

Geochronology of the basement rocks, Amazonas Territory, Venezuela and the tectonic evolution of the western Guiana Shield

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Abstract

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The Amazonas Territory of Venezuela is a large area of Precambrian basement rocks overlain in some locales by the supracrustal sedimentary and volcanic rocks of the Roraima Formation. The basement rocks are medium to high grade gneisses with both igneous and sedimentary protoliths, plutonic rocks ranging in composition from granite to tonalite, and meta-volcanic rocks.

Rb-Sr whole rock, and U-Pb isotopic analyses of zircons indicate a period of medium to high grade metamorphism and intrusion from 1860 to 1760 Ma. Post-tectonic plutonic activity continued to 1550 Ma. The volcanic rocks of the Roraima Formation in Venezuela give an age of 1746 Ma comparable to volcanic rocks of the Roraima Formation in other parts of the Guiana Shield.

The ages and distribution of the basement rocks suggest the presence of a tectonic zone, approximately coincident with the Venezuelan-Colombian border, representing an active orogenic boundary between distinct tectonic provinces. The rocks to the northeast of this zone are part of the Trans-Amazonian of the Guiana Shield, while to the southwest and in adjacent Brazil and Colombia, new younger continental crust has been developed and cratonized. We suggest a model of collision and subduction followed by a change in tectonic style to extensional-vertical to produce the basement rocks of the western Guiana Shield in the Amazonas Territory.

Introduction

The Amazonas Territory of southern Venezuela is a large (> 240 000 km²) area of Precambrian and presumed Precambrian plutonic and metamorphic rocks overlain in places by the supracrustal sedimentary and volcanic rocks of the Roraima Formation (Figure 1). The relationships between these rocks are complex and are very often obscured by extensive jungle cover and deep weathering. In

recent years, detailed field investigations by geologists of the Venezuelan Ministry of Energy and Mines (MEM) have resulted in the development of a better geologic framework upon which to base geochronological studies.

The plutonic rocks of the Amazonas Territory have a wide range of compositions and textures but are principally quartz diorites to granites. Textures vary from well developed equigranular igneous textures to moderately foliated and banded gneis-

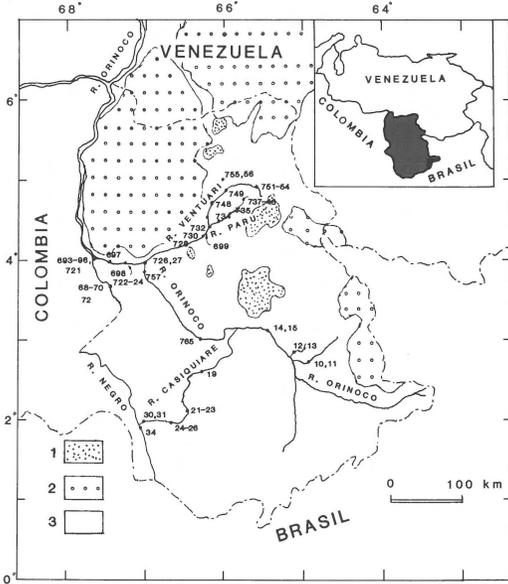


Fig. 1. Generalized geologic map of the Amazonas Territory of Venezuela showing the locations of the samples investigated. Legend 1. Roraima Formation sedimentary rocks; 2. Granite; Parguaza granite in the northern Amazonas Territory and correlated granites along the Venezuela-Brazil border; and 3. undifferentiated Precambrian basement rocks of the Amazonas Territory; granites, tonalites, gneisses, migmatites and schists with subordinate volcanic rocks. The numbers correspond to the sample numbers of Tables 1 and 2.

sic textures. Contact relationships between plutonic rocks are complex as well. For example, along the Casiquiare River, bodies of granite and granodiorite with xenoliths of tonalite are found near bodies of tonalite with granitic xenoliths. The precise time-space relationships of plutons such as these are not readily apparent, although as we discuss later, the plutonic rocks in any one area are essentially contemporaneous.

The plutonic rocks, in several instances, also show evidence of mechanical deformation. Shearing, grain crushing, and small scale faulting are present in some plutonic units. Some plutons, such as the Atabapo granite, are also extensively cut by aplite dikes, ranging in width from 1 cm to 1 metre, with a fine to medium grained texture. Cross cutting relationships indicate more than one episode of aplite intrusion.

The metamorphic rocks also exhibit considerable variability, with textures ranging from poorly foliated and mildly tectonized rocks, to well devel-

oped gneisses and migmatites. Metasediments (conglomerates, quartzites, phyllites and others) of low metamorphic grade (i.e. La Esmeralda Formation) are present, as well as a wide variety of meta-igneous rocks which range in composition from granite through granodiorite, tonalite, and diorite. Textures and degrees of metamorphism vary from poorly to moderately foliated, to intense metamorphic effects as in the migmatite at Mini-ciate or the augen gneiss at Macabana. Some of these medium to high grade gneisses suggest a volcanoclastic protolith.

Moderately tectonized and partially re-crystallized felsic volcanic rocks are also present. These volcanic rocks appear to have affinities to the Caicara Formation volcanic rocks of the Cuchivero province further to the North (Gaudette et al. 1978).

A complete description of the geology of the basement rocks of the Amazonas Territory of Venezuela can be found in Mendoza et al. (1977). A more general discussion of the geology of the Amazonas Territory with respect to the entire Guiana Shield is presented in Gibbs & Barron (1983).

In large areas of the Amazonas Territory, spectacular erosional outliers of the supracrustal Roraima Formation overly the basement gneisses and plutonic rocks. The Roraima Formation is a thick sequence of essentially flat-lying unmetamorphosed sedimentary rocks interstratified with occasional felsic volcanic rocks. This formation extends over large parts of southeastern Venezuela, as well as parts of Brazil, Guyana, and Suriname. The Roraima Formation is composed of 3 members (Gansser 1954, Ghosh 1977) with the middle member containing fine grained red and green felsic volcanic rocks. At Tafelberg in Suriname, these volcanic rocks have been dated by Priem et al. (1973) at 1654 Ma (recalculated with $87Rb/\lambda = 1.42 \times 10^{-11} \text{ yr}^{-1}$) with an initial strontium ratio of 0.7075.

