Gondwana Research, V. 7, No. 3, pp. 731-744.

ISSN: 1342-937X

GR Gondwana Research

Chemostratigraphy of Medium-grade Marbles of the Late Neoproterozoic Seridó Group, Seridó Fold Belt, Northeastern Brazil

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(Manuscript received November 8, 2002; accepted October 16, 2003)

Abstract

The age of metasedimentary rocks of the Seridó Belt, Borborema Province, a large Neoproterozoic orogen in northeastern Brazil, has been discussed for over three decades. Previous field and structural studies pointed to a Paleoproterozoic age, but recent isotopic data raised the possibility that the protoliths were deposited and metamorphosed during the Neoproterozoic. We carried out detailed C and Sr isotope studies in marbles of the Seridó Group to help clarifying this issue. In the Jucurutu Formation, at the base of the Seridó Group, $\delta^{13}C$ fluctuations indicate three stratigraphic levels of carbonate sedimentation. Marbles at the older carbonate horizon display $\delta^{13}C$ between +8.3 and +11.8‰. Marbles at the intermediate carbonate horizon exhibit $\delta^{13}C$ values between +6.7 and +8.7‰, and the youngest carbonate horizon in the Jucurutu Formation marbles, yielded $\delta^{13}C$ values between –8.9 and +3.8‰. In the Seridó Formation, at the top of the Seridó Group, two stratigraphic levels of carbonate sedimentation are observed. Marbles at the older carbonate horizon exhibit $\delta^{13}C$ values between +8.9 and +10.7‰, and negative $\delta^{13}C$ values mark the upper marble carbonate horizon of the Seridó Belt that exhibit a narrow range of $\delta^{13}C$ ratios –4.6 to –4.0‰. The C-isotope fluctuations observed in marbles of the Seridó Belt compared to C-isotope secular variation curves, suggest depositional age intervals of 640–570 and 590–570 Ma. The former age estimate is corroborated by $^{87}Sr/^{86}Sr$ values which varies from 0.7074 to 0.7077, typical of pre-Varangerian carbonates and is also in agreement with 650 Ma old zircon crystals within pelitic rocks of the Seridó Formation. Mica and amphibole $^{40}Ar/^{39}Ar$ ages indicate metamorphic events of 544±3 Ma and 500±5 Ma.

Key words: Vendian, C-isotopes, northeastern Brazil, Seridó Belt, marble.

Introduction

The reconstruction of the original stratigraphy of Precambrian sequences, whose sedimentary structures and original relationships of their strata have been masked or obliterated by both metamorphism and deformation, is very complex. An additional complication is the difficulty in recognizing any fossil record in medium- to high-grade terraine which precludes dating of the sedimentation and prevents inter and intra-basinal stratigraphic correlation. Petrographic, geochemical and structural studies can occasionally help to minimize these problems, allowing the inference, beyond deformation and metamorphism, the nature of protoliths and their original relationships. C and Sr chemostratigraphic studies applied to Precambrian marbles have helped both to establish stratigraphic correlation between strata and also to estimate the age of sedimentation (Melezhik et al., 2001).

Radiogenic dating methods applied to sedimentary carbonate rocks that have undergone thermal events, generally yield the age of the last thermal event. The combined use of C and Sr isotopic composition of carbonate rocks represents an additional tool, which can be used to estimate depositional ages.

Studies of marine carbonates have demonstrated the worldwide, systematic and consistent variations of $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ in carbonates of the same age, although other factors (e.g., depositional environment) particularly control these ratios, and may cause ratios to deviate from worldwide variation curves. The record of variation of C and Sr isotopes in seawater has allowed, by means of chemostratigraphic studies, the reconstruction of the secular C and Sr isotope variation curve of the oceans (e.g., Veizer et al., 1983; Knoll et al., 1986; Benner, 1989; Narbone et al., 1994; Kaufman and Knoll, 1995; Veizer et al., 1997; Hoffman et al., 1998; Jacobsen and Kaufman, 1999; Walter et al., 2000; Montañez et al., 2000). Deposition ages of marine carbonates exposed to metamorphism at variable degrees have been estimated by comparing their C and/or Sr isotope chemostratigraphic curves with the global, secular C and Sr variation curves for seawater (e.g., Melezhik et al., 2001).

Geological Setting

The Seridó fold belt, situated in the northeastern part of the Borborema Province in northeastern Brazil (Fig. 1), has been the target of several studies in the last two decades. This belt encompasses a volcanosedimentary sequence that was deposited discordantly on a Paleoproterozoic basement. It was subsequently affected by strong transpressional deformation, intrusion of voluminous granitic magmas and reworking by transcurrent structures that imparted a N–NE trend to the belt (Fig. 2). Intense deformation poses some difficulty in recognizing original stratigraphic relationships, which has led to divergent interpretations of the sedimentation age, stratigraphy and evolution of the supracrustal rocks, in spite of several geochronological, geochemical and structural studies carried out during the last two decades. (Jardim de Sá et al., 1988, 1995; Caby et al., 1995; Archanjo and Legrand, 1997; Van Schmus et al., 1996, 2000).

Among the different stratigraphic columns proposed for this belt, the most commonly used (Jardim de Sá and Salim, 1980) includes all metasedimentary rocks in the Seridó Group. This Group is subdivided in three formations, from base to top (Fig. 2): (a) the Jucurutu Formation, which is composed of gneisses with intercalations of marble, quartzite, micaschist, calc-silicate rocks, iron formations, metavolcanic rocks and a basal conglomerate; (b) the Equador Formation, predominantly composed of quartzite with metaconglomerate lenses, which become more abundant towards the top, calc-silicate rocks and paragneisses (this formation exhibits variable thicknesses, and can be absent in certain portions of the belt), and (c) the Seridó Formation, which is made up of feldspathic or aluminous micaschists, with subordinate marble, calc-silicate rocks, paragneiss, basic metavolcanic rocks, quartzite and metaconglomerate.

The association of marble, iron formation and the calcitic-quartzitic tendency of the paragneisses of the Jucurutu Formation (quartzite-pelite-carbonate association) points to deposition in a shallow marine environment. The Equador Formation represents the siliciclastic component of this shallow marine association, whereas micaschists of the Seridó Formation represent a thick package of turbiditic, flyschoid deposits (graywacke-greenstone association with predominance of the sedimentary component), marking the inversion of the basin (Jardim de Sá, 1994). Some schematic stratigraphic relationships of the Seridó Group, according to Jardim de Sá (1994), are illustrated showing both interfingered contacts, and that the sedimentation of both the top of the Jucurutu Formation and the base of the Seridó Formation are coeval (Fig. 3).

The age of the Seridó Group rocks has been investigated in several studies. Sm-Nd isochron data for basic metavolcanic rocks of the Jucurutu and Seridó Formations yielded extremely old ages (3027 Ma and 1399 Ma, respectively). Indirect dating of supracrustal rocks was obtained from granitic orthogneisses, regarded as intrusive into Seridó Group with ages between 2.0 and 1.9 Ga (Rb-Sr and U-Pb). However, the relationships between these intrusions and their metasedimentary hosts are far from unequivocal because contacts are usually marked by shear zones (Archanjo and Legrand, 1997). Investigation of TDM model ages of metasedimentary rocks points to maximum ages between 1.6 and 1.2 Ga for the Jucurutu and Seridó Formations (Van Schmus et al., 1996). Detrital zircon ages for Seridó micaschists indicate contribution from sources as young as 650 Ma (Van Schmus et al., 2003), and establish a late Neoproterozoic maximum age for the deposition of the original sediments.

Considering the difficulty in establishing a chronological sequence of events in the Seridó Belt based only on radiogenic methods, we suggest that Sr and C-isotope chemostratigraphy applied to the Seridó marbles may contribute to address this problem and to help establishing the age of sedimentation.

Petrography of the Seridó Belt

Lenses of marble are largely distributed within the Seridó Belt. In the Jucurutu Formation, marble lenses are abundant and occur in two or three stratigraphic levels, one of which is near the base of the sequence (Jardim de Sá, 1994). In the Seridó Formation, marble lenses are scarcer and can only be found near the base of the Formation (extensional tectonic stage). The lack of carbonates is due to the tectonic inversion (early compressional stage) in the evolution of the basin.

Marbles of the Jucurutu Formation occur as metric to decametric lenses of predominantly massive rocks, which are some times compositionally banded rocks (white and gray zebra-like pattern). They are represented by calcite marbles and dolomite-calcite marbles, with accessory silicate minerals.

