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GEOLOGY OF THE VENEZUELAN GUAYANA SHIELD AND ITS RELATION TO THE ENTIRE GUAYANA SHIELD

by

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ABSTRACT

The Guayana Shield in Venezuela is composed of five lithotectonic provinces: 1) an Archean amphibolite- to granulite-facies gneiss terrane; 2) an Early Proterozoic greenstone-granite terrane(s); 3) an Early Proterozoic unmetamorphosed volcano-plutonic complex; 4) Early to Middle Proterozoic continental sedimentary rocks; and 5) Middle Proterozoic anorogenic rapakivi-type granite. Early Proterozoic rocks in the Amazon Federal Territory of western Venezuela are undivided and their relation to other rocks of the Venezuelan Guayana Shield is unclear. Early to Middle Proterozoic continental tholeiitic dikes, sills, and small irregular intrusive bodies and Mesozoic dikes emplaced during the opening of the Atlantic Ocean cut all of the lithotectonic provinces. Major mineral deposits of the Venezuelan Guayana Shield include gold, iron, bauxite, and diamonds.

The Archean Imataca Complex, the oldest unit, consists of gneiss and granulite with minor dolomite and banded iron-formation (BIF). Large isoclinal folds, which have been refolded into relatively open folds, are common in the Imataca Complex. Metamorphic grade ranges from granulite facies in the northeast part of the belt to amphibolite facies in the southwest. Deposits of enriched BIF in the Imataca Complex contain more than 2 billion metric tons of iron ore. During the Pre-Trans-Amazonian tectonomagmatic event, between about 2,800 and 2,700 Ma, granitic rocks intruded the Imataca Complex, and injection gneisses and migmatite were developed.

The Early Proterozoic greenstone belts, which formed between about 2,250 and 2,100 Ma, consist of a submarine sequence of tholeiitic mafic volcanic rocks, a sequence of tholeiitic to calc-alkaline basalt to rhyolite, and an interval of turbiditic graywacke, volcaniclastic rocks, and chemical sedimentary rocks that characterize the basal, middle, and upper parts, respectively. Layered mafic complexes also occur in the greenstone belts. The greenstone-belt rocks range in metamorphic grade from greenschist to amphibolite facies. Low-sulfide gold-quartz veins are hosted by Early Proterozoic greenstone-belt rocks cut by major shear zones. Deposits of volcanogenic manganese are mined elsewhere in the Guayana Shield; in Venezuela, a moderate potential exists for the discovery of additional deposits of manganese in the greenstone belts. Platinum-group elements (PGE) and chromium are present in anomalous values in the layered mafic complex at Piston de Uroy, Venezuela. Also, PGE are anomalous in mafic metavolcanic and metagabbroic rocks adjacent to an exhalative (Homestake-type) gold prospect in the Cerro La Pinto area.

Granitic domes of the Supamo Complex intruded the greenstone-belt rocks between about 2,230 and 2,050 Ma and divided the metasedimentary and meta-igneous greenstone-belt rocks into branching synclinoria between intrusive uplifts. The Trans-Amazonian orogeny was a period of continental collision between about 2,150 and 1,960 Ma, during which the Imataca Complex and the greenstone-granite terranes were deformed and metamorphosed.

Volcanic, subvolcanic, and plutonic rocks of the Cuchivero Group represent post-collisional, post-Trans-Amazonian magmatism between about 1,930 and 1,790 Ma in the Guayana Shield. Silicic rocks (rhyolite and granite to granodiorite) dominate, with less abundant associated intermediate to mafic dikes and lava flows. Quartz-sulfide veins with 1) anomalous silver, bismuth, and molybdenum; 2) hydrothermal alteration in the felsic to intermediate volcanic host rocks; and 3) gold in panned concentrates indicate that epithermal precious-metal deposit models should be considered in an exploration program of the Cuchivero Group. Disseminated cassiterite in rhyolite and cassiterite in panned concentrates and molybdenite at the contacts between volcanic and granitic rocks of the Cuchivero Group suggest that rhyolite-hosted tin and porphyry molybdenum mineral deposit models should be part of an exploration program within the Cuchivero Group. The only known diamond-bearing kimberlite deposit in the Guayana Shield is in the Quebrada Grande area. This deposit and the carbonatite at Cerro Impacto, which is enriched in niobium, thorium, barium, cerium, and other metals and rare earth elements, are within the outcrop area

of the Cuchivero Group.

Undivided Proterozoic rocks in the Amazon Federal Territory of western Venezuela include granitic rocks, gneiss, and migmatite. Peak metamorphism and magmatism occurred between about 1,860 and 1,730 Ma.

Unmetamorphosed, post-tectonic sedimentary rocks such as quartz arenite, conglomerate, arkose, siltstone, and shale of the Roraima Group were deposited in fluvial, deltaic, shallow marine, and lacustrine or epicontinental environments. The Roraima Group is at least 1,670 Ma in age and possibly as old as about 1,900 Ma and as young as about 1,500 Ma. Paleo-placer deposits of gold and diamonds in the lower part of the Roraima Group are the source for modern placers.

Continental tholeiitic dikes, sills, and irregular intrusive bodies of the Avanavero Suite cut all older rocks of the Guayana Shield. These intrusions are about 1,650 Ma in age, and possibly as old as about 1,850 Ma.