Tassinari (1981) in his study of the basement rocks of the adjacent Amazon Territory of Brazil indicates ages of 1750 to 1400 Ma for the gneisses and migmatites of the crystalline basement of the Rio Negro-Juruena province. He has proposed

models for the tectonic evolution of the Rio Negro-Juruena system as either a 'mobile belt' at the border of an older craton, or as part of a magmatic arc produced by the interaction of a continental plate with an oceanic plate at about 1750 Ma.

Recently Priem et al. (1982) have made isotopic age measurements of basement granites and gneisses, and felsic volcanic rocks overlying the basement rocks in the Amazonas Territory of southeastern Colombia. They suggested that the basement was essentially formed by large-scale granite plutonism, and metamorphic reorganization of older crustal material during the period 1560-1450 Ma ago. Numerous mineral ages (principally micas) cluster between 1350 and 1250 Ma corresponding to the Nickerie metamorphic episode. No distinct ages older than about 1560 Ma were determined, but they indicated the presence of older radiogenic strontium and radiogenic lead suggesting a minimum age of about 1850 Ma for the pre-1560 Ma basement. This they related to the Trans-Amazonian Orogenic cycle so well established in the Guiana Shield to the northeast.

We have sampled the crystalline basement rocks for isotopic age determinations as part of a geological exploration program of the Amazonas Federal Territory conducted by the Direccion de Geologia, MEM, Caracas. This paper presents the results of the geochronological studies, and suggests a tectonic framework for the evolution of this portion of the Guiana Shield of northern South America.

Field sampling

Sampling of the rock units included in this study was carried out by the authors from 1976 through 1978, in concert with field programs of geologists of MEM. Because of the extensive cover of tropical forest, sample collection was done by boat and helicopter along the major rivers and streams of the Territory. Sampling outcrops along the rivers provided fresh materials in spite of the intense tropical weathering common to the area. Some samples however, were discarded after examina-

tion in the laboratory because of weathering effects. The samples that were collected were either single pieces or a collection of pieces of rock that weighed several kilograms. Several larger samples (> 10 kilograms) were collected for zircon separation for U/Pb analysis. In all cases, the samples were the freshest materials available. The 81 analyses presented in this paper are from samples for which we consider the Rb-Sr and U-Pb data to be good and unaffected by field conditions.

Laboratory techniques

Samples for Rb-Sr analysis were cleaned in the laboratory of any surface contamination, and examined carefully for weathering effects. The unweathered samples selected for analysis were crushed to < 200 mesh, and analyzed by X-ray fluorescence to determine approximate concentrations of Rb and Sr as a guide for sample selection, and for spiking of the samples for isotopic analysis. Samples of 0.1 grams weight were dissolved in hydrofluoric-perchloric acid mixtures, converted to chlorides, and Rb and Sr separated by cation exchange procedures. The Rb and Sr were converted to nitrates and analyzed on the 12 inch, 60 degree sector mass spectrometer at the M.I.T. Geochronology Laboratory. All isochrons were calculated using the regression equations of York (1969). Replicate analyses gave the following experimental errors: $^{87}\text{Rb}/^{86}\text{Sr} = 1.8\%$ $^{87}\text{Sr}/^{86}\text{Sr} = 0.13\%$. Correlation between these errors is 0.011. The decay constant for ^{87}Rb is $1.42 \times 10^{-11} \text{ yr}^{-1}$ (Steiger & Jager 1977).

For U-Pb analyses of zircons, 10 kilograms or more of rock were crushed and sieved to separate an 80 to 325 mesh fraction. This fraction was processed using heavy liquids to separate the zircons which were then separated into fractions by size and magnetic susceptibility. The zircons were dissolved, spiked and U and Pb separated using the procedures of Krogh (1973). U and Pb isotopic analysis was done using the phosphoric acid-silica gel method of Cameron et al. (1969) on the same mass spectrometer as used for the Rb-Sr. Errors for

Table 1. Rb-Sr Whole Rock Analytical Data.

