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Strontium isotopic geochemistry of Pan-African/Brasiliano rocks, Chapada copper deposit, Goiás, Brazil

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With 2 figures and 1 table

Zusammenfassung

Das Trägergestein der Chapada Kupferlagerstätte in Goiás ist in metamorpher Hoch-Amphibolitfazies ausgebildet. Gesamtgesteins- und individuelle Mineral Rb-Sr-Isochronen mit einem $^{87}Sr/^{86}Sr$-Initialwert (I) von 0,70414 ± 0.00005 ergeben für die Kristallisation der Vulkanite und Magmatite, die die Metamorphose vordatieren, ein Alter von 561 ± 9 Mio Jahre. Die Datierung der Metamorphose während der pan-afrikanisch/brasilianischen Orogenese (700 bis 450 Mio Jahre) ergibt 532 ± 1 Mio Jahre. Das Mineral-Isochronenalter eines Dioritkörpers porphyrischen Gefüges, der in die Schiefer intrudierte, beträgt 534 ± 16 Mio Jahre (I = 0,70415 ± 0,00004). Das Ergebnis niedriger Initial-Werte dieser Isochronen ergibt für die Schiefer bei Chapada ein Ausgangs-Material im Bereich des oberen Mantels oder der tieferen Kruste; diese Ausgangswerte sind charakteristisch für magmatische Tätigkeit in Verbindung mit Inselbögen. Das unterkambrische Alter des Trägergesteins bei Chapada steht im Widerspruch zu dem bisher angenommenen mittelproterozoischen Alter und ist ein Hinweis auf eine mögliche Phase intensiverer pan-afrikanisch/brasilianischer magmatischer Aktivität in Zentral-Brasilien als ursprünglich angenommen wurde.

Abstract

Whole rock and mineral Rb-Sr isochrons from the upper amphibolite grade metamorphic host rocks of the Chapada copper deposit in Goiás, Brazil, yield an age of 561 ± 9 Ma, with a $^{87}Sr/^{86}Sr$ initial (I) of 0.70414 ± 0.00005, for the crystallization of pre-metamorphic volcanic and igneous rocks and 532 ± 1 Ma for their metamorphism during the Pan-African/Brasiliano orogeny (700-450 Ma). A porphyritic diorite stock which intruded the host schists yields a mineral isochron age of 534 ± 16 Ma (I = 0.70415 ± 0.00004). The low I values determined from these isochrons suggest that the host schists at Chapada were derived from upper mantle or lower crust material and are characteristic of magmatic products associated with island arcs. The Early Cambrian age of the host rocks at Chapada contradicts the previously assigned mid-Proterozoic age and suggests that Pan-African/Brasiliano magmatic activity may have been more extensive in central Brazil than previously thought.

Résumé

Les roches qui contiennent le gisement de cuivre de Chapada (Goias, Brésil) sont des schistes cristallins appartenent au facies dupérieur des amphibolites. Dans des volcanites et des roches orthomagmatiques appartenant à cet ensemble, des isochrones Rb-Sr sur roches totales et sur minéraux donnent un âge de 561 ± 9 Ma avec un rapport initial de 0,70414 ± 0,00005 pour la cristallisation pré-métamorphique et un âge de 532 ± 1 Ma pour le métamorphisme, lié à l'orogenèse pan-africaine / brésilienne. Un pluton de diorite porphyrique, qui intrude les schistes cristallins donne, par isochrone sur minéraux, un âge de 534 ± 16 Ma (rapport initial de 0,70415 ± 0,00004). Les valeurs basses des rapports initiaux de ces diverses roches suggèrent que les schistes de Chapada sont dérivés de matériaux mantelliques ou crustaux profonds et présentent les caractères des produits magmatiques associés aux arcs insulaires. Leur âge éo-cambrien, en contradiction avec l'âge mésoprotérozoïque admis jusqu'ici, permet de penser que l'activité magmatique pan-africaine/brésilienne dans le centre du Brésil a été plus intense que ce qu'on croyait jusqu'ici.