In the seven marble lenses sampled for this study (Jucurutu, São Rafael, Caicó-Jardim do Seridó, Várzea São João do Sabugi, Ipueira, Messias Targino and

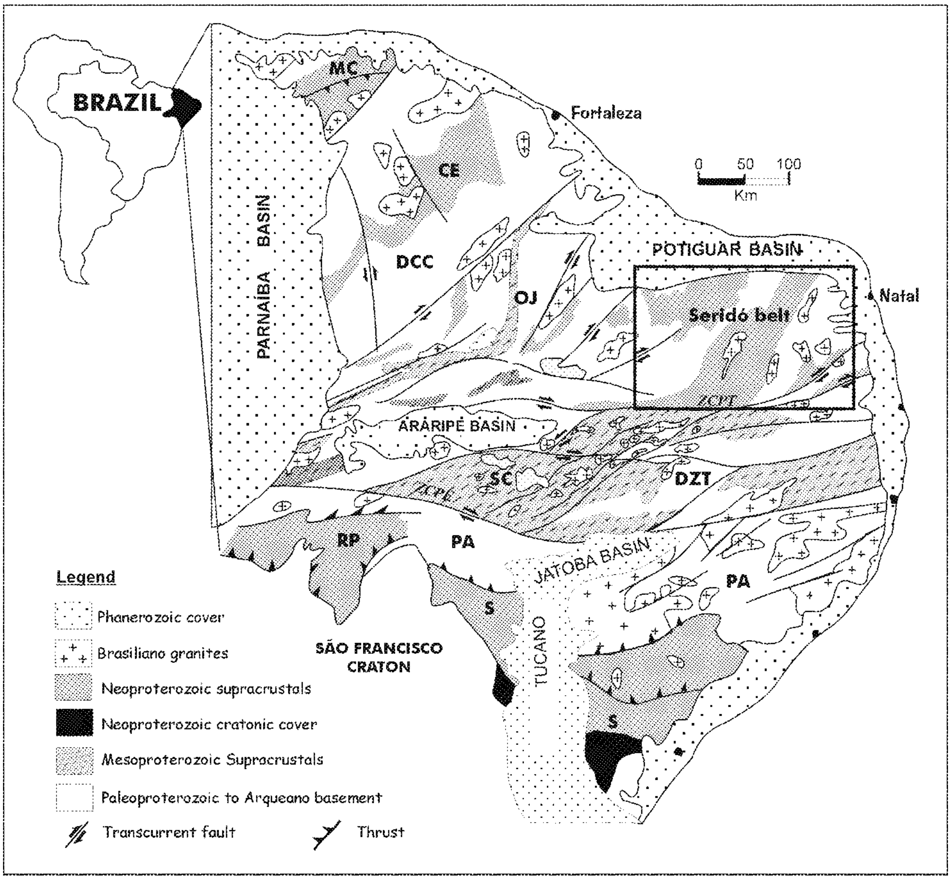

Fig. 1. Tectono-stratigraphic scheme for the Borborema province. PSZ–Patos shear zone; PESZ–Pernambuco shear zone. Supracrustal faults: MC–Médio Coreaú, DCC–Ceará Central Domain, OJ–Orós-Jaguaribe, SE–Seridó, SC–Salgueiro-Cachoeirinha (included in the Transversal Zone Domain- TZD), RP–Riacho do Pontal, S–Sergipean. Massifs: RP–Rio Piranhas, SJC–São José de Campestre, PA–Pernambuco-Alagoas. Modified from Jardim de Sá (1994).

Almino Afonso lenses; Fig. 2) silicate minerals are observed and are more abundant when closer to contacts with pelitic metasedimentary rocks. Amphibole is the most abundant among the silicate minerals and varies from tremolite to Mg-hornblende and edenite. Pyroxene is usually represented by diopside, although wollastonite was also detected both in lenses near granitic plutons and in marbles with intercalations of calc-silicate rocks and pegmatite dykes. Phlogopite, clinozoisite and forsterite were found in some lenses as rare accessory phases.

In the Seridó Formation, two marble lenses have been sampled: São Mamede and Serra do Cruzeiro da Maniçoba (Fig. 2). The São Mamede one is compositionally banded, and has been tightly and asymmetrically folded, with axial planes at 20°/68° SE. Mineralogically, it is constituted by calcite marbles with tremolite disposed according to the fold axial planes, in the contact zone with schists. The Serra do Cruzeiro da Maniçoba marble lens consists of pure marbles, essentially calcitic, with some quartz and opaques as rare accessory phases.

Sampling Procedure and Analytical Methods

Approximately 200 samples were collected perpendicular to the foliation strike that is assumed to be nearly parallel to the bedding. The spacing between samples was variable, depending on textural and compositional variation, as well as on the quality of the outcrop, resulting in a centimetric to decametric interval of sampling.

C and O isotope ratios were analyzed at the Stable Isotope Laboratory (LABISE) of the Federal University of Pernambuco. CO_2 gas was extracted from powdered carbonate samples by reacting 10–20 mg of the sample with 100% orthosphosphoric acid, under high vacuum, at 25°C for approximately 24 hours (72 hours were allowed when dolomite was present). The released CO_2 gas was analyzed in a SIRA II dual inlet, triple collector mass spectrometer, using the BSC reference gas (Borborema Skarn Calcite) calibrated against NBS-18 (carbonatite), NBS-19 (toilet seat limestone) and NBS-20 (Solenhofen limestone), with a composition of $\delta^{18}O$ = –18.3‰PDB and $\delta^{13}C$ = –8.6PDB. Whole-rock chemical analyses were carried out on fused beads, prepared with Li tetraborate at the XRF Laboratory of the LABISE, utilizing a Rigaku X-ray fluorescence unit, model RIX-3000.

The Sr isotope ratio analyses were performed at the Geochronology Laboratory of the University of Brasília. Only pure carbonate samples were used for the Sr isotopic analyses. Approximately 50 mg of powdered sample was reacted with 3 ml of cold dilute HCl for 24 hours. The solution was left to evaporate and the sample was taken in 2,5N HCl. Sr was separated using conventional ion exchange technique. The Sr isotope ratios were measured using a multi-collector ionization Finnigan MAT-62 mass spectrometer.

Changes in the Original $\delta^{13}C$

Some processes may modify the isotope signature of carbonate rocks after their sedimentation. Processes such as diagenesis, metamorphism and hydrothermal alteration can be responsible for isotope exchange reactions that result in the modification of the original isotopic composition. During progressive or thermal metamorphism, decarbonation reactions are frequent and several products can be generated, depending on the original mineralogy of the carbonate rocks. Carbonate minerals and quartz (or feldspar) react to produce Ca or Mg silicates releasing CO_2. This CO_2 is ^{13}C-enriched, and consequently there is a decrease of the $\delta^{13}C$ value of the carbonate (Shieh and Taylor, 1969). In the absence of silicate minerals, the isotope signature $\delta^{13}C$, in general, is kept in Precambrian marbles (Taylor and O'Neil, 1977; Valley and O'Neil, 1984; Ghent and O'Neil, 1985; Baker and Fallick, 1989; Wickham and Peters, 1993). Calcite is stable within a large pressure-temperature range, and only a small quantity of overgrown material is sufficient to prevent decomposition and the release of CO_2 (Deer et al., 1966). Without the interference of external fluids, calcite recrystallizes originating marbles and preserving the isotope composition.

The alteration could be detected either petrographically, by textural features and/or by the presence of diagnostic minerals, or geochemically, through the analysis of the behavior of some selected elements. Examples of geochemical correlations, used to identify altered samples and/or the degree of alteration of the samples, are found in Kaufman and Knoll (1995), Jacobsen and Kaufman (1999) and Melezhik et al. (2001).

