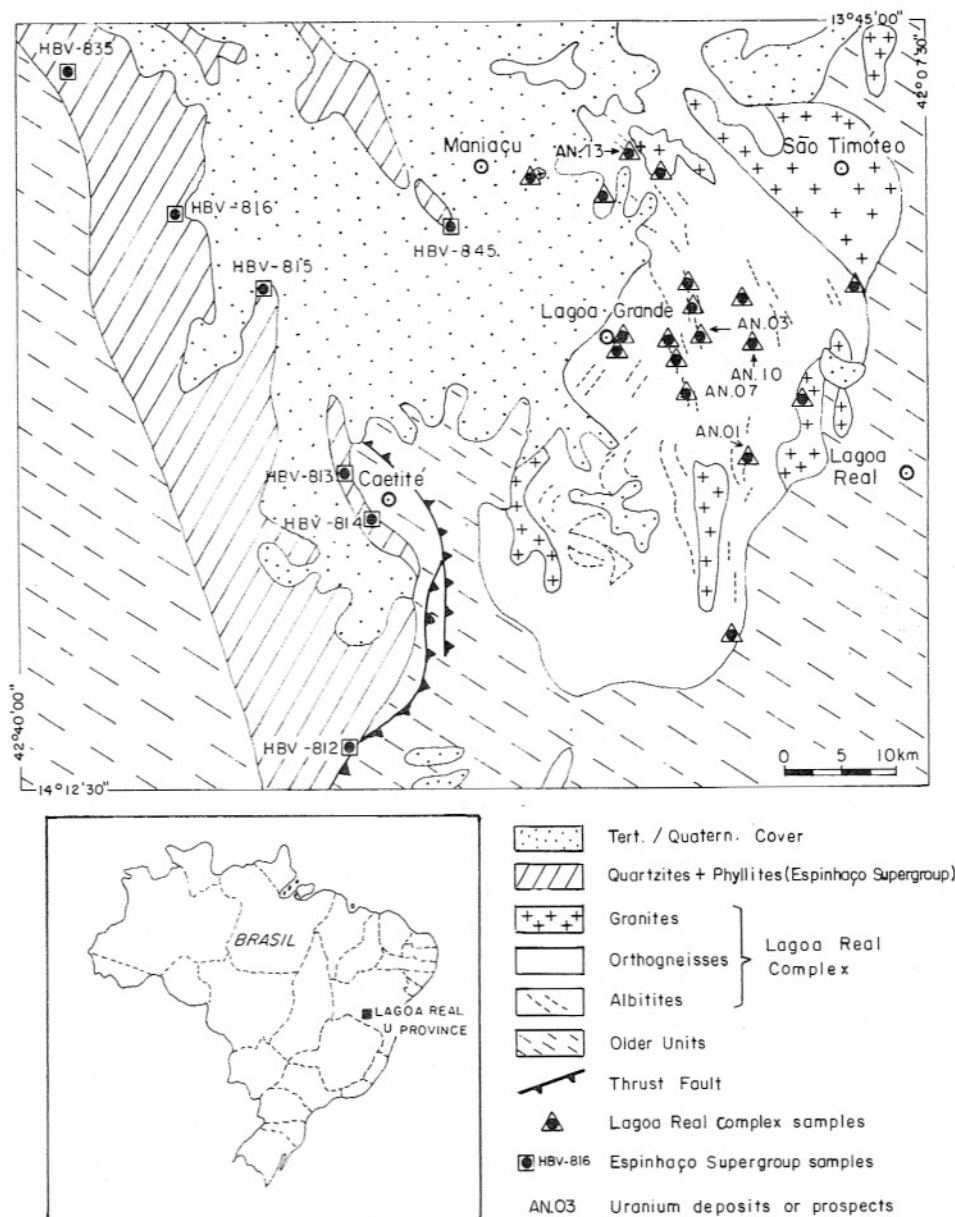


Figure 1 — Simplified geological map of the Lagoa Real region, Bahia State (modified from Costa *et al.*, 1985).

the São Timóteo granites and gneisses only by the feldspar variation (K-feldspar → Na-feldspar), the rest of mineral assemblage remaining largely unaltered; or they may have been submitted to wider range of mineral transformation: quartz leaching and the replacement of mafic minerals (amphibole + biotite) by pyroxene (aegirine/augite) and garnet (andradite). Maruéjol *et al.* (1987) have called quartz albitites the former group and pyroxene ± garnet albitites the latter. The uranium mineralization is hosted by the second type of albitites. Uraninite is the most important mineral of economic value which is preferentially associated with pyroxene and garnet.