<i>Gneisses, Orinoco, Ventuari and Paru Rivers</i>					<i>Padamo Granite</i>					
<i>Sample</i>	<i>Rb</i>	<i>Sr</i>	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	<i>Sample</i>	<i>Rb</i>	<i>Sr</i>	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	
<i>No.</i>	<i>(ppm.)</i>	<i>(ppm.)</i>			<i>No.</i>	<i>(ppm.)</i>	<i>(ppm.)</i>			
Minicia Suite	R8697	132	169	2.272	.7609	UNH10	173	372	1.350	.7402
	R8698A	150	339	1.287	.7374	UNH11A	234	450	1.508	.7451
	R8698B	128	229	1.629	.7434	UNH11B	214	469	1.326	.7411
	R8724	116	504	.6689	.7198	UNH12	195	324	1.750	.7514
Macabana Suite	R8699	300	198	4.450	.8215	UNH13	169	330	1.484	.7445
	R8722	162	298	1.580	.7458	UNH14	204	135	4.408	.8199
	R8723	134	342	1.133	.7289	UNH15A	192	201	2.784	.7789
	R8727	161	296	1.576	.7418	UNH15B	169	200	2.462	.7698
	R8747	236	145	4.754	.8264					
Quartz Diorite Suite	R8734	89.9	693	.3758	.7133	<i>Plutonic Rocks, Casiquiare River</i>				
	R8743	60.8	745	.2367	.7103	<i>Sample</i>	<i>Rb</i>	<i>Sr</i>	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$
	R8748	224	189	3.465	.7943	<i>No.</i>	<i>(ppm.)</i>	<i>(ppm.)</i>		
	R8752	116	489	.6910	.7241	UNH19	165	150	3.225	.7886
<i>Plutonic Rocks, Orinoco, Ventuari and Paru Rivers</i>					<i>Gneisses, Casiquiare River</i>					
<i>Sample</i>	<i>Rb</i>	<i>Sr</i>	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	<i>Sample</i>	<i>Rb.</i>	<i>Sr</i>	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	
<i>No.</i>	<i>(ppm.)</i>	<i>(ppm.)</i>			<i>No.</i>	<i>(ppm.)</i>	<i>(ppm.)</i>			
R8726	199	219	2.638	.7623	UNH21A	279	71.8	11.57	.9906	
R8728	131	440	.8651	.7223	UNH21B	271	70.2	11.50	.9986	
R8730	207	93.2	6.542	.8806	UNH22	216	231	2.729	.7697	
R8732	96.6	287	.9774	.7286	UNH23	226	148	4.473	.8206	
R8733	179	189	2.753	.7743	UNH24	132	437	.8774	.7266	
R8735	135	671	.5834	.7139	UNH25A	179	344	1.509	.7392	
R8736	60.2	840	.2078	.7122	UNH25B	191	342	1.622	.7427	
R8739	94.3	313	.8762	.7277	UNH26	149	503	.8605	.7247	
R8740	121	360	.9771	.7263						
R8741	140	668	.6073	.7199						
R8742	97.1	562	.5015	.7229						
R8744	139	530	.7586	.7219						
R8745	144	315	1.332	.7350						
R8746	131	501	.7597	.7187						
R8749	132	381	1.005	.7309						
R8751A	189	326	1.686	.7463						
R8753	106	983	.3119	.7121						
R8754	213	315	1.973	.7704						
R8757	269	58.4	13.80	1.042						
R8765	240	183	3.837	.7959						
<i>Atabapo Granite</i>					<i>San Carlos de Rio Negro Granite</i>					
<i>Sample</i>	<i>Rb</i>	<i>Sr</i>	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	<i>Sample</i>	<i>Rb</i>	<i>Sr</i>	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	
<i>No.</i>	<i>(ppm.)</i>	<i>(ppm.)</i>			<i>No.</i>	<i>(ppm.)</i>	<i>(ppm.)</i>			
UNH67	214	211	2.955	.7832	UNH30	411	82.7	14.87	1.038	
UNH78	240	196	3.561	.7960	UNH31	396	87.5	13.47	1.007	
R8695	252	176	4.177	.8081	UNH34A	264	349	2.195	.7519	
R8696	164	218	2.193	.7626	UNH34B	254	324	2.277	.7563	
<i>Rio Atabapo Gneiss</i>					<i>Roraima Formation Volcanic Rocks</i>					
<i>Sample</i>	<i>Rb</i>	<i>Sr</i>	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	<i>Sample</i>	<i>Rb</i>	<i>Sr</i>	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	
<i>No.</i>	<i>(ppm.)</i>	<i>(ppm.)</i>			<i>No.</i>	<i>(ppm.)</i>	<i>(ppm.)</i>			
UNH68A	239	151	4.631	.8273	UNH1	214	162	3.850	.8031	
UNH68B	252	149	4.952	.8317	UNH2	232	228	2.967	.7858	
UNH69	281	160	5.133	.8361	UNH3	264	324	2.377	.7703	
UNH70	234	210	3.251	.7888	UNH4	229	158	4.243	.8119	
UNH72	242	173	4.076	.8101	UNH5	237	164	4.233	.8136	
					UNH6	232	189	3.578	.7966	
					UNH83	244	658	1.077	.7321	
					UNH84	255	724	1.021	.7341	
					UNH85	131	78.4	4.907	.8378	

the U-Pb are $^{207}\text{Pb}/^{235}\text{U} = 1\%$, $^{206}\text{Pb}/^{238}\text{U} = 1\%$, with an error correlation of 0.9. The decay constants used are those suggested by Steiger & Jager (1977). Correction for modern lead contamination was done using laboratory blank compositions with 204: 206: 207: 208 = 1: 20.75: 15.82: 39.5. Discordia line regressions were also done using the equations of York (1969). All errors quoted are \pm one standard deviation of the mean unless otherwise noted.

Blanks for the analyses are: Rb = 6 ngm., Sr = 3.3 ngm. or less, Pb = 7 ngm., and less than 0.1 ngm. for U.

Results

The analytical results are presented in three groupings based upon the nature of the rocks and the geographic area. These are: 1: Basement rocks of the northern and central Amazonas Territory; 2: Basement rocks of the southern Amazonas Territory, and 3: Roraima Formation volcanic rocks.

1. Northern and Central Amazonas Territory

Three sets of gneisses separated by composition, texture, and geography are found along the Orinoco River between San Fernando de Atabapo and Santa Barbara, and along the Ventuari River north of Santa Barbara (Figure 1). The Minicia gneiss or migmatite is found for about 20 km eastward along the Orinoco River from about 20 km east of San Fernando. The Minicia gneiss is a well foliated equigranular quartz-biotite-feldspar gneiss with accessory garnet, magnetite, and very minor epidote. Metamorphism has reached amphibolite grade. Cataclasis is common. The Minicia gneiss is essentially granitic in composition.

The Macabana augen gneiss occurs in a wide area along the Orinoco River from the area to the west of Santa Barbara eastward along the Ventuari River to Macabana. Essentially granitic in composition, it is coarse-grained, and composed of two feldspars, biotite, quartz, hornblende, and minor epidote. The Macabana gneiss is well foliated, and characterized by well developed large augen of

K-feldspar. The feldspar and quartz grains show evidence of cataclasis. Present metamorphic grade is epidote-amphibolite, but this may be retrograde.

A third group of gneisses, which we call the quartz diorite gneiss suite, is found along the upper reaches of the Ventuari River as far as Tencua, as well as along the Paru River, a tributary of the Ventuari. This suite has a composition varying from diorite to tonalite, and averaging in the quartz diorite range. The rock samples are dark in colour, medium to coarse-grained with occasional augen, poorly foliated, and only moderately cataclastized. Dominant mineral compositions are plagioclase, biotite, hornblende, quartz, and epidote. Metamorphism is amphibolite grade.