Marbles in the Seridó Belt are characteristically poor in silicate minerals. Quartz occurs as a rare accessory phase and there is a relationship between the presence and abundance of silicates and the distance to contact between the marbles and micaschists. The absence of quartz and the presence of silicate phases close to contact zones suggest that the formation of the amphibole and pyroxene was closely related to the presence of quartz grains in the original carbonates, or to the exchange/or infiltration of fluids from silicate rocks. A silica-rich fluid would allow

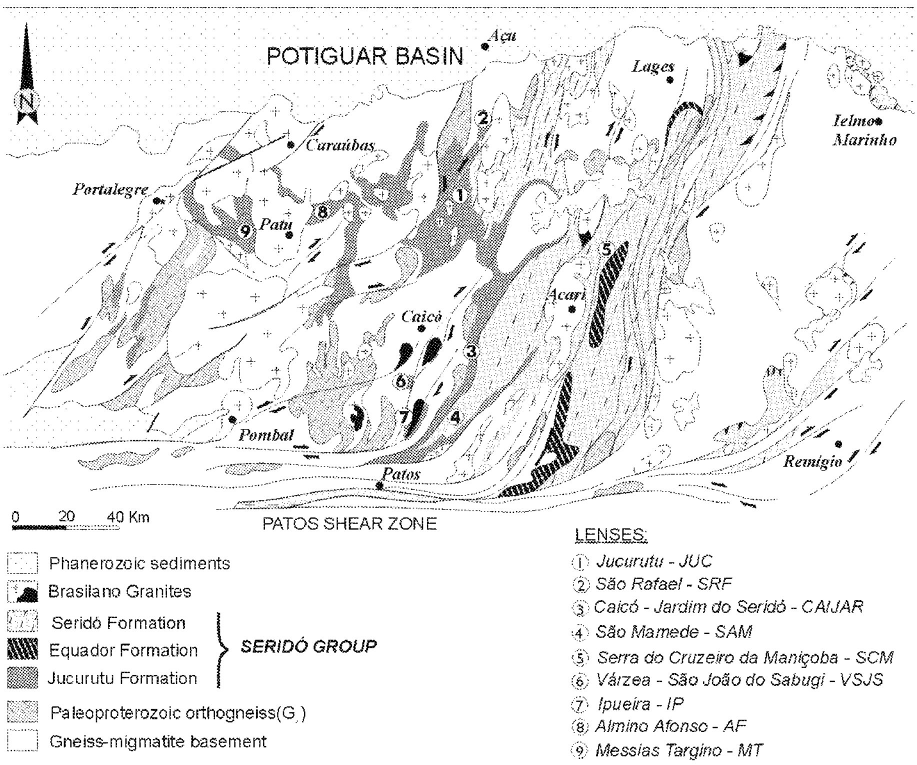

Fig. 2. Simplified geological map of the Seridó belt, showing the geographical and geological location of marbles in the present study. Modified after Jardim de Sá (1994).

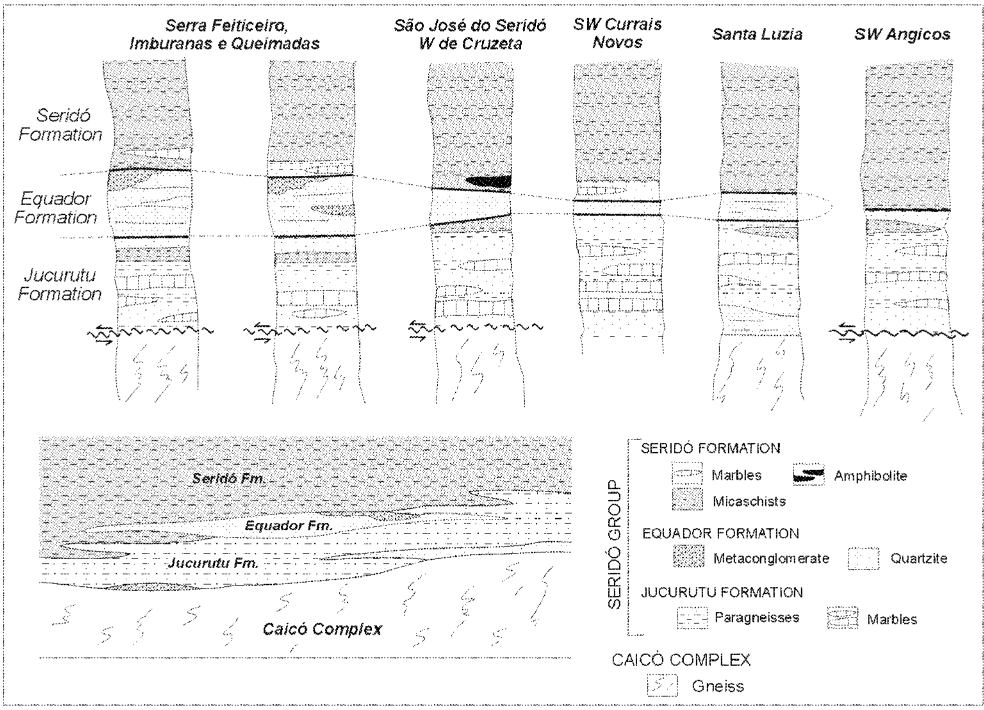

Fig. 3. Stratigraphic relationships in the Seridó fold Belt according to Jardim de Sá (1994).

the formation of diopside and tremolite by means of reactions similar to [1] and [2]. These reactions result in CO_2 release and, consequently, in the modification of the C-isotope original signatures.

$2SiO_2$ (aq) + Dol = Di + $2CO_2$ [1]

$8SiO_2$ (aq) + 5Dol + H_2O = 3Cal + Tr + $7CO_2$ [2]

C-isotope Geochemistry of the Seridó Belt Marbles

Three distinct levels of carbonate lenses can be recognized in the Jucurutu Formation based on their $\delta^{13}C$ values. The first one is observed in the Jucurutu, Caicó-Jardim do Seridó, Ipueira and Várzea-São João do Sabugi marble lenses, with $\delta^{13}C$ values between +2.8 and +11.8‰PDB and $\delta^{18}O$ between –20.3 and –5.6‰PDB. Silicate minerals are more common in marbles near their contact with pelitic metasedimentary rocks.

According to the alteration trends (Fig. 4), samples with the lowest $\delta^{13}C$ probably had their original isotopic signatures modified. Comparing the C-isotope to mineralogical compositions of the marbles, a close relationship between the amount of silicate and the depletion in ^{13}C is verified. If altered samples are discarded ($\delta^{13}C <$ +7.8‰PDB) the first carbonate sedimentation level of the Jucurutu Formation displays $\delta^{13}C$ between +8.3 and +11.8‰PDB.

The Almino Afonso marble lens represents the second level of carbonate sedimentation. In this lens, $\delta^{13}C$ varies from –1.1 to +8.7‰PDB and $\delta^{18}O$ from –19.1 to –5.7‰PDB. The negative values are found at the base of the section, in marbles with wollastonite and pegmatite veins and calc-silicate nodules. The alteration of samples more depleted in ^{13}C is clearly demonstrated in all geochemical variation diagrams in figure 5. The mineralogical constitution of those samples, demonstrates a large amount of fluid infiltration, which is indicated by the presence of wollastonite and calc-silicate nodules. This fluid allowed, by means of decarbonation reactions, the formation of wollastonite and subordinate Mg-olivine, resulting in the modification of the original $\delta^{13}C$ and $\delta^{18}O$ isotope signatures. In samples consisting essentially of calcite, $\delta^{13}C$ values vary from +7.6 to +8.7‰PDB and $\delta^{18}O$ from –10.9 to –5.7‰PDB.

The São Rafael and Messias Targino marble lenses define the third level of carbonate sedimentation. The Messias Targino marbles present a very homogeneous isotope composition with $\delta^{13}C$ values from +2.3 to +3.7‰PDB (Fig. 6) that apparently were not affected by modification of the isotopic composition due to alteration/ metamorphism. Differently, the São Rafael marbles are characterized by strong variation of their C and O isotopic compositions: $\delta^{13}C$ varies from –8.9 to +3.8‰PDB and $\delta^{18}O$ from –10.3 to –2.8‰PDB. Samples within the gray area in figure 6 are considered to be unaltered or only slightly altered. The remaining samples are regarded as potentially altered, considering their linear relationships for the chosen parameters. Excluding the altered samples,