Middle Proterozoic, about 1,545 Ma, undeformed granite with rapakivi texture is characteristic of the Parguaza province. Tin in quartz veins, pegmatite, and greisen are mined elsewhere in the Guayana Shield; in Venezuela, moderate potential exists for discovery of tin associated with the Parguaza granite. Similarities in age, composition, and tectonic environment indicate that Olympic Dam-type Fe-Cu-U-Au-REE deposits are possible in the Parguaza granite and its associated volcanic rocks.

Continental collision in the westernmost part of the Guayana Shield during the Nickerie orogeny reset many potassium-argon and rubidium-strontium mineral ages of Archean and Early Proterozoic rocks in the central and eastern parts to about 1,200 Ma. Tholeiitic diabase dikes intruded the Guayana Shield during the opening of the Atlantic Ocean from about 210 to 200 Ma. Erosion of the Precambrian terranes and uplift during the Mesozoic and Cenozoic Eras produced at least six erosional surfaces at distinct elevations between about 2,900 and 50 m above sea level in the Guayana Shield.

Tropical weathering of the diverse lithologies of the Guayana Shield has formed numerous occurrences of bauxite and lateritic bauxite. The largest bauxite deposit is Los Pijiguaos, which developed on the Parguaza granite. Deposits of bauxite and enriched BIF were formed on the Imataca-Nuria erosional surface. Placer diamond and gold deposits are mined in modern channels of the major rivers and in colluvial-alluvial deposits in low-order drainages.

PREFACE

This paper is a preliminary version of a chapter that will be published as part of a U.S. Geological Survey Bulletin edited by Gary B. Sidder, Jeffrey C. Wynn, and Norman J Page. Other chapters of the Bulletin are currently undergoing technical review. References cited as "this volume" in this paper refer to other chapters that will be published in the Bulletin. This citation distinguishes articles to be published from oral or written communications of information that is not published. Note that footnotes in the text appear as endnotes following the references.

INTRODUCTION

The U.S. Geological Survey has been assisting the Corporación Venezolana de Guayana-Compañia Técnica Minera C.A. (CVG-TECMIN or TECMIN) since 1987 in its assessment of and exploration for new mineral deposits in the Precambrian Guayana Shield of Venezuela (Wynn, Sidder, and others, this volume). The Guayana Shield, in the northern portion of the Amazonian craton of South America, measures about 1,100 kilometers (km) north to south and 2,100 km east to west, covering an area of about 2,310,000 km^2 (fig. 1). Shield rocks crop out in Colombia, Venezuela, Guyana, Brazil, Suriname, and French Guiana (fig. 1). The Guaporé or Central Brazilian Shield, located south of the Amazon River basin, forms the southern part of the Amazonian craton (Gibbs and Barron, 1983; Teixeira and others, 1989).

The Guayana Shield in Venezuela consists of five lithotectonic provinces. These include: 1) an Archean amphibolite- to granulite-facies gneiss terrane; 2) an Early Proterozoic greenstone-granite terrane(s); 3) an Early

Figure 1A. Location of the Guayana Shield and the Guaporé Shield of the Amazonian craton, South America.