Shear zones and granoblastic or polygonal textures present in granite-gneisses rocks can also be seen in albitites. Besides, uraninite distribution along the schistosity is a strong evidence for the uranium mineralization preceding the metamor-

phism (Fig. 2). Additionally, field evidences of the concordance of well developed regional foliation in orthogneisses and albitites seem to confirm that sequence of events. This foliation is considered a metamorphic product of an overthrusting of the Lagoa Real Complex and older units over the Espinhaço metasediments (Fig. 1). These sediments show a decrease in metamorphic grade (from subanatexis to greenschist facies) moving away from the thrust fault (Maruéjol *et al.*, 1987).

Three hypothesis have been proposed for the albitization and uranium mineralization at Lagoa Real.

Fyfe (1979, written comm.) proposed a genesis based on "thin skinned tectonics" overthrusting model (Cook *et al.*, 1979). The granite/gneissic rocks would have thrust over the Espinhaço sediments soaked with fluids. An inverted thermal gradient was established causing

a retrograde metamorphism in the crystalline rocks and a prograde one in the sediments. This process would explain the observed mineral transformations: 1) K-feldspar is changed to albite or oligoclase; 2) ~10% silica leaching (Lobato *et al.*, 1982) leading to almost complete dissolution of quartz; 3) formation of aegirine-augite and andradite with which U is associated; 4) ~10% SMOW $\delta^{18}\text{O}$ depletion in minerals from albitites compared to their granitic or gneissic counterparts (Lobato *et al.*, 1983) and indicating influence of meteoric waters; 5) development of an oxidation process (hematite replacing magnetite).

Geisel (1981, written comm.) presented an alternative model idealized by a hidden intrusive igneous body which would have been the source of fluids and heat. The problem is that in such a model one would rather have silica deposition and it would be incompatible with the oxygen isotope signature.

Maruéjól *et al.* (1987) determined the age of albitization and U mineralization at 1.395 ± 4 Ga and the regional metamorphism as being related to the regional overthrusting during the Brasiliano tectonic cycle. Based on these data they presented a new model where the U mineralization occurred in a process similar to the French U deposits in the Hercynian granites at ~1.4 Ga and were metamorphosed at ~0.49 Ga.

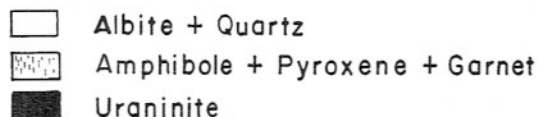
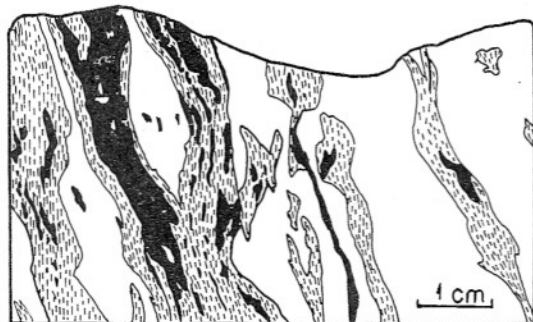


Figure 2 — Sample HAV-775. Metamorphic texture showing the uraninite remobilized along the schistosity.

FLUID INCLUSION STUDIES

Fluid inclusions were studied in 39 samples from the following units (Figs. 3 and 9).

1. Quartz veinlets and segregations in quartzites, schists and graphitic schists from the Espinhaço Supergroup;
 2. Underformed São Timóteo granites;
 3. Orthogneisses at variable degrees of deformation;
 4. Barren albitites;
- from the
Lagoa Real

5. Uraniferous albitites;
6. Quartz-veins cutting the mentioned types of rocks. Complex

The studies indicated two different population of inclusions: one from Espinhaço Supergroup and the other from Lagoa Real Complex.