Краткое содержание

Вмещающие породы залежи меди Chapada в Goiás представляют собой амфиболитовую фацию высшей степени метаморфизма. Цельная порода и отдельные минералы дают для кристаллизации вулканитов и магматитов до метаморфизма начальное значение соотношения стронция в 0,70414 ∓ 0,00005, что разрешает принять их возраст в 561 ∓ 9 Мио лет, а возраст метаморфизма в 532 ∓ 1 Мио, т. е. отнести его к периоду панафриканского –бразильского орогенеза / 700 до 450 Мио /. При определении возраста минералов из диоритных тел порфиритовых текстур, интрудированных в сланец, получили даты в 534 ∓ 16 Мио лет / 1 = 0,70415 = 0,00004 /. Такое низкое значение исходных величин соотношения изотопов разрешает предполагать, что материал для Chapada принесен был из мантии, или глубинных регионов коры. Эти исходные значения характерны для магматической деятельности типа островных дуг. Возраст вмещающих пород считают средне-протерозойским; это стоит в противоре-

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чии с новейшими данными, по которым он может быть только нижнекембрийским. Это также указывает на то, что фаза пан-африканско-бразильской магматической активности в центральной Бразилии протекала, возможно, гораздо интенсивнее, чем принимали это до сих пор.

Introduction

This study presents strontium isotopic data from the Chapada copper deposit in central Brazil that document magmatic activity related to the Pan-African/Brasiliano orogenic event (700 – 450 Ma). This research is an outgrowth of a detailed study of the Chapada copper deposit (RICHARDSON et al., 1986) which, prior to our work, was thought to be of mid-Proterozoic age (RIBEIRO FILHO, 1981). While the principal focus of our investigation of the Chapada deposit has been elucidation of its origin and geochemistry, rather than clarification of its regional setting and timing of emplacement, we present these data in the hope that they will aid in the effort to delineate areas of Pan-African/Brasiliano rocks in central Brazil.

Geologic Setting and Characteristics of the Chapada Deposit

Chapada lies in the Brasilia-Uruacu mobile belt, which forms part of the Tocantins province between the Guaporé and São Francisco cratons. This mobile belt is geologically complex and contains rocks of Archean to Paleozoic age (DANNI et al., 1982; BERNASCONI, 1983). The principal stratigraphic divisions determined by regional mapping and radiometric dating in the Chapada region are: (1) Archean granite-gneiss, (2) Archean greenstone, (3) Early to Mid-Proterozoic metavolcanic and metasedimentary rocks (RIBEIRO FILHO, 1981). Archean granite-gneiss and greenstone constitute the Goiás Central Massíf, the basement upon which younger units have developed. Chapada itself is on the flank of the Hidrolina Dome, an Archean granitic block belonging to the Goiás Central Massíf (Fig. 1).

Our geological, mineralogical, and geochemical data on the Chapada deposit indicate that it is a metamorphosed wallrock-hosted porphyry copper deposit (RICHARDSON et al., 1986). Analogous porphyry Cu-Mo-Au deposits, some of which are metamorphosed, are found in terranes of Archean age in Canada, W. Australia, and Zambia (WAKEFIELD, 1978; AYRES & CERNY, 1982; BARLEY, 1982), of Proterozoic age in Finland (GAAL & ISOHANNI, 1979), of Devonian age in Scotland (FORTEY, 1980). Mineralization at Chapada is found as disseminated chalcopyrite and pyrite hostes primarily by biotite schist that is interlayered with lesser amounts of muscovite schist, amphibolite, and feldspathic quarzite. These rocks have been regionally metamorphosed to the upper amphibolite facies (650 ± 20 °C, 9 ± kb; RICHARDSON et al., 1986).

Mineralization clearly occurred prior to metamorphism as indicated by foliated sulfide minerals, sulfide inclusions in metamorphic minerals, evidence of sulfide-wall rock interaction such as zincian staurolite and gahnite, and the sensitivity of iron contents of biotite to fO_2 conditions dictated by accompanying sulfide-oxide mineral assemblages. Field relations, isotopic data discussed in this paper, and petrochemistry indicate that the host schists at Chapada were calcalkaline, peraluminous basaltic andesites to andesites of island arc affiliation. These rocks were intruded by a petrologically similar porphyritic diorite stock now separated from the Chapada deposit by a mylonite zone (RICHARDSON et al., 1986, Fig. 3). Mica-amphibole schists within the deposit are considered metamorphosed hydrothermally altered equivalents of this diorite.