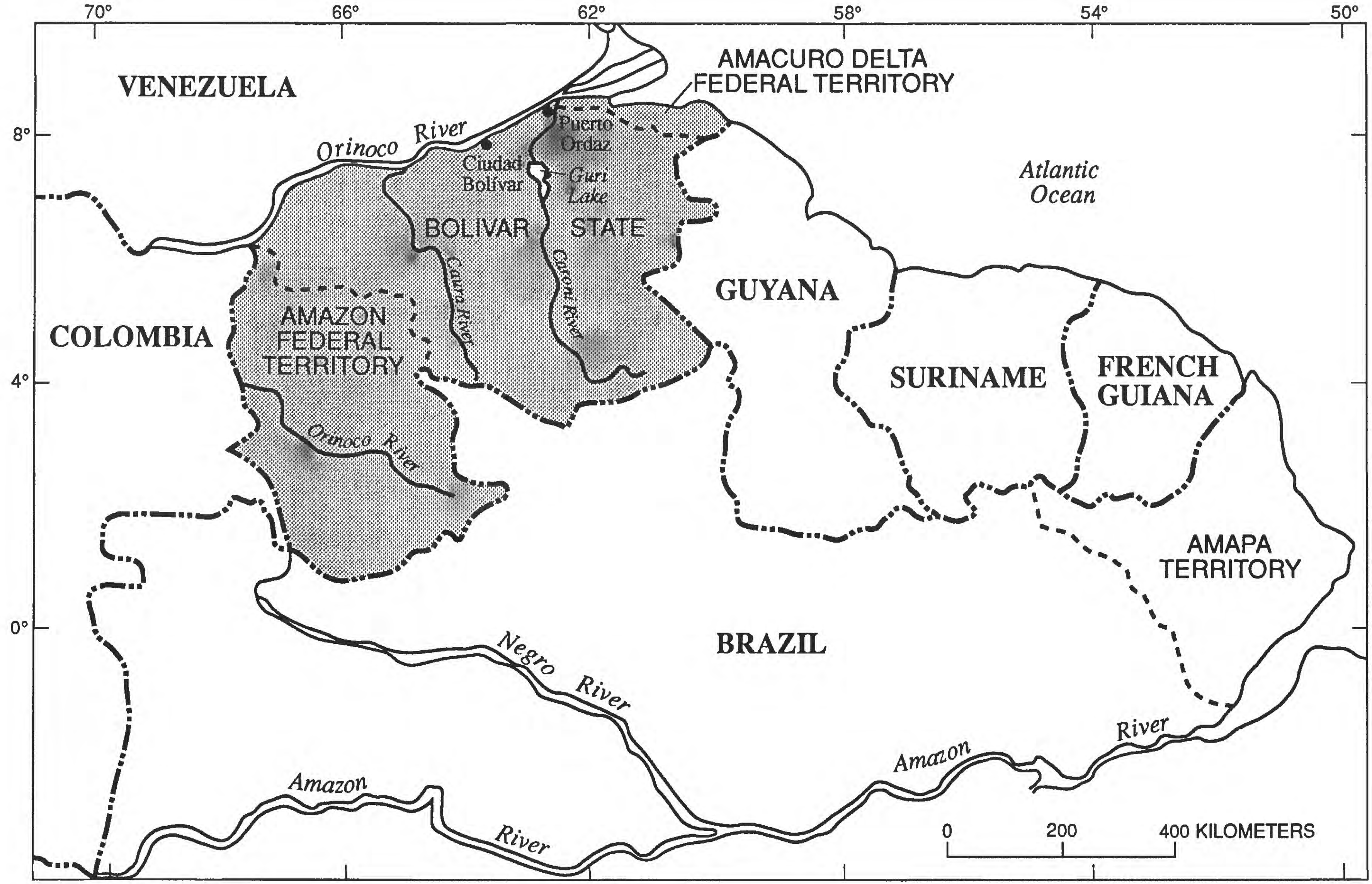

Figure 1B. Geography of northern South America. Shaded area indicates the Venezuelan portion of the Guayana Shield.

Proterozoic unmetamorphosed volcano-plutonic complex; 4) Early to Middle Proterozoic continental sedimentary rocks; and 5) Middle Proterozoic anorogenic rapakivi-type granite (Gibbs and Barron, 1983; Teixeira and others, 1989). Early Proterozoic rocks in the Amazon Federal Territory of western Venezuela are undivided and their relation to other rocks of the Venezuelan Guayana Shield is unclear. Early to Middle Proterozoic continental tholeiitic dikes, sills, and small irregular intrusive bodies and Mesozoic dikes emplaced during the opening of the Atlantic Ocean are in all of the lithotectonic provinces. Table 1 is a simplified stratigraphic chart of the rock units and tectonic events of the Guayana Shield of Venezuela. Plate 1 is a geologic province map of the Venezuelan Guayana Shield, and Figure 2 is a simplified geologic province map.

This paper provides an overview of the geology of the Venezuelan Guayana Shield and its relation to the entire Guayana Shield. The evolution of the shield, as described here, includes recent uranium-lead and samarium-neodymium isotopic data. All geochronological data used have been standardized by recalculation with one set of constants as recommended by the Subcommission on Geochronology of the International Union of Geological Sciences[1] (Steiger and Jäger, 1977); errors in all dates are quoted at the 1-sigma level. Such standardization helps to define more narrowly the ranges of specific magmatic or tectonic events. For example, a single tectonic episode such as the Trans-Amazonian orogeny, which previously has been reported to span 400 million years (m.y.), is herein constrained to a much shorter interval of 190 m.y. Similarly, the formation of the Supamo Complex (granite and gneiss associated with the greenstone-belt rocks), which reportedly formed between 2,700 and 2,100 Ma, is herein restricted to 2,230 to 2,050 Ma. We believe that these recalculated dates of the major geologic events in the Venezuelan Guayana Shield allow its history to be interpreted more realistically (Table 1).

IMATACA COMPLEX

The Archean Imataca Complex is a northeast-trending belt of amphibolite- to granulite-facies metasedimentary and meta-igneous rocks. This belt is about 510 km long and 65 to 130 km wide, and it forms the northernmost margin of the Venezuelan Guayana Shield (pl. 1). Rocks of the Pliocene and Pleistocene Mesa Formation (not shown on pl. 1) and alluvium from the floodplain of the Orinoco River cover the Imataca Complex along its northern margin, and to the south the Guri shear zone separates the Imataca Complex from the Early Proterozoic greenstone-granite terrane. The Imataca Complex abuts against plutonic and volcanic rocks of the Early Proterozoic Cuchivero Group along the Caura River in the west. The nature of the contact is unknown because it is obscured by thick overburden and alluvium along the Caura River (Kalliokoski, 1965; Ascanio, 1975; Mendoza, 1977a).

The Imataca Complex includes more than 80 percent quartzo-feldspathic orthogneiss, paragneiss, and felsic granulite, 10 to 15 percent intermediate to mafic orthogneiss, granulite, and charnockite, 1 percent metamorphosed banded iron-formation (BIF), and minor manganiferous metasedimentary rocks, dolomitic marble, and anorthosite. The protolith of the Imataca Complex consisted of clastic and chemical sedimentary rocks, silicic calc-alkaline subaerial volcanic rocks, and lesser plutonic rocks (Kalliokoski, 1965; Dougan, 1977; Gibbs and Wirth, 1986).