Espinhaço Supergroup

Seven samples from this unit were studied (Figs. 1 and 4). The sample HBV-835 is the farthest from the thrust zone.

The microthermometry indicated H_2O , CO_2 , and CH_4 or N_2 as the main fluids in inclusions. At room temperature they consisted of carbonic (one-phase), aquo-carbonic (two-phase), and aqueous (one- or two-phase) inclusions. The temperature of melting of the carbonic phase in most inclusions indicate pure CO_2 . The CH_4 or N_2/CO_2 and $\text{CO}_2/\text{H}_2\text{O}$ ratios and the density of CO_2 increased moving away from thrust fault area (Fig. 4). These data and microscopy suggest an increasing decrepitation of inclusions toward the fault zone as a consequence of increase in metamorphic conditions. The build-up of temperature and especially pressure by tectonic compression and the higher internal pressure of carbonic inclusions would be the factors leading to fluid leakage in these inclusions.

Microthermometry of aqueous inclusions presenting different clusters or planes with different salinities indicate aqueous fluids of different generations. The highest salinity was 4 wt% equiv. NaCl. Many groups of one-phase inclusions contained pure water (Fig. 3). Near the fault zone the salinities were lower or even zero (pure water). The consequence of these results is that they make the Fyfe's genetical model less feasible. These weak brines could hardly be accounted for the albitization of the Lagoa Real Complex rocks.

Lagoa Real Complex

The Lagoa Real Complex rocks all contain inclusions with the same type of fluids: H_2O and/or CO_2 . They form carbonic (one-phase), aquo-carbonic (two- or three-phase; Figs. 5a, d, e), and aqueous (one- or two-phase; Fig. 6) inclusions. Aquo-carbonic inclusions may become multiphased when they contain solid phases (Figs. 5b, c). Finally, most samples contain empty inclusions (Fig. 7).

The carbonic and aquo-carbonic inclusions had very limited occurrences. Only undeformed or weakly deformed granites, augen gneisses and thick (< 5 cm) quartz veins presented these types of inclusions with no clearly defined primary origin. Raman spectroscopy analysis (Dubessy *et al.*, 1984) indicated the carbonic phases as pure CO_2 (Fig. 8). Less fractured granites presented higher frequency of these types of inclusions and CO_2 with higher density. This evidence could be seen examining, for instance the