In the Chapada region, greenstone sequences have been designated as the Pilar de Goias Group and are thought to be Archean in age because of their inclusion as xenoliths within radiometrically dated Archean granitoids (RIBEIRO FILHO, 1981). The rocks hosting the Chapada deposit have been designated the Mara Rosa Sequence and unconformably overlie or are thrust over the Archean Pilar de Goiás Group (Fig. 1). They have been considered early to mid-Proterozoic in age, based on their position immediately above Archean basement rocks (RIBEIRO FILHO, 1981). The Mara Rosa Sequence comprises diverse metavolcanic and metasedimentary rocks of upper amphibolite metamorphic grade. The Araxá Group, which lies to the southeast of the Chapada deposit (Fig. 1), comprises similar lithologies of slightly lower metamorphic grade (greenschist to epidote-amphibolite). Although the Araxá Group is similar to the Mara Rosa Sequence in that it unconformably overlies Archean rocks (RIBEIRO FILHO, 1981), Araxá rocks have generally been assigned to the Uruacuano orogenic cycle (1.4 to 1.1 Ga) on the basis of dating of granitic bodies which cross cut them. Intrusive rocks are found in all of the above units and include gabbro, diorite, granodiorite, tonalite, granite, serpentinite, and mafic dikes.

While the São Francisco craton and the high-grade mobile belts of the Brazilian coast have been the subject of a considerable number of geochronological studies (JARDÍM de SÁ, et al., 1976; CORDANI & IYER, 1979; CORDANI & TEIXEIRA, 1979; WERNICK, 1981; CORDANI & BRITO NEVES, 1982; BERNASCONI, 1983),