The grade of metamorphism in the Imataca Complex varies from granulite facies in that part of the belt generally northeast of the Guri Lake area (pl. 1) to amphibolite facies to the southwest. Gneisses are commonly migmatitic, with assemblages consisting of quartz-potassium feldspar-plagioclase ± biotite ± hornblende ± orthopyroxene ± clinopyroxene ± garnet ± sillimanite ± cordierite ± muscovite. Estimates of peak metamorphic conditions in granulite-facies rocks indicate that temperature varied between about 750° and 800°C and pressure ranged from about 8.0 to 8.5 kbar (Short and Steenken, 1962; Swapp and Onstott, 1989), whereas amphibolite-facies rocks were subjected to temperatures between

Table 1. Stratigraphic chart of rock units and tectonic events of the Guayana Shield of Venezuela. Map symbols are used on plate 1.

Alluvium (Qal): Quaternary alluvial sediments.

•••MESOZOIC-CENOZOIC UPLIFT (uplift and formation of erosion surfaces)

Diabase dikes (Mzd): thin, elongated tholeiitic dikes (about 210 to 200 Ma).

•••NICKERIE TECTONOTHERMAL EVENT (about 1,200 Ma)

Parguaza Granite (Yp): massive, coarsely crystalline, porphyritic granite and biotite granite, commonly with rapakivi (wiborgite-type) texture (about 1,545 Ma).

Avanavero Suite (Ya): continental tholeiitic dikes, sills, inclined sheets, and small irregular intrusive bodies (about 1,650 Ma; possibly as old as 1,850 Ma).

Roraima Group (YXr): continental (fluvatile-deltaic and lacustrine) quartz sandstone and quartz-pebble conglomerate with lesser feldspathic arenite, arkose, siltstone, shale, jasper, chert, and interlayered felsic volcanic rocks (at least 1,650 Ma; possibly as old as 1,900 Ma and as young as at least 1,545 Ma).

Matauí Formation
Uaimapué Formation
Kukenán Formation
Uairén Formation

Undivided Proterozoic (Pu): synkinematic plutonic rocks (granite to tonalite and quartz diorite) and medium to high-grade gneiss with both igneous and sedimentary protoliths in the Amazon Federal Territory only (about 1,860 to 1,730 Ma).

•••UNNAMED OROGENY (Amazon Federal Territory; about 1,860 to 1,730 Ma)

Cuchivero Group (Xc): thick sequence of unmetamorphosed felsic to intermediate subaerial volcanic rocks and their associated granitic rocks (about 1,930 to 1,790 Ma).

Granite of Guaniamito
Granites of San Pedro and Santa Rosalia (including the granite of Las Trincheras)
Caicara Formation

•••TRANS-AMAZONIAN OROGENY (about 2,150 to 1,960 Ma)

Supamo Complex (Xs): gneiss, schist, migmatite, and granitic rocks such as tonalite, granodiorite, trondhjemite (sodic granite), and quartz monzonite associated with the greenstone-belt terrane (2,230 to 2,050 Ma).

Greenstone-belt rocks (Xg): sequences as much as 11,000 m thick of metamorphosed tholeiitic basalt and gabbro with interflow chemical sedimentary rocks at the base; interstratified, porphyritic, tholeiitic and calc-alkaline basaltic to rhyolitic lava flows and tuffs in the middle portion; and tuffaceous, volcaniclastic, turbiditic, pelitic, and chemical sedimentary rocks at the top (about 2,250 to 2,100 Ma).

Table 1 (continued).

Botanamo Group	
Los Caribes Formation	
Caballape Formation	
Pastora Supergroup	Real Corona-El Torno assemblage
Yuruari Formation	
Carichapo Group	
Cicapra Formation	
El Callao Formation	

•••PRE-TRANS-AMAZONIAN TECTONOMAGMATIC EVENT (about 2,800 to 2,700 Ma)

Imataca Complex (Wi): amphibolite- to granulite-facies quartzo-feldspathic orthogneiss, paragneiss, and felsic granulite, intermediate to mafic orthogneiss, granulite, and charnockite, metamorphosed banded iron formation (BIF), and minor manganiferous metasedimentary rocks, dolomitic marble, and anorthosite (>2,800 Ma; protolith possibly 3,700 to 3,400 Ma).