The Rb-Sr analytical data for these gneisses are shown in Table 1. All of the gneiss data are plotted in Figure 2; Rb-Sr data for each of the separate suites we have distinguished are plotted in Figures 3, 4 and 5. In addition to the Rb-Sr results, U-Pb analyses were made on zircons from the Macabana gneiss (sample R8699) and the Minicia gneiss (sample R8697). The U-Pb results are shown in Table 2 and are plotted in Figure 6. Zircons from both gneisses show similar characteristics. They are pink to light brown in colour, cloudy, and principally rounded to subhedral. Occasional more euhedral shapes occur in the larger size fractions. The grains are irregularly fractured, and are covered with zones of overgrowth. The cores of the zircons are rounded to subhedral, while the over-

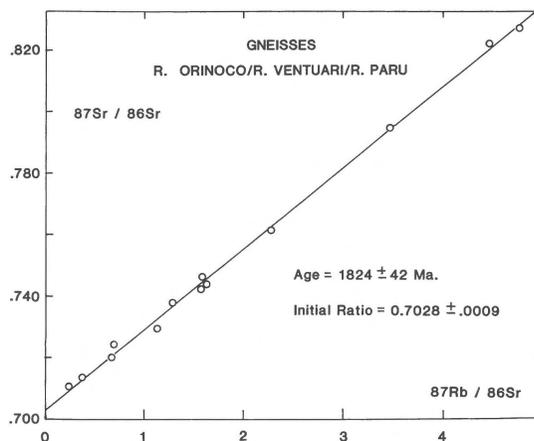


Fig. 2. Rb-Sr diagram for the basement gneisses of the Orinoco, Ventuari and Paru Rivers. Mean squared weighted deviation (MSWD) for the data is 3.19.

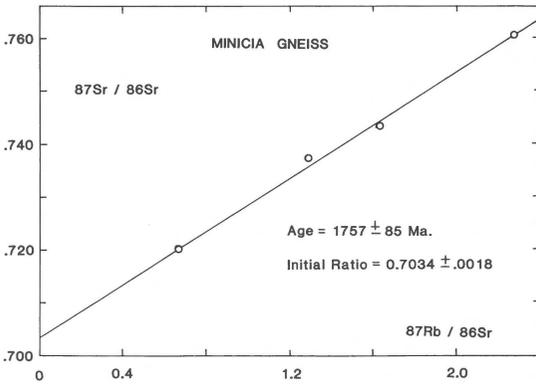


Fig. 3. Rb-Sr diagram for samples of the Minicia gneiss, Orinoco River. MSWD = 1.47.

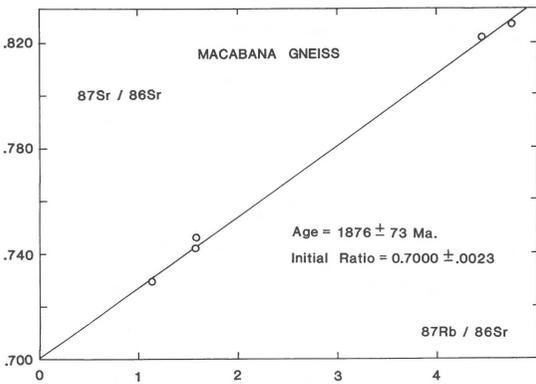


Fig. 4. Rb-Sr diagram for samples of the Macabana gneiss, Ventuari River. MSWD = 3.4

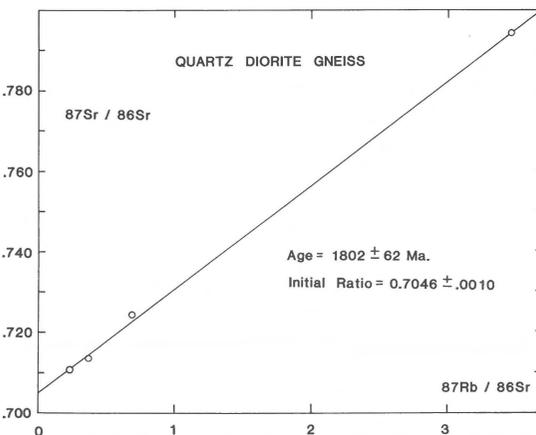


Fig. 5. Rb-Sr diagram for samples of the quartz diorite gneiss of the Ventuari and Paru Rivers. MSWD = 2.00.

growths are more euhedral. The smallest size fractions (-270 to $+325$ mesh) contain a population of clear, unzoned and euhedral zircons. The zircon morphology suggests a sedimentary origin

for the cores of the zircons, while the pervasive overgrowths on the cores, as well as the fine fraction population of clear unzoned zircons, is suggestive of new growth of zircon due to a metamorphic episode. It is thus likely that the U-Pb systematics of the zircons have been completely, or almost completely reset by loss of Pb from the cores, and the overgrowth and formation of a metamorphic zircon population. The results shown in the figures suggest that the gneisses formed between 1860 and 1760 Ma ago. We interpret this age range as a time of intense metamorphism which reset both the Rb-Sr and U-Pb systems. The reasons for this interpretation are:

- 1) Zircon morphology suggesting a mobility of zirconia, and thus most likely of Pb as well.
- 2) The similarity of the zircon ages and the whole rock Rb-Sr ages (which average 1826 Ma), in spite of an obvious sedimentary protolith for the zircons which should yield older ages. The fact that the ages are similar implies a complete resetting of the zircons and the Rb-Sr system as well since an event strong enough to re-set the zircons should be capable of homogenizing the Rb-Sr systems, especially if a mobile fluid phase is present.
- 3) The metamorphic grade (amphibolite) is sufficient to mobilize Pb in zircons;
- 4) The similarity between the age of the gneisses and the ages of the many plutonic rocks of the area suggests re-setting. Many of the plutonic rocks (to be discussed below) intrude the gneisses, yet give similar ages;
- 5) The quartz diorite suite, which we interpret as metamorphosed igneous rock, gives an age similar to the meta-sediments of Minicia and Macabana.

In addition to the evidence for a metamorphic episode at this time (1860 to 1760 Ma) which reset the Rb-Sr and U-Pb systems, other evidence suggests that the gneisses are not significantly older than this. The existence of reset metasediments with low initial strontium ratios (0.7034, 0.7000) implies that the protoliths of the metasediments are not considerably older basement terrains. The Minicia and Macabana gneisses may represent metamorphosed reworked volcanic rocks associated with the intrusive activity of the region, or they may have been derived by erosion of late

Table 2. U-Pb Analyses of Zircons.