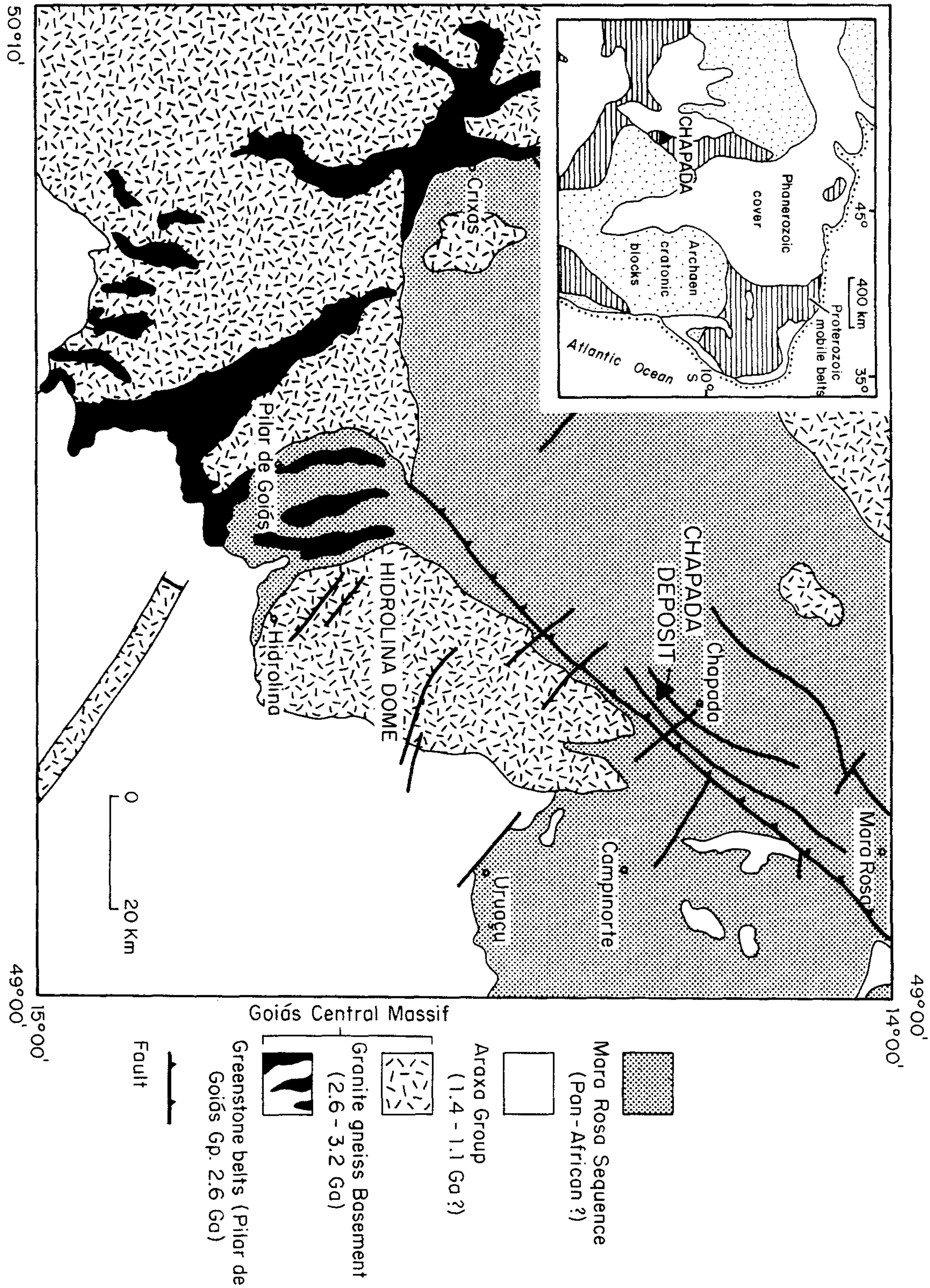

Fig. 1. Simplified geologic map of the Chapada region (after MACHADO, 1981 and RIBEIRO, 1981) showing distribution of local rock types. Inset shows location of the Chapada area (modified from RICHARDSON et al., 1986).

largely due to their favorable exposures, only a few Rb/Sr studies have been performed on rocks from the Tocantins province of central Brazil. A larger body of K-Ar data exists for this region, but most K-Ar dates reflect only the latest thermal event during the Brasiliano cycle and yield ages of 700 to 450 Ma. Archean Rb/Sr dates of 2.6 to 3.2 Ga (HASUI et al., 1980) have been obtained on granite-gneiss in the Goiás Central Massív, including the Hidrolina Dome (Fig. 1). Granitic intrusions that cross cut the Archean massifs and their surrounding mobile belts have yielded Rb/Sr ages from 2000 to 520 Ma, with intrusions related to the Brasiliano cycle clustering at 700 to 520 Ma (HASUI et al., 1980). Initial $^{87}Sr/^{86}Sr$ (I) values of these Brasiliano granitoids range from 0.706 to 0.760 and indicate varying degrees of crustal contamination and/or reworking. Chapada lies south of the area where most Pan-African/Brasiliano Rb/Sr ages have been obtained.

Analytical Procedures

Thirteen whole rock samples and nine mineral separates from the Chapada deposit were analyzed in this study. All samples but one, PCC-12, were taken from drillholes intersecting the mineralized schists at depth and therefore are free from the effects of weathering. An effort was made to sample apparently correlative lithologies from closely spaced drillholes in order to increase the probability of obtaining a cogenetic rock suite. Conventional methods were used for the preparation of whole rock samples. Mineral fractions were obtained by combinations of magnetic, heavy liquid, and hand picking separation techniques. Whole rock samples were powdered before analysis, while mineral separates were not further pulverized following separation. Strontium isotopic analyses were made at CONOCO, Inc. on a Varian® MAT 260 thermal

Sample	Description	Rb[a]	Sr[a]	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$[b]
4-100	Muscovite schist	124±1.8	68±1.5	5.295±0.14	0.74672±0.00008
12-40[d]	Pegmatite	201±2.28	80±1.21	7.33 ±0.14	0.79006±0.00004
30-80[d]	Amphibolite	8±1.09	475±6.1	0.049±0.007	0.70402±0.00004
31-80	Biotite schist	94±2.93	177±4.0	1.538±0.059	0.71611±0.00002
38-78	Amphibolite	13±0.6	418±6.9	0.090±0.004	0.70487±0.00002
41-65.2	Biotite schist	115±2.36	73±1.91	4.572±0.152	0.74049±0.00003
44-79.6	Biotite schist	71±1.90	105±3.30	1.958±0.081	0.71981±0.00002
59-68.8[d]	Pegmatite	230±3.88	72±0.86	9.314±0.192	-/78840±0.00003
63-80	Amphibolite	131±2.9	127±2.03	2.990±0.082	0.72870±0.00004
64-80	Biotite schist	89±3.24	360±5.4	0.715±0.028	0.70933±0.00005
87-80B[c]	Biotite	210±1.7	367±6.3	1.657±0.031	0.71713±0.00003
87-80M[c]	Muscovite	132±3.7	324±6.4	1.180±0.040	0.71655±0.00003
87-80P[c]	Plagioclase	46±1.1	399±4.6	0.334±0.009	0.70834±0.00003
87-80WR[d]	Biotite schist	75±2.4	402±5.6	0.540±0.019	0.70933±0.00001
88-79B[c]	Biotite	216±5.6	97±1.9	6.472±0.210	0.75490±0.00001
88-79M[c]	Muscovite	152±2.1	116±2.6	3.801±0.100	0.73509±0.00003
88-79P[c]	Plagioclase	37±1.7	82±2.4	1.306±0.071	0.71569±0.00002
88-79WR	Muscovite schist	93±2.5	153±4.0	1.760±0.066	0.71871±0.00003
PCC-12B[c]	Biotite	163±2.7	237±7.6	1.99 ±0.07	0.71892±0.00002
PCC-12H[d]	Hornblende	24±1.8	51±1.3	1.36 ±0.11	0.71141±0.00002
PCC-12P[c]	Plagioclase	18±0.9	819±8.3	0.064±0.003	0.70463±0.00002
PCC-WR	Foliated diorite	63±2.0	471±4.9	0.387±0.013	0.70717±0.00003