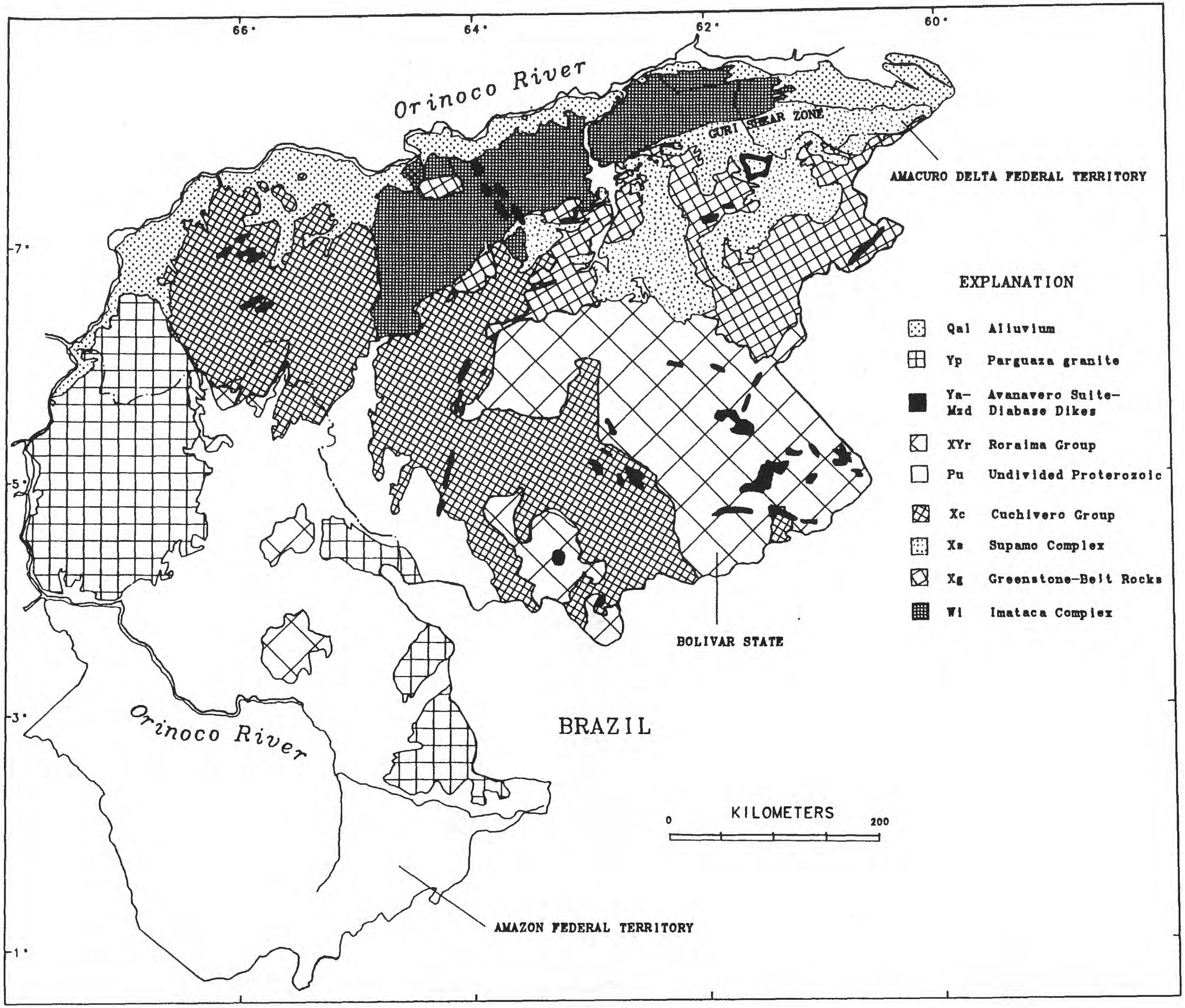

Figure 2. Simplified geologic province map of the Venezuelan Guayana Shield.

about 625° and 700°C and pressures from 4 to 7 kbar (Dougan, 1974, 1977).

Rocks of the Imataca Complex are strongly deformed. The entire stratigraphic sequence of the complex has been folded into large isoclinal folds, which have been refolded into relatively open folds (Ruckmick, 1963; Onstott and others, 1989). In the northern part of the Imataca Complex, the isoclinal fold axes strike generally northwest, whereas they strike east-west in the southern part. The fold axes are deflected to the northeast close to the Guri shear zone (pl. 1), which is traceable in the field for a distance of more than 400 km (Onstott and others, 1989). This shear zone, 1 km to several hundred meters in width, is marked by alternating bands of mylonite, pseudotachylite, and strongly sheared gneisses and amphibolites. Crushed rock is visible in thin sections of samples collected as much as 2 km on either side of this shear zone (Short and Steenken, 1962). The deflection of structural trends and mineral lineations adjacent to the Guri fault indicate that its major movement was left slip, possibly with later vertical displacement. Ascanio (1975) suggested that the rocks of the Imataca Complex are also cut by north-verging low-angle thrust faults associated with the Guri shear zone that in part caused the folding. High-grade mylonite zones, such as the El Pao and the Claro River fault zones, also cut the Imataca Complex (Short and Steenken, 1962; Onstott and others, 1989; Swapp and Onstott, 1989).

Age of the Imataca Complex

Most of the radiometric dates of rocks in the Imataca Complex record regional metamorphic and magmatic events. Metasedimentary protoliths for some gneissic rocks of the Imataca Complex have been dated at 3,700 to 3,400 Ma by whole-rock rubidium-strontium isochron and lead-lead analyses (Montgomery, 1979); it is possible that these dates reflect an inherited detrital Archean component rather than a primary age of deposition (R.M. Tosdal, U.S. Geological Survey, oral commun., 1990). Rocks of the Imataca Complex were deformed, intruded, and regionally metamorphosed at about 2,800 to 2,700 Ma. During the Trans-Amazonian orogeny, they underwent upper amphibolite- to granulite-facies metamorphism and granitic intrusion at about 2,150 to 1,960 Ma (Hurley and others, 1976; Onstott and others, 1989). A SHRIMP (sensitive high mass-resolution ion microprobe) study of the uranium-lead ages of zircons collected from sand in the Orinoco River west of Ciudad Bolívar identified a small, discrete population of zircons that have an age of about 2,800 Ma in addition to a larger population of about 2,100 to 2,000 Ma (Goldstein and Arndt, 1988). Goldstein and Arndt (1988) noted that the scarcity of zircon grains with an Archean age demonstrates that Archean rocks form only a minor proportion of the Venezuelan Guayana Shield.