<i>Minicia Gneiss (8697)</i>						
Sample	U(ppm.)	Pb(ppm.)	$\frac{206\text{Pb}}{204\text{Pb}}$	$\frac{207\text{Pb}}{235\text{U}}$	$\frac{206\text{Pb}}{238\text{U}}$	$\frac{207\text{Pb}}{206\text{Pb}}$
8697 M@1° Composite	395.1	122.3	1201	4.3857	.29036	.10955
8697 M@2° Composite	402.0	124.2	1580	4.4901	.29194	.11279
8697 NM@1° + 140	369.6	120.7	1084	4.7023	.30389	.11223
8697 NM@1° - 140	380.6	119.4	1727	4.6174	.29924	.11191
8697 NM@1° - 270	450.3	141.1	1067	4.4755	.29113	.11149
<i>Macabana Gneiss (8699)</i>						
8699B M@2° Composite	1097.4	288.3	1734	3.5148	.24156	.10553
8699B NM@1° Composite	825.4	267.5	1219	4.4376	.29289	.10989
8699B M@5° Composite	1067.3	264.9	1896	3.4035	.23580	.10469
8699B NM@1° + 200	870.8	270.8	1553	4.4523	.29584	.10915
8699B NM@1° - 200	1055.0	317.4	915	4.2915	.28558	.10899

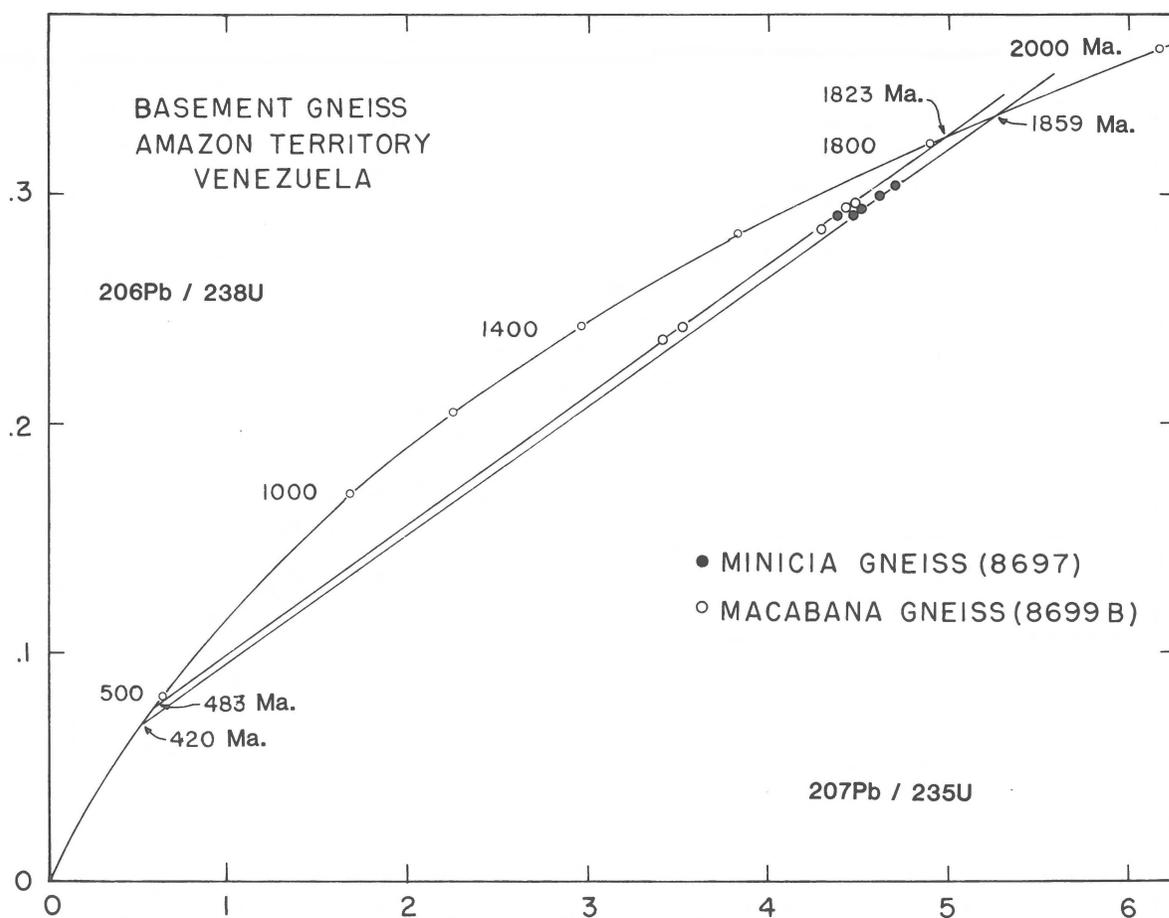


Fig. 6. Concordia diagram for zircons from the Minicia and Macabana gneisses.

pre-tectonic or early syn-tectonic intrusives. The $^{87}\text{Rb}/^{86}\text{Sr}$ ratio for the gneisses averages 2.4. Even if their initial strontium ratio was as low as 0.7000, they could not be significantly older than 2100 Ma. Moreover, there does not appear to be any evidence for massive exchange of Sr with a reservoir of low initial ratio such as the plutonic rocks, a necessary requirement to lower the Sr ratios of sediments with previously higher initial ratios.

The gneisses suggest a strong metamorphic and deformational episode at 1825 Ma ago which we equate to the Trans-Amazonian orogeny in this part of the Guiana Shield. The lower intercepts on Concordia of the Minicia and Macabana zircon data, if interpreted by an episodic Pb loss model, suggest an early Paleozoic event which caused partial Pb loss in the reset zircons. These ages (420 and 483 Ma) are compatible with the ca 500 Ma event recognized in other parts of northern South America. The exact nature and significance of this event in the Amazonas Territory remains undocumented.

The Rb-Sr results for a series of unnamed plutonic rocks occurring along the Orinoco, Ventuari, and Paru Rivers are shown in Table 1. Figure 7 plots the combined data for these samples. Although these 20 samples come from a large geographic area, and involve a wide range in composition from granites to quartz diorites, there does not seem to be any significant difference between groups of plutonic rocks either in age, initial ratio, or geographic distribution. For this reason, the isochron has been determined with all of the available data. The age of 1793 ± 79 Ma shown in Figure 7 is similar to that obtained for the gneisses. Field evidence indicates that some of these plutonic rocks intrude the gneisses. The similarity in ages of the two suggests that plutonism and metamorphism may have been contemporaneous from 1860 to 1760 Ma.