Table 1. Isotopic Rb/Sr data for Chapada whole rock and mineral samples. Superscripts: a — values in ppm; b — analytical error less than 0.01% (2 sigma); c — mineral separate; d — isochron outlier. All samples normalized To E&A 0.70800.

ionization mass spectrometer. A rhenium double-filament arrangement was used in the evaporation-ionization process and measurements were made with double Faraday collectors. The standard deviation for the analyses was usually within ± 0.00004 (2σ). During the course of this study, six independent determinations of the E & A standard gave an $^{87}Sr/^{86}Sr$ (I) of 0.70807 ± 0.00004 (2σ). Rubidium and strontium concentrations were determined by X-ray fluorescence using an ORTEC TEFA system. Replicate analyses indicate a precision of approximately two percent. Rb and Sr concentrations and Sr isotopic determinations of analyzed rocks and minerals are show in Table 1.

Strontium Isotopic Composition of Chapada Rocks and Minerals

A whole rock isochron calculated for eight metavolcanic rocks from Chapada defines an isochron age of 561 ± 9 Ma with an I value of 0.70414 ± 0.00005 (2σ) (Fig. 2A). Although a biotite schist, 87–80, and an amphibolite, 30–80, were excluded from this isochron because of their slight statistical deviation from the isochron calculated from the other eight samples, these samples clearly lie close to the calculated isochron, and are undoubtedly cogenetic with the eight host rocks constituting the isochron. Neither rock is lithologically different from other rocks on the isochron and they are not chemically altered or weathered. Two pegmatite samples fall above the isochron and are probably younger anatectic melts developed during the metamorphic event (discussed below) at 532 ± 1 Ma which followed formation of the host rocks. When the diorite whole rock sample, PCC-12, is included with the host schists, a calculated whole rock isochron age 560 ± 8 Ma with an I value of 0.70413 ± 0.00004 is obtained, values which are indistinguishable from those of the whole rock isochron calculated from the host schists alone. However, for reasons discussed below, we have chosen to leave the diorite off the whole rock isochron. A plot of 1/Sr versus a back-calculated $^{87}Sr/^{86}Sr$ value at 561 Ma for each sample shows no