Rocks correlative in age to the Imataca Complex are not known elsewhere in the Guayana Shield. Tonalitic and trondhjemitic rocks associated with granulitic rocks in the Cupixi area, Amapa Federal Territory, northeastern Brazil, may be Late Archean in age (De Vletter and Kroonenberg, 1984; Teixeira and others, 1989). Granulite and charnockite in the Kanuku Complex, Guyana, and in the Bakhuis Mountains, Suriname, are part of the central Guyana granulite belt (Gibbs and Wirth, 1986). Although these rocks and the L'Ile de Cayenne Complex in French Guiana have structural, stratigraphic, and petrographic similarities to the Imataca Complex, they have apparent protolith ages of about 2,200 to 2,300 Ma, with peak metamorphism related to the Trans-Amazonian orogeny at about 2,000 Ma (Priem and others, 1978; Ben Othman and others, 1984; Teixeira and others, 1984; Gibbs and Wirth, 1986; Rowley and Pindell, 1989; Teixeira and others, 1989). Uranium-lead and rubidium-strontium isotopic evidence for an age older than 2,400 Ma does not exist for these rocks (Priem and others, 1978).

Amphibolite- to granulite-facies rocks of the Archean (>2,700 Ma) Kasila Group in Sierra Leone (Williams, 1988) and comparable rocks in Liberia, including BIF (Gruss, 1973; Tysdal and Thorman, 1983), of the Kenema-Man Domain of the West African craton may be correlative with those in the Imataca Complex (Cohen and Gibbs, 1989). The Kasila Group consists of quartzo-feldspathic gneiss, migmatite, granulite, and layered and massive gabbro, with minor banded iron-formation, anorthosite, and calc-silicate beds. The peak temperature of metamorphism reached about 850°C, and pressure estimates indicate a depth of equilibration at about 25 to 30 km (Williams, 1988). Paleomagnetic reconstructions and geochronological data indicate that the Guri shear zone in the Guayana Shield is aligned with the Sassandra-Trou Mountain fault zone in the Man Shield of the West African craton, which also separates Archean high-grade metamorphic rocks from an Early Proterozoic, lower grade greenstone-granite terrane (Onstott and Hargraves, 1981; Caen-Vachette, 1988; Cohen and Gibbs, 1989).

Mineral deposits of the Imataca Complex

Iron is the predominant metal produced from the Imataca Complex. Numerous world-class deposits of enriched Algoma-type banded iron-formation, such as the Cerro Bolívar, San Isidro, and El Pao mines (pl. 2), are in the Imataca Complex (Gruss, 1973; Sidder, 1990; Sidder, this volume). Reserves of iron ore are greater than 2 billion metric tons (César Bertani, Ferrominera Orinoco, oral commun., 1989). BIF protore consisted of an oxide facies assemblage, with hematite and magnetite as the dominant iron minerals. Enriched BIF ore, composed predominantly of goethite and limonite, generally occupies the limbs and centers of synclines. The iron-rich beds are intimately interbedded with layers of silica, present as quartz, and iron-bearing metamorphic minerals such as greenalite, grunerite, cummingtonite, crossite-magnesioriebeckite, acmite, and chlorite (Ruckmick, 1963; Gruss, 1973; Ascanio, 1985; Moreno and Bertani, 1985). The precious metal content of these deposits is reported to be low (Engineering and Mining Journal, 1987); trace amounts of gold have recently been discovered at Cerro Bolívar (Bertani, oral commun., 1989).

Small deposits and prospects of manganese and bauxite occur in the Upata-El Palmar-Guacuripia area (pl. 2). Beds of secondarily enriched manganese ore are interstratified with gneiss, migmatite, amphibolite, and granulite of the Imataca Complex (Drovenik and others, 1967). These rocks are part of a stratigraphic sequence of gondite, quartz-biotite schist, amphibole schist, and dolomitic marble that is less than 500 m thick. The individual manganiferous beds are generally less than 10 m thick and have strike lengths as much as 20 km or longer (Drovenik and others, 1967). Drovenik and others (1967) concluded that the sedimentary-nonvolcanogenic manganese deposit model best represents the protore occurrences of manganese in the Imataca Complex. However, the association of felsic to intermediate volcanic rocks (Dougan, 1977), rather than a sedimentary protolith, suggests that the Cuban-type volcanogenic manganese model (Mosier and Page, 1988) may better characterize the manganese deposits in the Imataca Complex. Bauxite in the Upata district (pl. 2) is locally associated with weathered gabbro, amphibolite, and possibly granitic gneiss of the Imataca Complex (Candiales, 1961). Volcanogenic massive sulfide deposits have not been discovered anywhere in the Imataca Complex or elsewhere in the Guayana Shield (Gibbs and Barron, 1983).