The Atabapo granite is a greyish pink, coarse grained, inequigranular granite rich in blue quartz (distinctive to this granite) which crops out extensively along the Orinoco and Atabapo Rivers

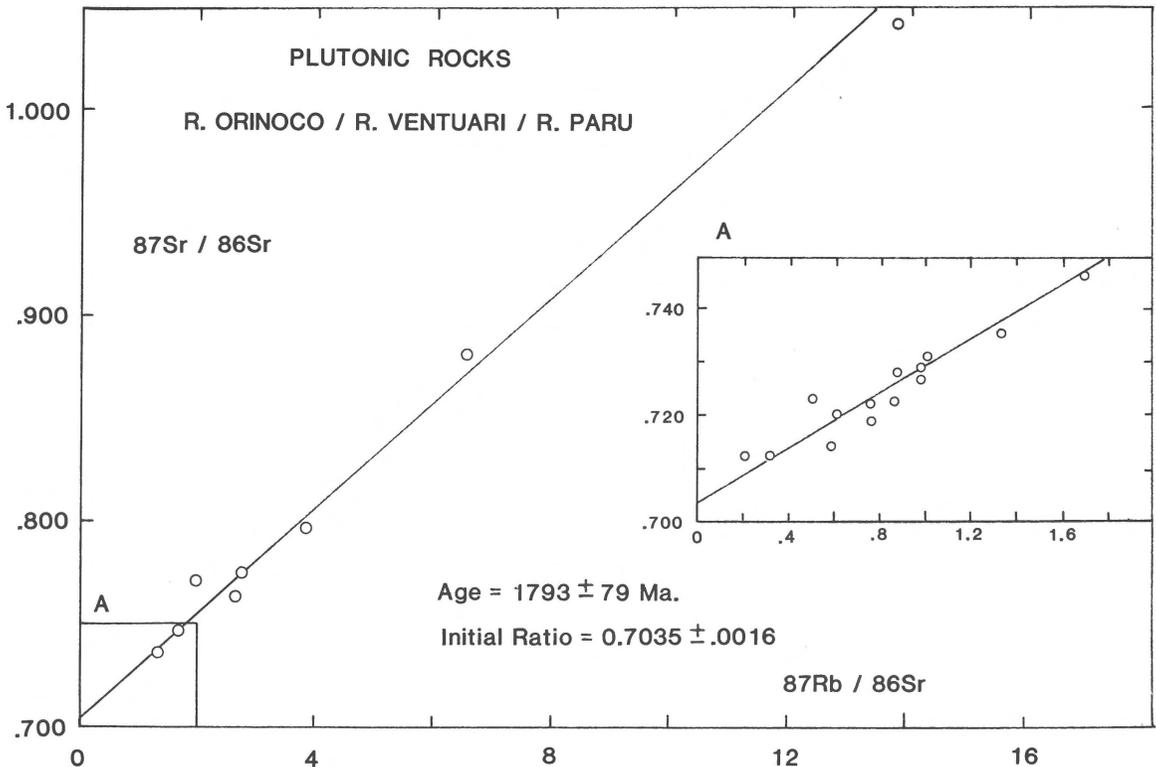


Fig. 7. Rb-Sr diagram for plutonic rocks, Orinoco, Ventuari and Paru Rivers. MSWD = 18.4.

around the town of San Fernando de Atabapo. The Rb-Sr analytical data for the Atabapo granite are listed in Table 1 and plotted in Figure 8. The age of 1617 Ma is consistent with the field relationships of the granite to the surrounding rocks. For example, the Atabapo granite is older than the nearby Parguaza granite (1550 Ma, Gaudette et al. 1978) which shows little or no sign of tectonism. On the other hand, the granite is younger than the more intensely deformed and metamorphosed gneisses of the area, such as the Rio Atabapo gneiss. Thus, we feel that the Atabapo granite represents an intrusive episode younger than the plutonic rocks to the east and north which were described above. The higher initial strontium ratio of the Atabapo granite suggests that it had a crustal source, unlike most of the nearby rocks. Based upon these criteria, the Atabapo granite may represent a plutonic episode unrelated to the older event (1860 to 1760 Ma) described above.

A group of medium- to coarse-grained, well foliated, tonalitic to granodioritic gneisses crop out along the Atabapo River about 40 km south of San Fernando de Atabapo. The tonalitic endmembers are plagioclase-biotite-hornblende-quartz gneisses. As the composition becomes more felsic, quartz and biotite increase in abundance, and augen of K-feldspar may occur. Cataclasis and shearing are common. The Rb-Sr results for these rocks are shown in Table 1 and plotted on Figure 9. The age of 1791 Ma and the initial ratio of 0.7053 are similar to the data from the gneisses farther to

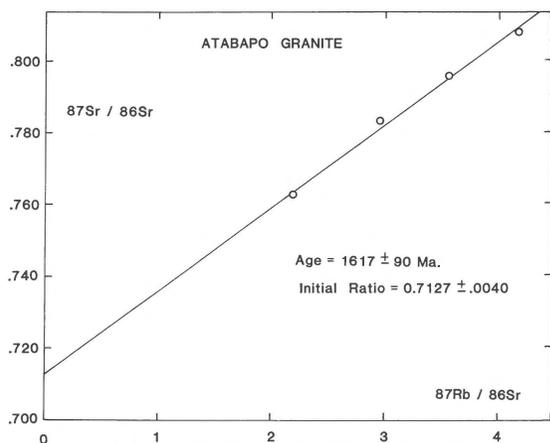


Fig. 8. Rb-Sr diagram for the granite at San Fernando de Atabapo. MSWD = 1.35.

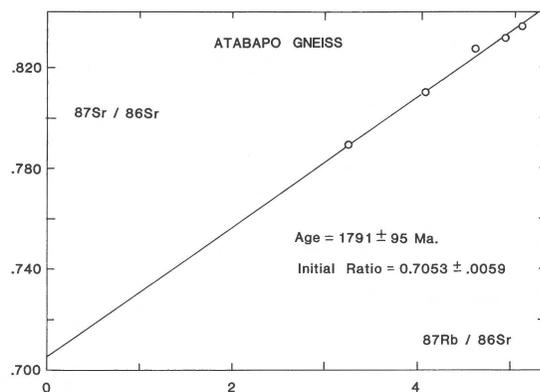


Fig. 9. Rb-Sr diagram for samples of gneiss, Atabapo River. MSWD = 0.61.

the north and east. The Rio Atabapo gneiss has many of the characteristics of the Macabana and quartz diorite gneisses described earlier.