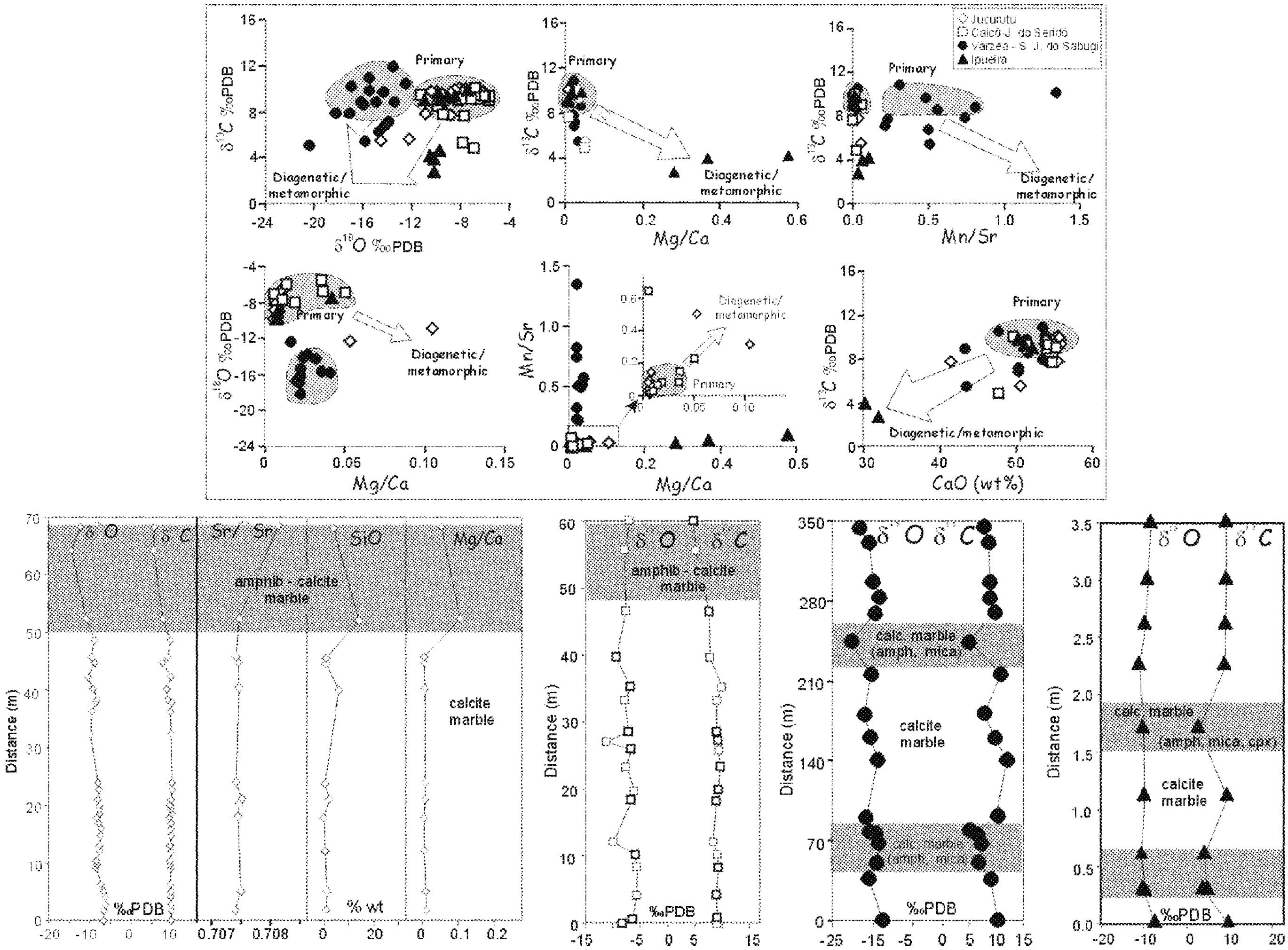

Fig. 4. Geochemical correlations applied to Jucurutu, Ipueira, Caicó-Jardim do Seridó and Várzea-São João do Sabugi marble lenses (first plateau of $\delta^{13}C$ values in the Jucurutu Formation), with the objective of selecting samples for chemostratigraphic studies of $\delta^{13}C$. Arrows indicate alteration trends.

$\delta^{13}C$ and $\delta^{18}O$ values for the São Rafael marbles are between +0.7 and +3.8‰PDB and –5.5 to –10.3‰PDB respectively. São Rafael marbles are constituted by calcite and dolomite in variable proportions (up to 50% of dolomite). In reactions (1) and (2), dolomite is consumed to generate amphibole or pyroxene. The more dolomite-rich the rock is, the higher the decrease of the Mg/Ca ratio due to decarbonation reactions.

In the Seridó Formation the two lenses sampled gave distinct $\delta^{13}C$ composition. The São Mamede lens has $\delta^{13}C$ values between +4.4 and +10.7‰PDB and $\delta^{18}O$ from –6.9 to –9.4‰PDB, with lowest values located near the contact with the host schist. In these samples, the silicate mineralogy is represented by tremolite and phlogopite. The altered character of the most ^{13}C-depleted samples is seen in figure 7. If altered samples were discarded, $\delta^{13}C$ would be in the interval between +8.9 and +10.7‰PDB and $\delta^{18}O$ between –6.9 and –9.4‰PDB.

The samples from Serra do Cruzeiro da Maniçoba lens have negative $\delta^{13}C$. These values range from –4.0 to –4.6‰PDB and $\delta^{18}O$ from –15.2 to –16.4‰PDB and according to diagrams in figure 8, the original isotope signatures are preserved. Silicate minerals are absent in these marbles.

Sr-isotope Geochemistry in Seridó Marbles

$^{87}Sr/^{86}Sr$ ratios have been determined for both Jucurutu ($\delta^{13}C$ between +8.5 and +10‰PDB; Fig. 4) and Messias Targino lenses ($\delta^{13}C$ varies from +2.3 to +3.7‰PDB; Fig. 6), intercalated in the Jucurutu Formation, and São Mamede ($\delta^{13}C$ varies from +8.9 to +10.7‰PDB; Fig. 7) and Serra do Cruzeiro da Maniçoba lenses ($\delta^{13}C$ varies from –4.6 to –4.0‰PDB; Fig. 8), intercalated in the Seridó Formation.

The Jucurutu and Messias Targino lenses, although displaying variable $\delta^{13}C$ compositions gave similar Sr isotopic ratios ($^{87}Sr/^{86}Sr$ ratio between 0.7074 and 0.7075; Table 1). The São Mamede marble lens, although intercalated in the Seridó Formation, yielded Sr isotope composition similar to the stratigrafically older marble lenses of the Jucurutu Formation ($^{87}Sr/^{86}Sr$ ratio between 0.7041 and 0.7056). In the section of Serra do Cruzeiro da Maniçoba, $^{87}Sr/^{86}Sr$ is higher and more variable, with values ranging from 0.7077 to 0.7094 (Table 1).

In the Serra do Cruzeiro da Maniçoba lens section, despite the general enrichment in radiogenic Sr, the gradational increase in $^{87}Sr/^{86}Sr$ indicates different degrees