PRE-TRANS-AMAZONIAN TECTONOMAGMATIC EVENT

Intrusion of homogeneous granitic rocks and injection gneisses as well as the development of migmatite characterize the Pre-Trans-Amazonian tectonomagmatic event at about 2,800 to 2,700 Ma in the Guayana Shield. The Cerro La Ceiba migmatite in the Imataca Complex is representative of rocks formed at this time (Hurley and others, 1976).

This event may be correlative with the Liberian tectonothermal event in the Man Shield of the West African craton, during which Archean rocks were metamorphosed and intruded by plutonic rocks between about 2,780 and 2,750 Ma (Hedge and others, 1975; Rollinson and Cliff, 1982; Tysdal and Thorman, 1983). This event is also known as the Aroense in Venezuela, the Guriense in Guyana, or Jequié in Brazil (Singh, 1974; Schobbenhaus and others, 1984).

GREENSTONE-BELT ROCKS

Early Proterozoic greenstone-granite terranes crop out in the central and eastern parts of the Venezuelan Guayana Shield (pl. 1), an area of about 360 km by 250 km. Felsic to intermediate volcanic rocks of the Cuchivero Group and clastic sedimentary rocks of the Roraima Group overlie rocks of the greenstone-granite terranes to the west and south. Rocks of the greenstone-granite terranes are continuous with those identified in Guyana to the east. The contact between the greenstone-granite terranes and the Imataca Complex to the north is along the Guri shear zone (Gibbs and Olszewski, 1982; Onstott and others, 1989).

Greenstone-belt rocks in Venezuela have a total thickness of at least 11,000 m. Named stratigraphic units of the Venezuelan greenstone belts include the Pastora Supergroup and Botanamo Group (table 1). The Pastora Supergroup, which consists of the Carichapo Group (El Callao and Cicapra Formations) and the Yuruari Formation, are discordantly overlain by the Botanamo Group, which contains the Caballape and Los Caribes Formations. Granitic plutons and domes, gneisses, and migmatites of the Supamo Complex divide these metasedimentary and meta-igneous rocks of the greenstone belts into branching synclinoria between intrusive uplifts (Menendez, 1968, 1972; Benaim, 1972, 1974). Metasedimentary and metavolcanic rocks of the Real Corona-El Torno assemblage to the west of the Aro River (pl. 1) were tentatively correlated with those of the Pastora Supergroup (Kalliokoski, 1965). Rocks of the Pastora-Botanamo greenstone belts are correlative with those of the Barama-Mazaruni Supergroup in Guyana, the Marowijne Group in Suriname, the Paramaca Series (Orapu and Bonidoro Groups) in French Guiana, and the Vila Nova Group in Brazil (Bosma and others, 1983; Gibbs and Barron, 1983; Schobbenhaus and others, 1984; Teixeira and others, 1984; Gruau and others, 1985; Teixeira and others, 1989). All of these meta-igneous and metasedimentary rocks form part of the Maroni-Itacaiunas Province, a so-called mobile belt or greenstone belt comprising a large portion of the supracrustal rocks of the Amazonian craton (Cordani and Brito Neves, 1982; Teixeira and others, 1989).

These Early Proterozoic greenstone belts of the Guayana Shield are comparable in age and lithology to the Birrimian schist belts of the Man Shield in West Africa (Black, 1980; Cohen and Gibbs, 1989). Although the greenstone-belt rocks have been correlated on the basis of grossly similar lithostratigraphy, chemistry, age, structure, and intensity of metamorphism, the rocks have not been mapped and studied in sufficient detail to construct accurately a lithostratigraphic column. The rocks of the Guayana Shield and the West African craton probably represent several penecontemporaneous greenstone belts, not one continuous belt.

The greenstone-belt rocks of the Guayana Shield were deposited in a submarine environment. Basalt with pillow structures and chemical and mineralogical alteration characteristic of submarine spilitization dominates the lower parts of the section. The middle section has a higher proportion of porphyritic andesite, dacite, and rhyolite submarine and possibly subaerial lava flows and siliceous and tuffaceous interflow sediments. Turbiditic graywacke, pelite, tuff, chemical sedimentary rocks, and volcaniclastic rocks are dominant in the uppermost part of the greenstone-belt section. The transition from volcanic to sedimentary rocks is conformable, and units are interstratified (Menendez, 1972; Bosma and others, 1983; Gibbs and others, 1984; Gibbs and Wirth, 1986; Gibbs, 1987; Day and others, 1989). In the greenstone belt of western Guyana (which is continuous into Venezuela), Renner and Gibbs (1987) estimated that basalts and gabbros (some representing slow-cooled interiors of thick flows and sills) form about 75 percent of the igneous rocks, of which about 25 percent are intermediate to felsic flow and pyroclastic rocks and about 8 percent rhyolite flows. Both tholeiitic and calc-alkaline chemical trends are present in the volcanic rocks of the greenstone belts (Renner and Gibbs, 1987; Day and others, 1989).