We interpret the age for the Rio Atabapo gneiss as a resetting age, reflecting the same period of metamorphism that affected the gneisses to the north and east. The Rio Atabapo gneiss has an initial strontium ratio low enough to suggest a probable volcanic or volcanoclastic protolith which is not significantly older than the resetting age.

2. Southern Amazonas Territory

In an area along the Orinoco River between Tamatama and Ocamo, and along the Ocamo and Padamo Rivers which are tributaries to the Orinoco, a distinctive coarse grained porphyritic granite occurs. This Padamo granite contains two feldspars with K-feldspar occurring as large phenocrysts, with biotite, hornblende, and epidote. Shearing and grain crushing, and a vague foliation can be seen in some samples.

The Rb-Sr analytical results are listed in Table 1, and plotted in Figure 10. The age of 1803 Ma and initial strontium ratio of 0.7060 are similar to the gneisses and plutonic rocks along the Orinoco and Ventuari Rivers farther to the north and west, suggesting that the Padamo granite is part of the same plutonic and metamorphic episode. The Padamo granite probably represents a late syntectonic intrusion.

A series of granites, granodiorites, quartz monzonites, and tonalites with mutual intrusive rela-

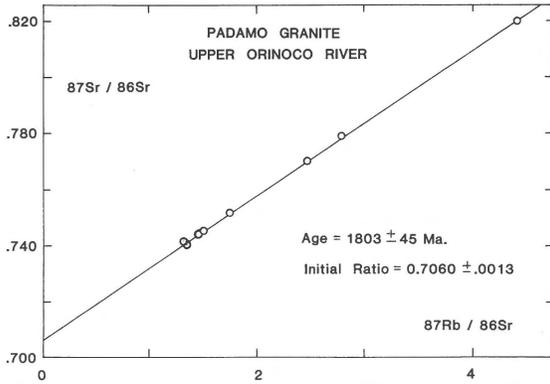


Fig. 10. Rb-Sr diagram for the Padamo granite, upper Orinoco River. MSWD = 0.18

tionships crop out along the Casiquiare River between Tamatama and San Carlos de Rio Negro on the Colombian border. In some areas, the tonalite is found intruding granite, granodiorite or quartz monzonite, while at other outcrops, the same tonalite is cut by similar granites or quartz monzonite. All of the rocks are massive, medium- to coarse-grained, with a weak foliation. The Rb-Sr results for these rocks are listed in Table 1; the data are plotted in Figure 11. We have plotted the data for all of these rocks on the same diagram since the field evidence of mutual intrusion strongly suggests that all of the plutonic rocks are related. These intrusions may actually represent differentiates from a single magma source that were emplaced approximately contemporaneously.

The age of 1782 ± 34 Ma for these plutons is toward the later stages of the 1860 to 1760 Ma plutonic and metamorphic episode we have proposed previously. This is in agreement with the

weak foliation, and minor tectonism apparent in these rocks, suggesting a very late syntectonic timing to their emplacement.

Four samples of the San Carlos granite were collected from the area around the confluence of the Casiquiare River and the Rio Negro near the town of San Carlos de Rio Negro on the Venezuelan-Colombian border. This granite is massive, medium- to coarse-grained with large K-feldspar phenocrysts and shows no evidence of tectonism or metamorphism. The Rb-Sr results are found in Table 1; Figure 12 shows the isochron plot. The age of 1567 ± 25 Ma (initial ratio = 0.7038) is significantly younger than most of the data presented in this study, but is strikingly similar to the age and initial ratio reported for the Parquaza granite of the northern Amazonas Territory (Gaudette et al. 1978). Both granites are similar in texture and composition, lack metamorphic and tectonic effects, and are clearly post-tectonic. They may be correlated as well to the Rapakivi granites reported by Dall'Agnol et al. (1975) in the Serra Parina area on the Venezuelan-Brazilian boundary which are similar in composition, texture, and age.

A dark grey tonalitic gneiss crops out along the Casiquiare River near San Carlos de Rio Negro. This gneiss is a medium-grained, well foliated rock with 0.5 to 2.0 cm plagioclase augen. Veins of quartzo-feldspathic material are common in some outcrops. The Rb-Sr results are given in Table 1, however the results are too scattered to produce a meaningful isochron plot (MSWD = 23.3). The calculated values of 1394 ± 179 Ma for the age, and 0.7318 ± 0.0154 for the initial ratio strongly suggest

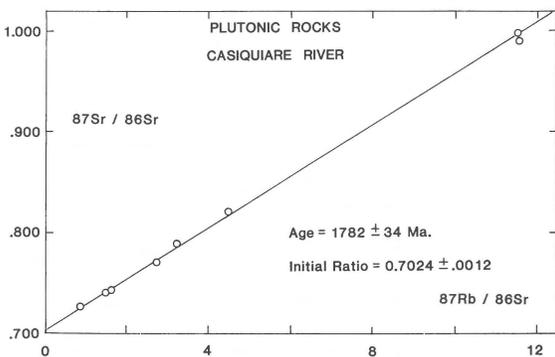


Fig. 11. Rb-Sr diagram for the plutonic rocks of the Casiquiare River. MSWD = 2.54.

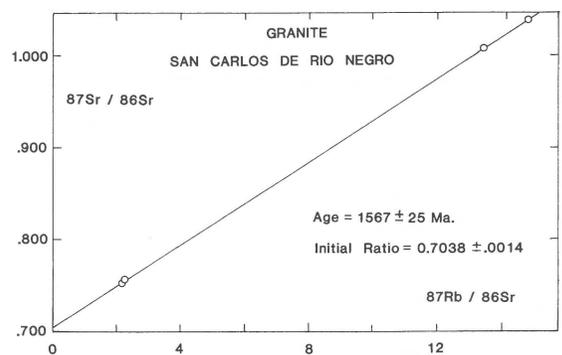


Fig. 12. Rb-Sr diagram for the San Carlos de Rio Negro granite. MSWD = 0.93.

that the age for the Casiquiare gneiss is a resetting age. This may be related to the intrusion of the San Carlos granite, or may be a reflection of the same overprinting effect which Priem et al. (1982) described in their work in adjacent Colombia.