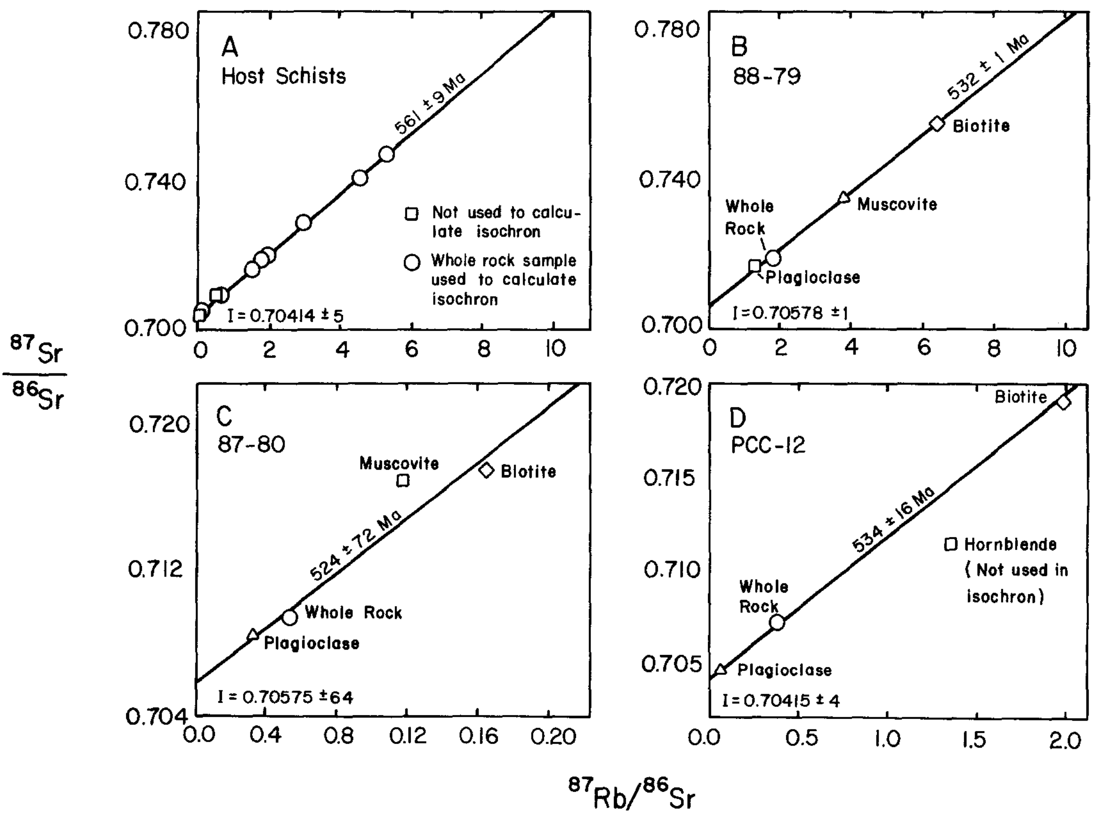

Fig. 2. A. Whole rock isochron for Chapada rocks. Isochron outiliers are pegmatites inferred to have formed during metamorphism. This and accompanying isochrons were calculated using a computer program (FAURE, 1977) based on equation 6 of YORK (1969). B. Mineral isochron, sample 88–79. C. Mineral isochron, sample 87–80. D. Mineral isochron, sample PCC-12. As discussed in the text, the hornblende fraction is not included in this isochron.

correlation and indicates that the rocks did not form by mixing of two Sr isotopic sources.

Mineral isochrons were determined for three rocks at Chapada to assess the age of metamorphism (Figs. 2B, 2C, 2D). Two biotite schists, 87–80 and 88–79, are from within the deposit and PCC-12 is a sample of the adjacent diorite. The best constrained mineral isochron is from sample 88–79, a biotite schist which falls on the whole rock isochron. This mineral isochron gives an age of 532 ± 1 Ma with an I value of 0.70578 ± 0.00001 (Fig. 2B). The other schist mineral isochron (87–80), which deviated slightly from the whole rock isochron, is not as well constrained. It gives an age of 524 ± 72 Ma, with an I value of 0.70575 ± 0.0006. This deviation probably reflects incomplete isotopic homogenization during metamorphism. The age of the mineral isochron for sample 88–79, 532 Ma, probably indicates the time of the latest thermal event to have affected these rocks. The temperature of 650 ± 20 °C which we have determined for peak metamorphism at Chapada (RICHARDSON et al., 1986) should have reset all minerals in the schists to the same I value. The diorite (PCC-12) yields an isochron for the whole rock, and plagioclase and biotite fractions, although the hornblende fraction does not fall on this line (Fig. 2D). We have no petrographic justification for omitting the hornblende, although the similarity of the whole rock-plagioclase-biotite isochron to the other mineral isochrons discussed above suggests to us that it should be excluded. Note that the resultant whole rock-plagioclase-biotite isochron has an I value, 0.70415 ± 0.00004, which is identical to that of the whole rock isochron, but an age, 534 ± 16 Ma, which is indistinguishable from that of metamorphism, 532 ± 1 Ma.