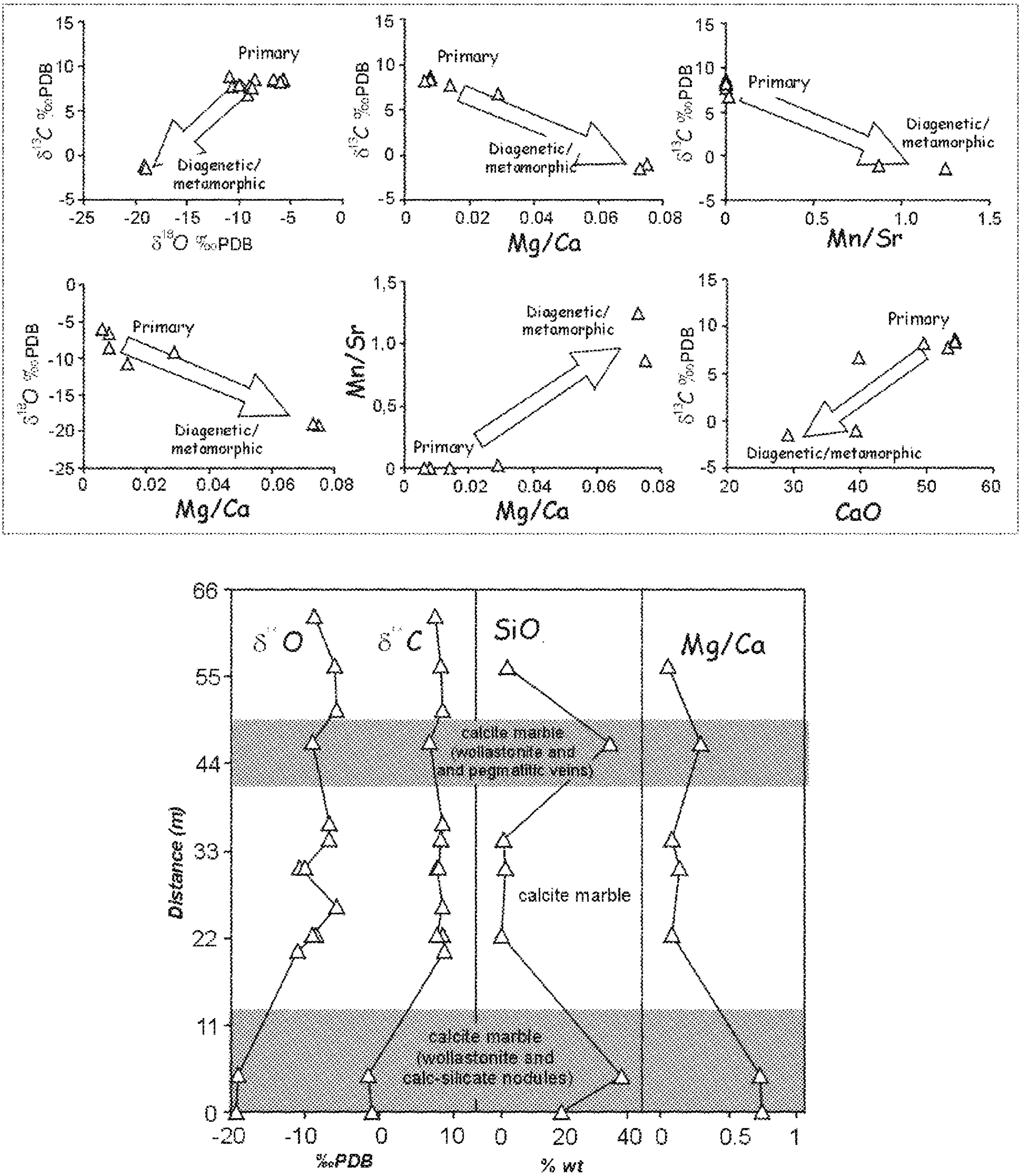

Fig. 5. Geochemical correlations applied to marbles of the Almino Afonso lens (second plateau of $\delta^{13}C$ values in the Jucurutu Formation) with the objective of selecting samples for chemostratigraphic studies of $\delta^{13}C$. Arrows indicate alteration trends.

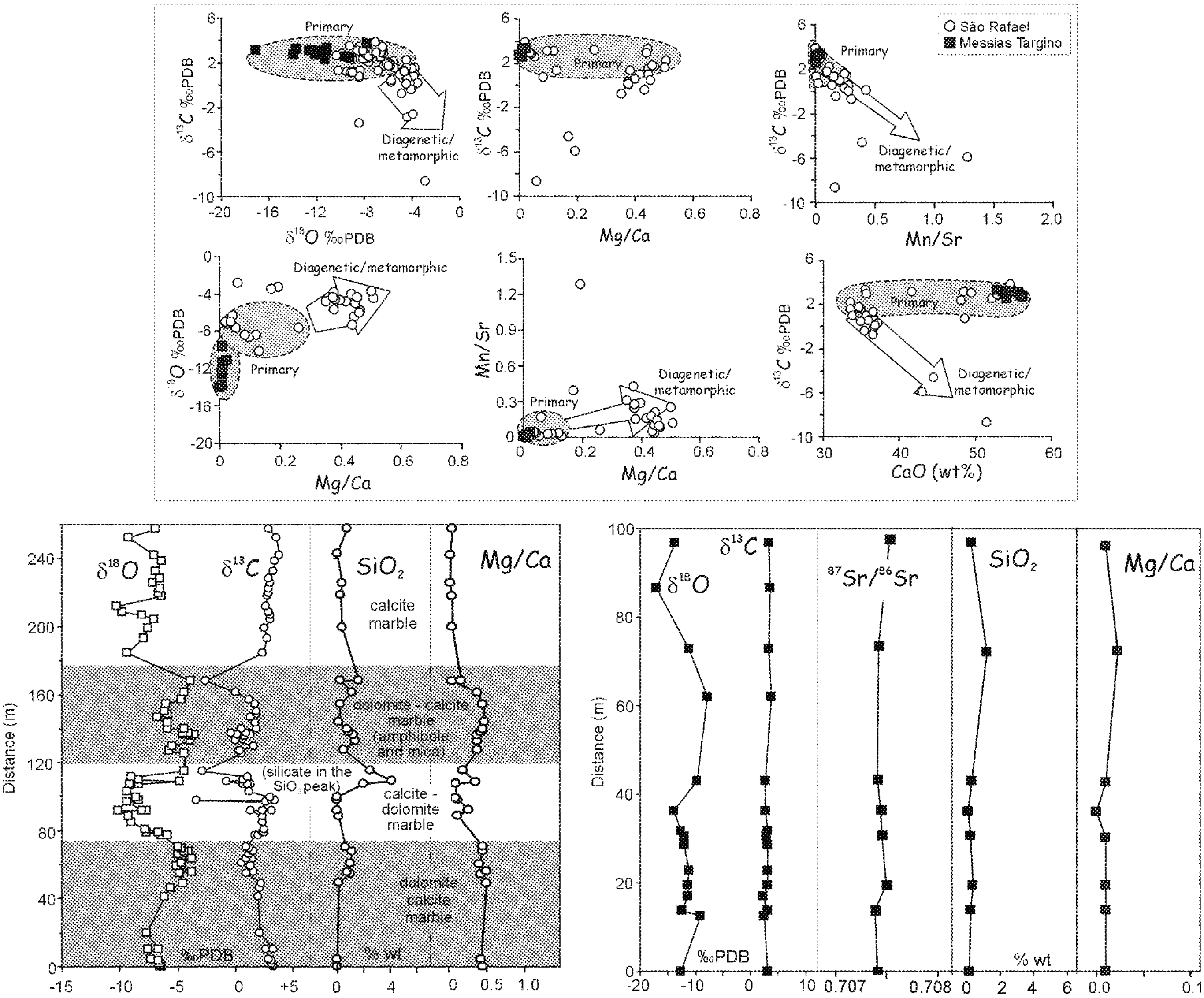

Fig. 6. Geochemical correlations applied to marbles of the São Rafael and Messias Targino lenses (third plateau of $\delta^{13}C$ values in the Jucurutu Formation) with the objective of selecting samples for chemostratigraphic studies of $\delta^{13}C$. Arrows indicate alteration trends.

of isotopic exchange. Samples in figure 9, when compared to those of the remaining chemostratigraphic sections, lead us to conclude that the isotope exchange was rather limited in samples with $^{87}Sr/^{86}Sr$ <0.7080. For this reason, and by comparison with the composition of samples in the São Mamede lens section, samples with $^{87}Sr/^{86}Sr$ <0.7080 from the Serra do Cruzeiro da Maniçoba section, have not been discarded from our chemostratigraphic studies.

Sedimentation Age of the Seridó Marbles Inferred from C-isotope Stratigraphy

The majority of $\delta^{13}C$ values for the Jucurutu Formation lenses are between +8.3 and +11.8‰PDB (Jucurutu, Caicó-Jardim do Seridó, Várzea-São João do Sabugi, Ipueira), despite their distinct geographic locations and compositional/mineralogical variations. This suggests that the carbonate sedimentation was temporally homogeneous in the Seridó Belt. The characterization of three compositional plateaus of $\delta^{13}C$ implies more than one stratigraphic level of carbonate rocks deposition in the Jucurutu Formation, as alreaday suggested by Jardim de Sá (1994; Fig. 3). The correlation with stratigraphic profiles proposed by Jardim de Sá (1994), in the region of São José do Sabugi and Ipueira, allows inferring that the Ipueira marble lens is the oldest one, and it is probably equivalent to the Caicó-Jardim do Seridó, Jucurutu and Várzea-São João do Sabugi marble lenses, as they exhibit similar C-isotope compositions (+8.3 and +11.8‰PDB).

Table 1. $^{87}Sr/^{86}Sr$ for marbles interlayered in the Jucurutu and Seridó Formations.