3. Roraima Formation Volcanic Rocks

In order to extend the dating of the Roraima Formation into Venezuela, and to compare it to the Roraima at Tafelberg, we have analyzed a series of nine samples of the silicic volcanic rocks from the Roraima Formation in Estado Bolivar, Venezuela to the northeast of the Amazonas Territory. We collected six of the samples (UNH 1-6) from the Roraima Formation near Canaima. Dr. Alan Gibbs provided us with 2 additional samples (UNH 83 and 84) from the same locality, as well as a single sample (UNH 85) of the Roraima volcanic rock from the area north of Sta. Elena de Uairen.

The samples from Canaima are green, very fine-grained felsic pyroclastic volcanic rocks. The sample from Sta. Elena is a red, fine-grained volcanic rock with the red colour due to fine-grained dispersed hematite. Except for the colour, the sample is the same as the Canaima samples in texture, and composition.

Table 1 lists the Rb-Sr analytical results while Figure 13 shows the resulting isochron. This isochron calculation is based only on the Canaima samples, and gives an age of 1746 Ma and an initial ratio of 0.7077. These results are similar to those reported by Priem et al. (1973) from the Tafelberg, and suggest that the volcanic rocks of the Roraima Formation are probably contemporaneous throughout the great lateral extent of the Roraima in eastern Venezuela, Guyana, and Suriname.

Discussion

The results presented from the basement rocks of the Amazonas Territory show a period of strong metamorphism, deformation, and intrusion between 1860 and 1760 Ma. This age range may represent a series of smaller separate orogenic events, or a single event of 100 Ma duration. In

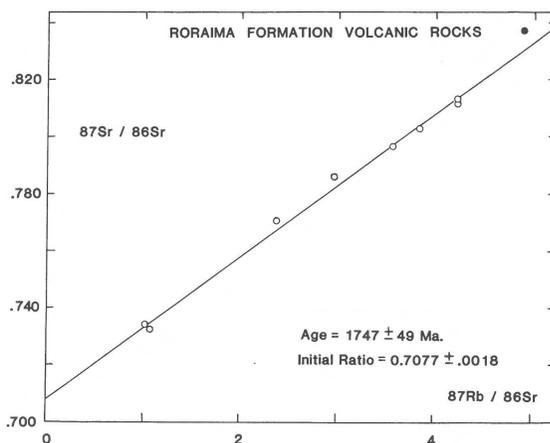


Fig. 13. Rb-Sr diagram for the Roraima Formation volcanic rocks in Estado Bolivar. The age has been calculated without the sample from St. Elena (solid circle). MSWD = 2.84.

either case, this period of tectonism can be directly correlated with the Trans-Amazonian Event (Hurley et al. 1968, Moreno et al. 1977) of 1900 ± 200 Ma recognized throughout the Guiana Shield. The general distribution of ages within the Trans-Amazonian shows that in general, the oldest ages occur to the northeast. The ages we report here for the basement rocks in the Amazonas Territory fall well to the younger end of the age range for the Trans-Amazonian Event, suggesting a progressive migration of tectonic activity with time from the northeast to the southwest in Venezuela. This migration of tectonism represents a progressive addition of material to a developing craton through time as recognized in other shield areas (i.e.: North America), and suggests that tectonic processes which formed other major shield areas operated in the South American Guiana Shield during the Precambrian.

On a more regional scale in the Venezuelan Amazonas Territory, the ages of the rocks tend to decrease to the southwest. A marked difference seems to occur between the ages which may be attributed to the Trans-Amazonian Event, and the younger ca 1500 Ma ages shown by the San Carlos and Parguaza granites, and the basement gneisses and intrusive rocks of Tassinari (1981) and Priem et al. (1982) in adjacent Brasil, and Colombia, respectively. This evidence suggests to us the presence of an important tectonic zone or boundary along the Orinoco River and the Rio Negro closely

corresponding to the border between Venezuela and Colombia. This zone represents an orogenic zone where new continental crust has been developed and cratonized, and the boundary between two distinct tectonic provinces, similar to, or an extension of, the tectonic province 'Rio Negro-Juruena' as proposed by Tassinari (1981) in Brasil. A strong linear geophysical anomaly (Mendoza 1977) may coincide with a portion of this zone near San Fernando de Atabapo.

A possible model which is compatible with these results involves subduction, followed by a change in tectonic style from compressional-horizontal to tensional-vertical. Beginning with a subduction zone probably descending to the northeast at or before 1900 Ma, volcanic, volcanoclastic, and pre-orogenic intrusive material would have developed from the descending plate forming new continental crust. Our evidence from the older gneisses suggests intense metamorphism and deformation by ca 1830 Ma, so it seems likely that a major orogeny resulting from island arc or continental collision was underway at this time. The orogenic activity continued for about 100 Ma probably as a result of multiple collisions. After about 1760 Ma, orogenic activity diminished perhaps due to a change in the location of subduction.

The end of subduction also marks the change in tectonic style to extensional-vertical. Vertical uplift following compressional tectonics would bring deep, high temperature rocks into lower pressure regimes without simultaneous reduction in temperature. The lowering of the solidus due to the pressure release may have caused melting and could explain the emplacement of anorogenic granites such as the San Carlos and Parguaza granites (Gaudette et al. 1978), which are younger (1550 Ma), and similar in age and initial strontium ratios. Allegre & Ben Othman (1980) based upon Nd-Sr isotopic relationships, suggested derivation of the Parguaza granite magma from undifferentiated mantle, a process compatible with the vertical tectonic model.

The extension of the tectonic zone to the north is unknown, but the results of Priem et al. (1982) suggest a continuation of this zone through the

Amazonas region of Colombia. To the south, the proposed tectonic zone coincides with the Rio Negro-Juruena province suggested by Tassinari (1981) in Brasil. It would also seem to extend well into central Brasil where ca 1500 Ma basement underlies the Amazon basin (Kovach et al. 1976), and where 1500 Ma rocks are exposed as part of the Guapore craton.

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