The relatively low I value of 0.70414 ± 0.00005 for the whole rock isochron suggests that the Chapada metavolcanic rocks were not derived from melting of older Precambrian crustal material. If, for example, they represented remelted mid-Proterozoic crustal material, even with a very low I value, such as 0.701, using an assumed Rb/Sr value of 1.8, their I value at 561 Ma would be around 0.73, far above the value observed here. The calculated I values for the biotite schist mineral isochrons, 0.70578 ± 0.00001 and 0.70575 ± 0.0006 are consistent with evolution from their original value of 0.70414 ± 0.00005 over the twentynine million years between formation at 561 Ma and metamorphism at 532 Ma. In the case of the diorite it is difficult to determine whether the mineral isochron age of 534 ± 16 Ma represents the age of formation or the age of metamorphism. Because of the obvious folded and foliated nature of the diorite, we know it has been dynamically metamorphosed. We also know from mineralogical and trace element data that the diorite is related to the surrounding schists (RICHARDSON et al., 1986). However from thin section examination of diorite samples, it is clear that there has not been extensive recrystallization during metamorphism; plagioclase is found as one centimeter-long zoned andesine phenocrysts, and some diorite samples contain igneous clinopyroxene. The plagioclase, hornblende, and biotite separated from the diorite for analysis were probably original magmatic phases as well (GILL, 1981). The close similarity of the diorite I value, 0.70415 ± 0.00004, to that of the host schists, 0.70414 ± 0.00005, suggests that the diorite was derived from the same relatively primitive isotopic reservoir and not from melting of older Precambrian upper crustal material. This observation, coupled with the presumed original magmatic nature of the diorite mineralogy, suggests that the diorite mineral isochron represents its age of formation, and not a metamorphic event which followed its formation at a significantly later date. If the diorite had formed considerably before metamorphism, its I value would have had to have been very primitive, and its K_2O abundance much lower than the observed 1.50 weight percent, to permit its evolution to the relatively primitive value, 0.70415 ± 0.00004, indicated by the isochron, assuming isotopic rehomogenization during metamorphism. Conversely, if the diorite had intruded with an I value equal to that of the host schists, 0.70414, significantly before metamorphism, its I value would be higher than indicated, again assuming isotopic rehomogenization during metamorphism. If we make the reasonable assumption that the diorite stock acted as a competent bulwark during metamorphism and that recrystallization and isotopic rehomogenization did not occur, as is indicated petrographically, a scenario involving diorite emplacement sometime between formation of the host schists at 561 ± 1 Ma and metamorphism at 532 ± 1 Ma, become plausible. As mentioned previously, the diorite does fall on the whole rock isochron. However, this could be fortuitous and it is unlikely that the diorite was emplaced long before metamorphism, as the folded and foliated nature of the diorite in outcrop suggests a synorogenic origin.

Relation of Chapada Ages to Geochronology of Central Brazil

The indicated age of formation of the rocks at Chapada, 561 ± 9 Ma, contradicts the previously assigned early to mid-Proterozoic age for the Mara Rosa Sequence (RIBEIRO FILHO, 1981). Either the host schists at Chapada do not belong in the Mara Rosa Sequence, or the Mara Rosa Sequence is actually much younger and related to volcanism and plutonism associated with the Brasiliano cycle (700–450 Ma). Our field work in the vicinity of Chapada did not permit a distinction to be made between Chapada rocks and the surrounding Mara Rosa Sequence, as both appeared lithologically similar and equally metamorphosed. Thus, we cannot say, at this time, whether our age data for Chapada should be extended to the entire Mara Rosa Sequence.

The significance of our results to regional geochronological relations lies in the recognition of Pan-African/Brasiliano magmatic activity of a type not previously seen in this area. Pan-African/Brasiliano granitoids with I values less than 0.710 are found in the northern part of the Brasília-Uruacu belt, but were not known as far south as Chapada. A Rb/Sr geochronological study near Chapada (HASUI et al., 1980) has identified rocks of Pan-African/Brasiliano age (550 Ma) with I value of 0.760, indicating at least partial reworking of continental crust. However, the magmatism represent by the Chapada deposit is not related simply to rejuvenation of older basement rocks; its I values are too low to permit extensive crustal residence. Our Sr isotopic results from Chapada indicate not only a thermal event at this time but also chemically primitive, arc-related calc-alkaline andesitic magmatism. This activity within the Brasilia-Uruacu mobile belt may represent cratonization of the South American continent. Calc-alkaline andesitic magmatism related to subduction was also occuring in northeast Africa during this time and has been suggested as an important factor in cratonization there (GASS, 1982). In addition, the recognition of Pan-African/Brasiliano magmatic activity may be of possible metallogenetic significance in that we know, from our investigation of the Chapada deposit (RICHARDSON et al., 1986), that high level granitoids of the age and type represented by Chapada are mineralized in this area of Brazil and constitute an important target for mineral exploration.

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