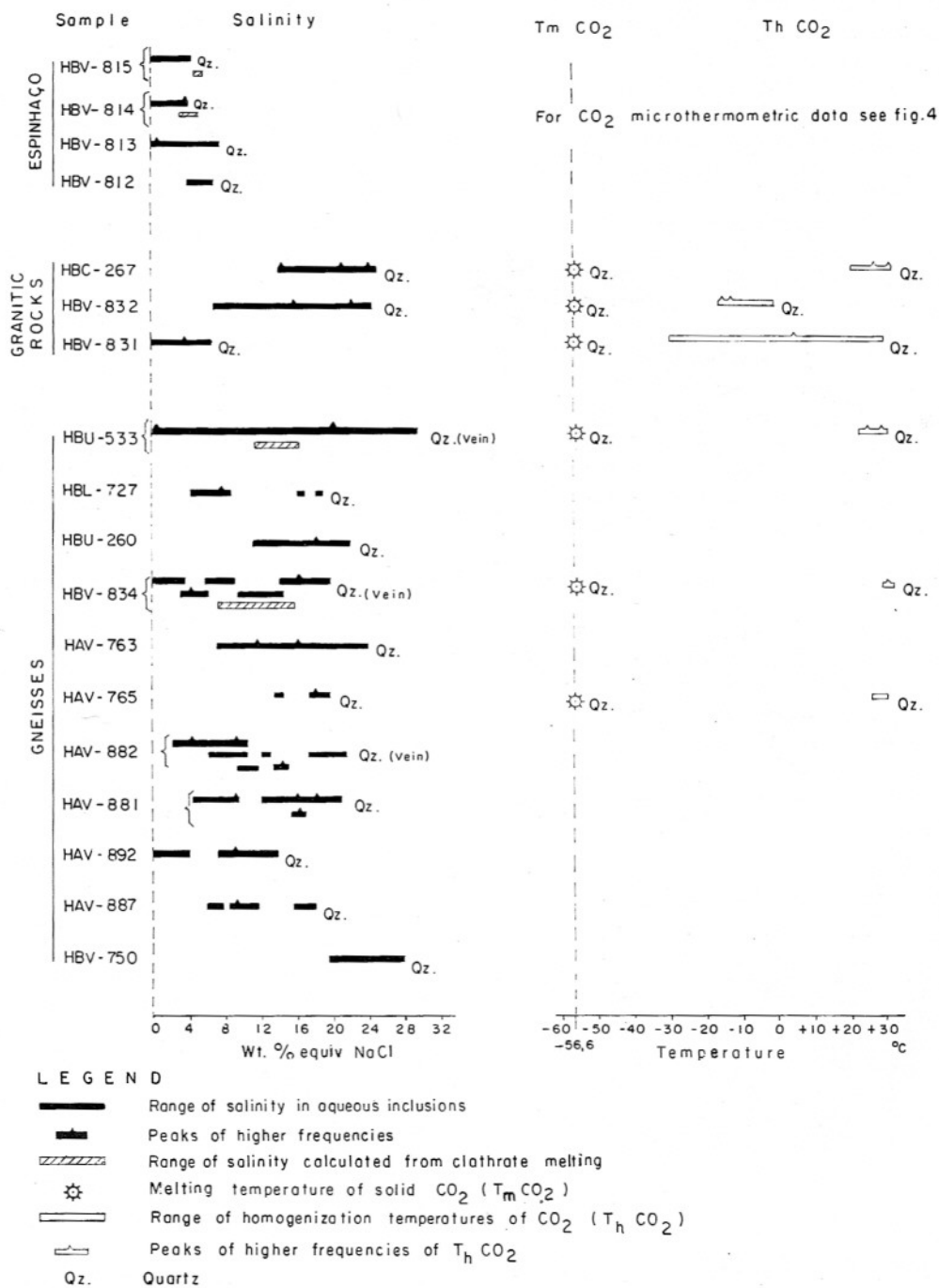


Figure 3 — Salinities of aqueous inclusions and microthermometric values of carbonic fluids: Espinhaço metasediments and Lagoa Real Complex (granites and gneisses).

sample HBV-831 and their foliated equivalent less than one meter apart. Similar situations from other areas indicated the same results. Only one augen gneiss exhibited aquo-carbonic inclusions. Even in quartz veins, when hosted by strongly sheared gneisses, CO₂ was completely absent (Fig. 3; sample HAV-882).

These features point out again to a strong decrepitation and elimination of inclusions with carbonic phases during the metamorphic event (probably Brasiliano cycle).

The aqueous inclusions were obviously affected in the same event: samples with strong

foliation or well laminated textures presented fewer and smaller inclusions than the less tectonized ones. The salinities of the aqueous fluids varied from pure water to >30 wt% NaCl equiv., but inclusions within the same cluster of fracture had the same value (Fig. 3). There were samples with more than ten groups of inclusions each one presenting different salinity. Ice melting below the eutetic point (-21.1°C) of the NaCl-H₂O system in some inclusions indicates the presence of other ions (Ca⁺⁺, Mg⁺⁺, etc.).

Albitites with sugary texture are common. Some albitites in these rocks presented primary