JUCURUTU FORMATION				SERIDÓ FORMATION			
JUCURUTU		MESSIAS TARGINO		SÃO MAMEDE		C. DA MANIÇOBA	
Sample	$^{87}Sr/^{86}Sr$	Sample	$^{87}Sr/^{86}Sr$	Sample	$^{87}Sr/^{86}Sr$	Sample	$^{87}Sr/^{86}Sr$
JUC-02	0.70740 ± 2	MT-01	0.70741 ± 4	SAM-08	0.70749 ± 5	SCM-1	0.70860 ± 8
JUC-05	0.70750 ± 8	MT-03	0.70739 ± 4	SAM-10	0.70741 ± 4	SCM-2	0.70831 ± 6
JUC-15	0.70745 ± 8	MT-05	0.70749 ± 8	SAM-11	0.70744 ± 4	SCM-3	0.70779 ± 5
JUC-18	0.70746 ± 6	MT-08	0.70745 ± 5	SAM-13	0.70756 ± 4	SCM-4	0.70797 ± 5
JUC-19	0.70751 ± 7	MT-10	0.70744 ± 5	SAM-15	0.70740 ± 5	SCM-5	0.70945 ± 8
JUC-21	0.70741 ± 8	MT-12	0.70741 ± 6	SCM-6	0.70772 ± 5		
JUC-26	0.70747 ± 4	MT-14	0.70742 ± 4	SCM-7	0.70804 ± 4		
JUC-28	0.70745 ± 5	MT-16	0.70753 ± 4				
JUC-29	0.70742 ± 6						
JUC-31	0.70746 ± 4						

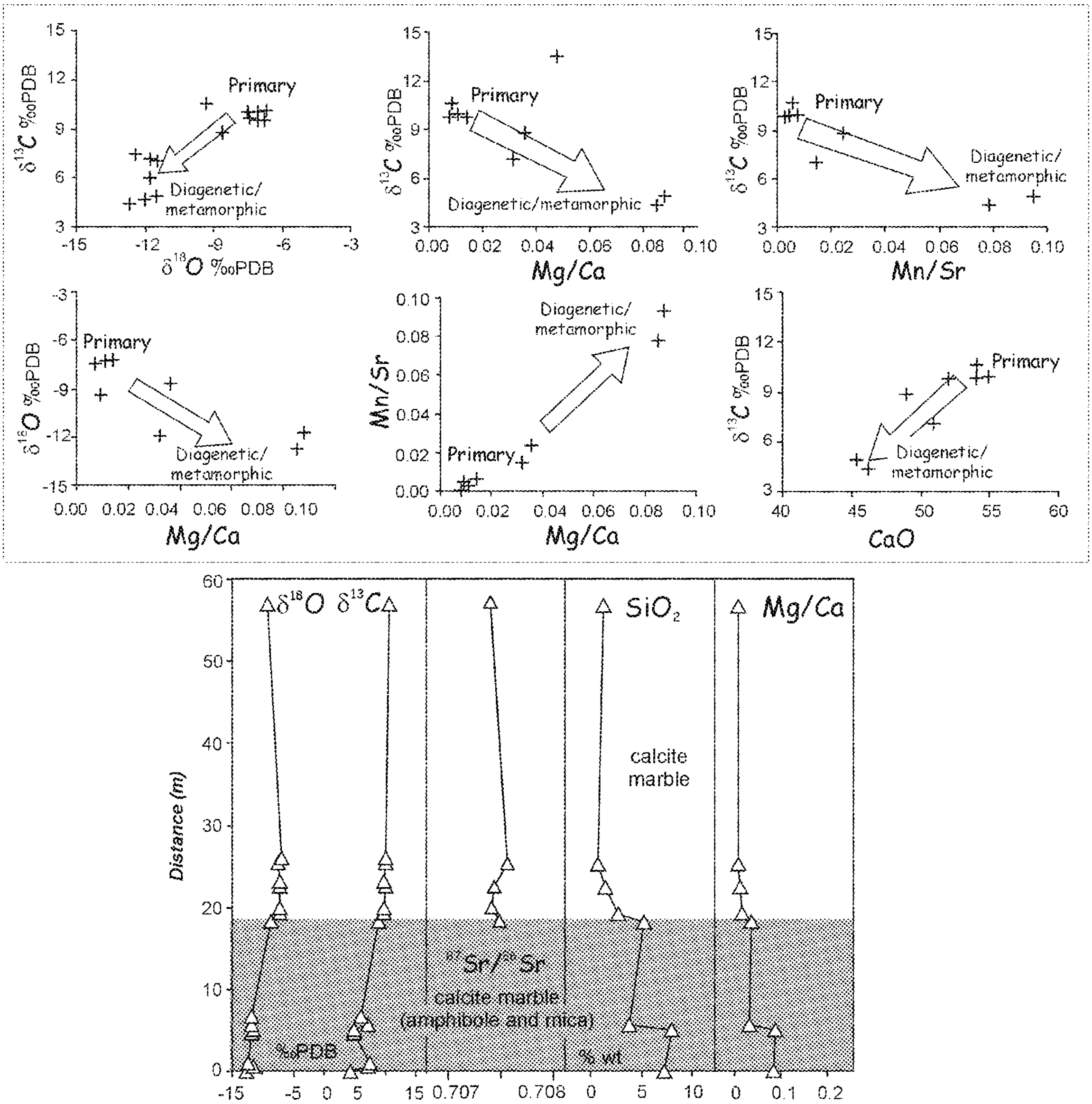

Fig. 7. Geochemical correlations applied to marbles of the São Mamede lens (first plateau $\delta^{13}C$ values of the Seridó Formation), with the objective of selecting samples for chemostratigraphic studies of $\delta^{13}C$. Arrows indicate alteration trends.

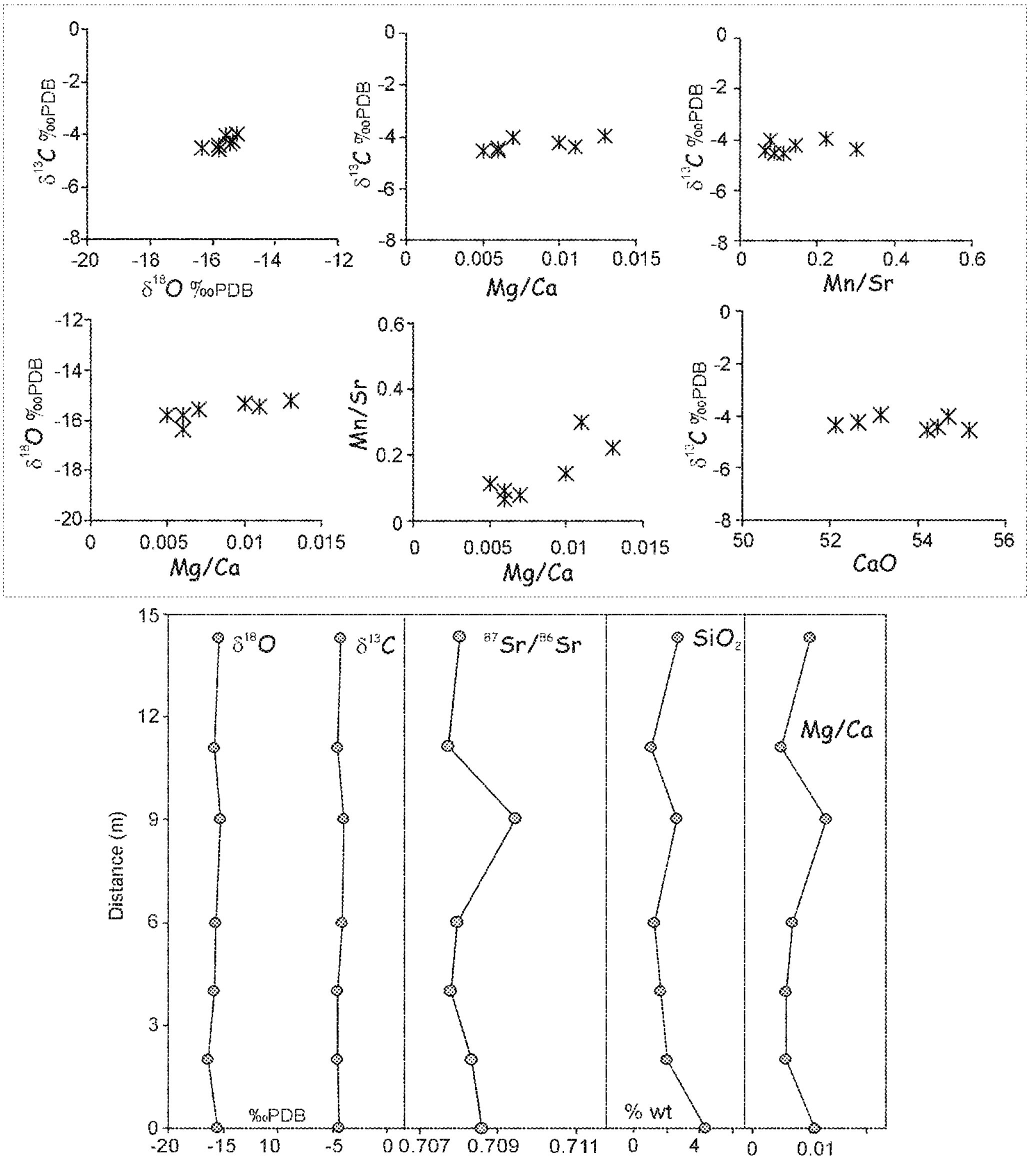

Fig. 8. Geochemical correlations applied to marbles of the São Mamede lens (second plateau of $\delta^{13}C$ values in the Seridó Formation*)*, with the objective of screening samples for chemostratigraphic studies of $\delta^{13}C$. Arrows indicate alteration trends.

The Almino Afonso lens represents the intermediate stratigraphic level ($\delta^{13}C$ between +7.6 and +8.7‰PDB) and the São Rafael lens forms the upper stratigraphic level ($\delta^{13}C$ between +0.7 and +3.8‰PDB) of the Jucurutu Formation. In the Seridó Formation, the $\delta^{13}C$ variation intervals also demonstrate the existence of more than one depositional level. Likewise the Jucurutu Formation, the gradational decrease of $\delta^{13}C$ values towards the top, suggests that the São Mamede lens ($\delta^{13}C$ = +8.9 to +10.7‰PDB) represents the base of the Seridó Formation, while the Serra do Cruzeiro da Maniçoba marble lens ($\delta^{13}C$ = –4 to –4.6‰PDB) represents an upper depositional level (Fig. 10A).

The comparison between the C-isotope composition of Seridó Belt marbles with the C-isotope secular variation trend (Hoffman et al., 1998) is presented in figure 10B, aiming at establishing an age interval for the sedimentation of the Seridó carbonates, as well as the relative stratigraphy for the marble lenses investigated. According to the secular C-isotope variation curve (Hoffman et al., 1998), continuous and vigorous oscillation in $\delta^{13}C$ values, from –4.6 to +11.8‰PDB, is restricted to the Neoproterozoic. These are also the extreme $\delta^{13}C$ values found in the marbles of the Seridó Group.

A zoom in the Neoproterozoic is seen in the figure 11A, with vertical areas illustrating the composition interval of the marble lenses studied. The estimate age for the original carbonate sedimentation of the Seridó Belt, obtained from

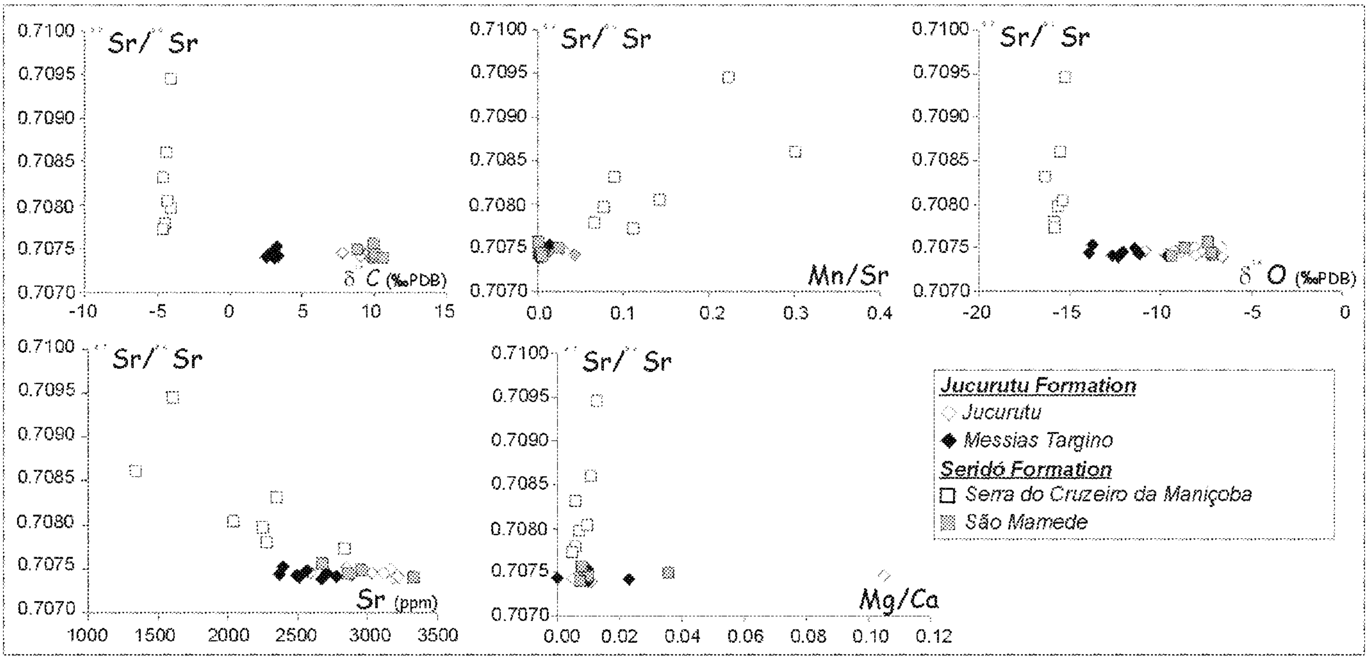

Fig. 9. Geochemical correlations applied to marbles of the Seridó group for screening samples for Sr-isotope chemostratigraphic studies.

the $\delta^{13}C$ fluctuations in marble lenses and compared with the C-isotope secular variation curve (Hoffman et al., 1998), suggests that the carbonate sedimentation of the Seridó Group is pre-Varanger (640 to 570 Ma; Fig. 11A). Regarding the general tendency for a decrease of ^{13}C upsection in all of the studied Seridó Group marbles, the age interval for deposition of these carbonates most probably lies between 590 and 570 Ma (Fig. 11A).

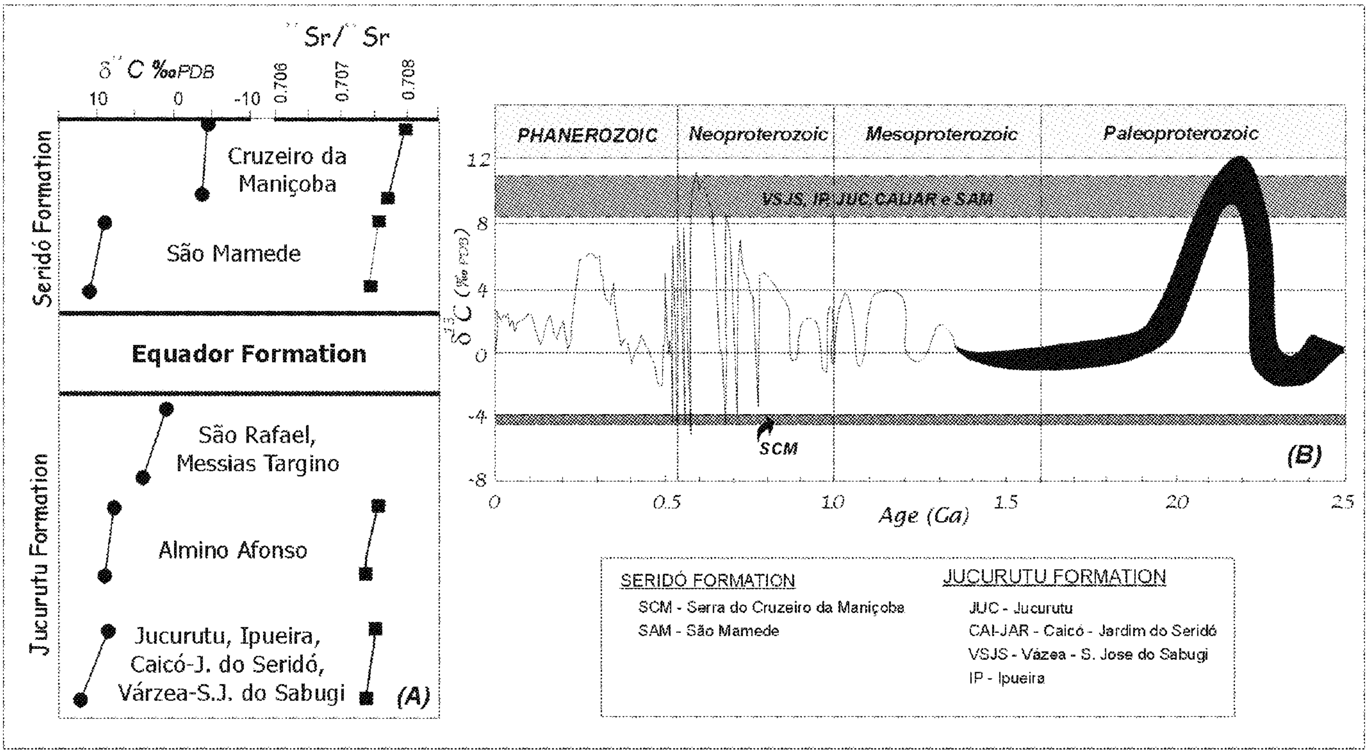

Fig. 10. Summarizes the C and Sr-isotope variations for marbles in the Seridó Belt (A) and (B) $\delta^{13}C$ secular variation curve for carbonates (2.5Ga to present times) - modified from Hoffman et al. (1998), to include Meso- to Neoproterozoic data from Kha et al. (1994).