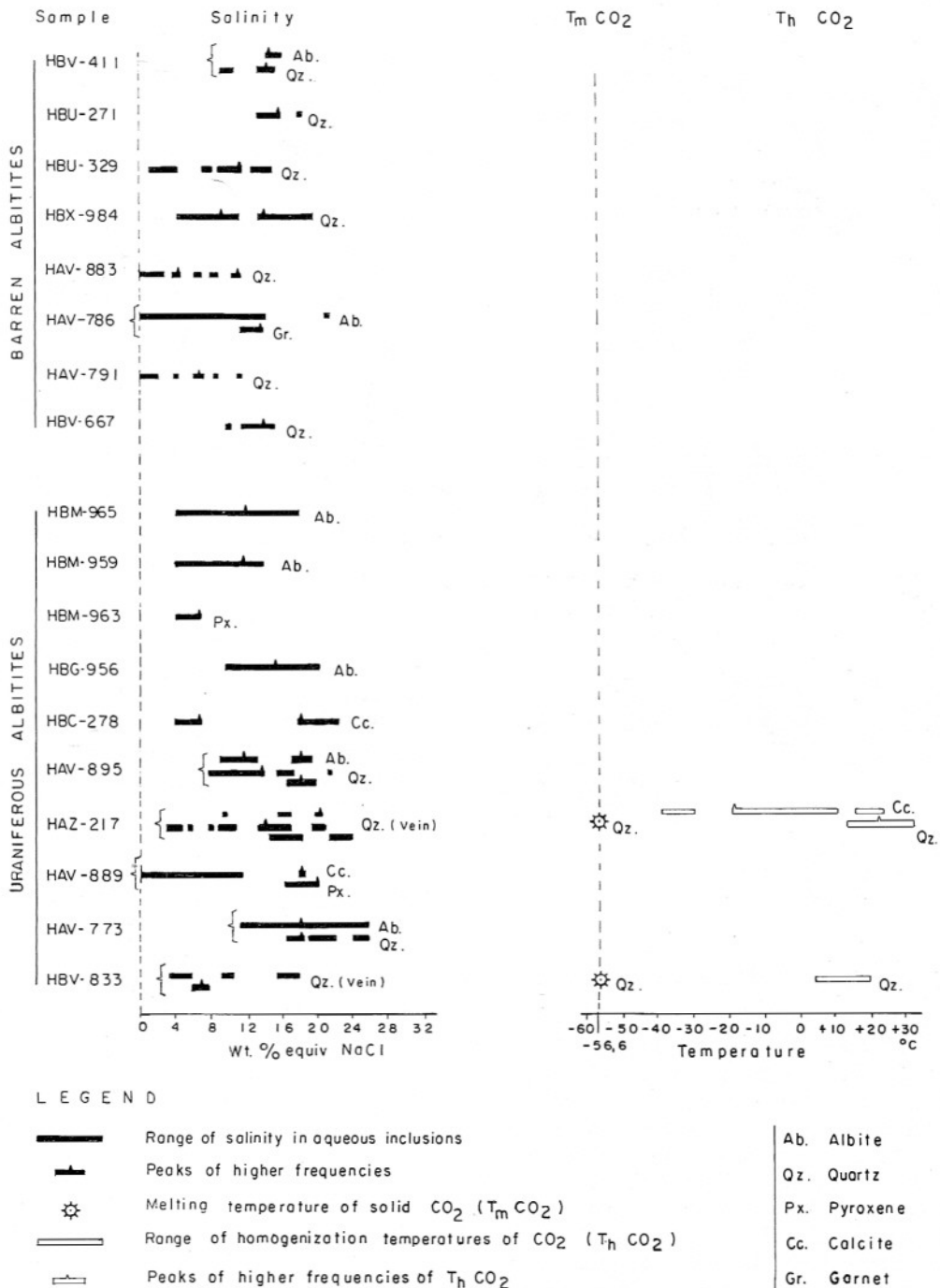


Figure 9 — Salinities of aqueous inclusions and microthermometric values of carbonic fluids in albitites.

Quartz veins cutting all types of rocks presented the best fluid inclusions for study both in number and size (Figs. 4 and 9). The aqueous inclusions dominated the ones with CO₂. A sample of vein cutting an uraniferous albitite provided the best information (Fig. 9; sample HAZ-217). Quartz, calcite, and biotite from the vein were completely barren although the host was mineralized indicating a good chronological relationship between the mineralization and the vein emplacement. At the same time effects of a tectonism could be seen in the vein minerals (rolling extinction, recrystallization, curved twinings) indicating the metamorphism as the latest

event. The absence of U mineralization into the vein and the lack of retrogression evidence point out to the metamorphism as a rather dry event. The vein quartz contained patches with abundant aquo-carbonic inclusions. The trails of secondary H₂O CO₂ inclusions in this sample point out to the circulation of a carbonic fluid in the system after the vein emplacement, which is younger than the U mineralization. Therefore, the absence of CO₂ inclusions in albitites and gneisses is again a strong indication for the decrepitation of carbonic inclusions by a metamorphism at the latest stage. Some inclusions with CO₂ contained strongly birefringent solid phases (Figs. 5b, c)