Sr-isotope composition also supports a Neoproterozoic age for the Seridó Belt marbles. $^{87}Sr/^{86}Sr$ values ranging from 0.7074 to 0.7079, in Precambrian sedimentary carbonates are typical of the Neoproterozoic. In figure 11B, ages estimated by $\delta^{13}C$ and by $^{87}Sr/^{86}Sr$ for the Jucurutu and Messias Targino marble lenses (Jucurutu Formation) and São Mamede and Serra do Cruzeiro da Maniçoba lenses (Seridó Formation) are compared.

The $^{87}Sr/^{86}Sr$ ratios suggest a shorter age interval, between 610 and 595 Ma according to the trend of Melezhik et al. (2001) and 580 to 575 Ma according to the global trend of Azmy et al. (2001). In both cases, the ages estimated lie within the maximum age interval estimated from C isotope stratigraphy (640 to 570 Ma). However, if the minimum age for the Seridó group is taken into account (590 to 570 Ma), ages inferred from Azmy et al's (2001) Sr trend overlaps with the age interval estimated from the C chemostratigraphy (Fig. 11B).

The slight difference in the ages observed for carbonate deposition in the Seridó Belt obtained from the C chemostratigraphy, could result from the difference in residence time of Sr and C in the oceans. The residence time for Sr is estimated to be around 4 Ma (Kaufman and Knoll, 1995), while for C it is around 10^5 years (Kump and Arthur,

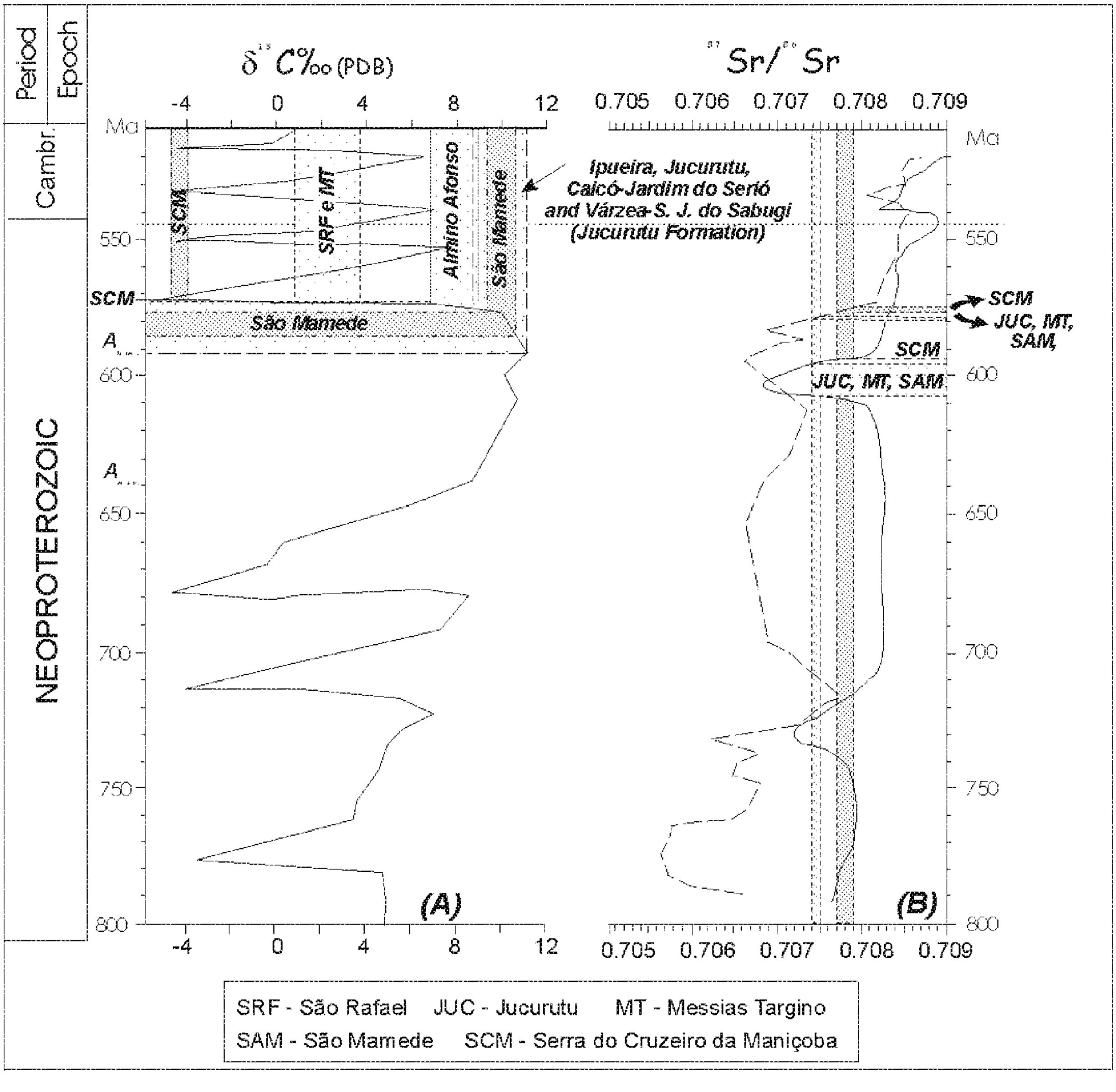

Fig. 11. Global trends of C isotope variation (A) and Sr (B) for the Neoproterozoic. Two Sr-evolution curves used are shown: the dashed curve was extracted from Azmy et al. (2001) and the solid curve from Melezhik et al. (2001). Dotted areas represent compositions of profiles of the Jucurutu Formation; gray areas, Seridó Formation. A_{max} and A_{min}, maximum and minimum ages respectively, for the sedimentation of carbonate rocks of the Seridó fold Belt.

1999). A time of residence so short for C implies variations in the C isotopic ratio of the oceans, are more perceptible, and more easily recorded than the Sr compositional variations (Jacobsen and Kaufman 1999).

Conclusions

C-isotope stratigraphic studies in marbles of the Seridó Belt do not support the hypothesis raised by Caby et al. (1995) of a time hiatus (≈1.0 Ga) between the deposition of the Jucurutu Formation/Equador Formation and the Seridó Formation. The progressive decrease of $\delta^{13}C$ values towards the top, suggests continuous sedimentation for the Seridó Group and synchronism during a certain time interval between the sedimentation of upper carbonate levels of the Jucurutu Formation and the sedimentation of the basal levels of the Seridó Formation.

The age interval (590 to 570 Ma) for the deposition of the Seridó Group is in agreement with U-Pb ages obtained for detrital zircons from the Seridó Formation (650 Ma; Van Schmus et al., 2003). These data are also further supported by $^{40}Ar/^{39}Ar$ studies of mica and amphibole by Figueiredo et al. (1992), in supracrustal rocks which indicate two metamorphic events: an earlier one of high temperature, aged 544±3 Ma, and a later one of low temperature (retrometamorphic age) with minimum age of 505–500 Ma.

Acknowledgments

We wish to thank E.F. Jardim de Sá for valuable suggestions and geological information about the Seridó Belt. We are also grateful to thank Valderez P. Ferreira for a critical review of an earlier version of this manuscript, and Simone Gioia for helping with the Sr isotope analyses at the University of Brasília. This is the contribution n. 202 of the NEG-LABISE, Department of Geology, Federal University of Pernambuco, Brazil.

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