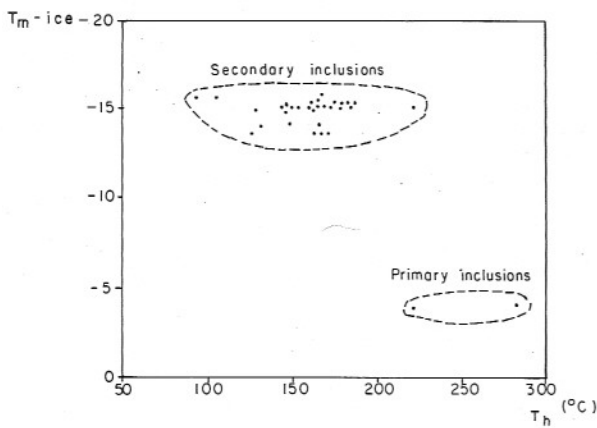


Figure 10 — $T_h \times T_m$ of aqueous inclusions in calcite (sample HBC-278).

which were determined as nahcolites (NaHCO_3) by Raman spectroscopy (Fig. 11). This mineral is supposed to have been formed when aquo-carbonic inclusions, which usually presented very low salinities, were mixed with strong brines of the late stages as it has previously indicated. Furthermore, the quartz also presented the largest and the most numerous empty inclusions. Their

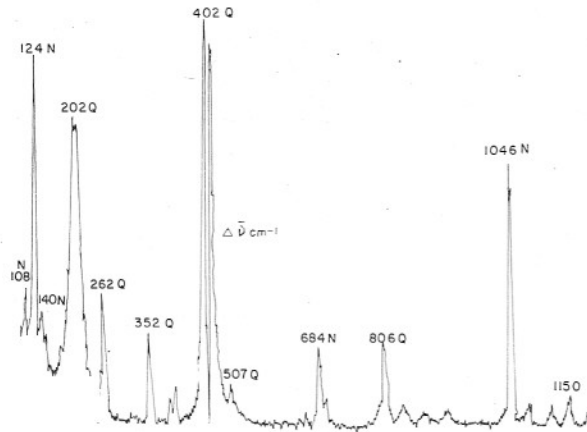


Figure 11 — Raman spectra of nahcolite (N) in aquo-carbonic inclusion. Q = quartz.

emptiness were defined by Raman spectroscopic analysis. Few of them contained solid prismatic phases (Fig. 7a) which are hard to be accepted as products of crystallization without a fluid. They are probably the remnants of fluid loss (decrepitation) during the metamorphic event.

CONCLUSIONS

Some petrographic evidences (HAV-773; HAZ-217) and field relations indicated the uranium mineralization as a process preceding the metamorphism, in agreement with the sequence proposed by Maruéjol *et al.* (1987).

Fluid inclusion studies showed fluids of different characteristics in the Espinhaço Super-group and in the Lagoa Real Complex. The low salinity or pure water aqueous inclusions found in the Espinhaço unit is difficult to be considered as the albitizing and mineralizing fluid.

The metamorphism as the last regional event

precludes most interpretations of obtained fluid inclusion data. Nevertheless, in the Lagoa Real Complex CO_2 was present after the U mineralization, because it forms secondary fluid inclusions in quartz veins cutting uraniferous albitites (e.g. sample HAZ-217). Its presence as a primary fluid in the São Timóteo granite has not been detected although possible (Weisbrod, 1981). The absence of inclusions with CO_2 in albitites and gneisses is supposed to be the result of decrepitation during metamorphism. CO_2 is a common fluid associated with U deposits (Poty & Pagel, 1988). The presence of aqueous inclusions of different salinities is evident. The increase in salinity of younger fluids is strongly suggested. The presence at random of nahcolite daughter crystals is supposed to be the result of mixing of these saline fluids with CO_2 rich inclusions.

The present work may be of some interest to fluid inclusion study in metamorphic terrain. This interest may be enhanced in Brazil where large areas of the territory were affected by the Brasiliano cycle at the Proterozoic/Phanerozoic interface.

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