Gibbs (1987) estimated that ultramafic rocks comprise about 1 to 2 percent of the igneous rocks in the greenstone belts of the entire Guayana Shield. Komatiite has been tentatively identified in two isolated areas of the Guayana Shield in Venezuela on the basis of high magnesian content (22 wt % MgO or more) (Tosiani and Sifontes, 1989); however, reported relic spinifex texture (Tosiani and Sifontes, 1989) is actually rosettes of actinolite in contact metamorphic aureoles of gabbroic intrusions (Gray and others, this volume). Spinifex textures have not been reported elsewhere in the Guayana Shield (Gibbs, 1987), although Gruau and others (1985) have distinguished peridotitic komatiite in central French Guiana on the basis of whole-rock chemistry.

Mafic-ultramafic intrusions are present throughout the stratigraphic sequence of the greenstone belts of the Guayana Shield. They commonly form layered complexes that include cumulate rocks such as pyroxenite[2] and peridotite associated with gabbro and lesser anorthosite and diorite. Wynn, Page, and others (this volume) describe a mafic-ultramafic layered complex at Piston de Uroy (pl. 2). These intrusive complexes occur as both strongly metamorphosed and deformed bodies and as relatively unmetamorphosed and undeformed bodies. In a few cases, the lower grade of metamorphism and less intense deformation are present only in the interior parts of massive gabbroic bodies; the outer portions of these bodies are strongly deformed and metamorphosed. Some gabbroic bodies are relatively fresh and undeformed and therefore are apparently younger than the Trans-Amazonian orogeny (table 1); these gabbroic rocks may be associated with the Early to Middle Proterozoic Avanavero Suite (Benaim, 1972; Menendez, 1972, 1974; De Roever and Bosma, 1975; Gibbs, 1986).

Mafic and ultramafic rocks in the Venezuelan Guayana Shield form belts of small bodies of serpentinite and amphibole-talc-serpentine-carbonate rocks with chromite. Menendez (1972) noted that some of these gabbroic complexes are apparently preferentially intruded into the upper part of the El Callao Formation, where they are parallel to subparallel with basaltic lava flows of this formation. The maximum thickness of these gabbroic bodies is about 500 m (Menendez, 1972). Possibly some gabbro represents the slowly cooled interior of thick lava flows.

Geology of the Pastora Supergroup

The Pastora Supergroup consists of the Carichapo Group (El Callao and Cicapra Formations) and the Yuruari Formation (table 1). The El Callao Formation is the oldest unit of the Pastora Supergroup. Its basal contact is everywhere intruded by granitic rocks of the Supamo Complex, and its upper contact is transitional with the Cicapra Formation or concordant with the Yuruari Formation. The El Callao Formation was originally described in the El Callao area by Korol (1965) and Menendez (1968). Rocks called El Callao Formation in other areas do not necessarily conform to the description of the unit from the type section. This is also true for other units of the greenstone belts, ie., descriptions outside of the type-section area may not agree with those of the type section. Thus, it is possible, or even likely, that more than one greenstone belt is present in the Venezuelan Guayana Shield, even though present stratigraphic nomenclature implies that only one belt exists.

The El Callao Formation, as much as 3,000 m thick, consists almost exclusively of metamorphosed low-potassium basaltic to andesitic lava flows, commonly with pillowed lava and amygdular and brecciated flow tops (Menendez, 1968, 1972; Benaim, 1972). Minor ferruginous quartzite and ferruginous and manganiferous chert (metamorphosed banded iron-formation?) are present in several areas. Rocks of the El Callao Formation have been metamorphosed to the greenschist facies and locally the almandine amphibolite subfacies of the amphibolite facies. Greenschist facies rocks typically are biotite-chlorite-albite-epidote±actinolite schists. Close to granitic intrusions of the Supamo Complex, the rocks become amphibolites with blue-green hornblende and plagioclase (albite to andesine). Menendez (1968) defined a metamorphic and color zonation in pillow lavas as far as 6 km from the intrusives. The light green greenschist-facies lavas become darker, grayish green to greenish black, amphibolite-facies rocks toward the intrusive bodies.

Hills with irregular crests typify the topographic expression of the El Callao Formation. They are 300 to 800 m in elevation, about 100 to 500 m above the surrounding terrain. In contrast, gabbro in mafic complexes forms slightly higher and smoother crested hills. Red soil on this formation supports a dense forest (Menendez, 1968).

The Cicapra Formation overlies the El Callao Formation and includes a sequence as much as 2,000 m thick of rhythmically bedded submarine andesitic tuff, turbiditic graywacke, and siltstone in packets about 10 m thick. Lithic tuff, tuff breccia, and volcanic agglomerate, and, in the uppermost part of the formation, manganiferous hematitic chert are minor components of the Cicapra Formation (Menendez, 1972). These rocks are greenschist-facies, porphyroblastic, quartz-poor actinolite-biotite-epidote-albite schists. Amphibolites developed locally in this formation near granitic rocks do not contain biotite or porphyroblasts of amphibole. Schistosity, oblique to parallel to the stratification, is generally poorly developed; in areas near granitic intrusions, it is better developed. Rocks of the Cicapra Formation form a completely flat topography covered by a clayey soil the color of red wine. This unit wedges out and disappears southeast of El Callao, at which point the Yuruari Formation rests on the El Callao Formation (Menendez, 1968).

The basal contact between the Yuruari and the Cicapra Formations is gradational, and that between the Yuruari and El Callao Formations is both depositional and faulted. The Yuruari Formation is characterized by epiclastic and turbiditic rocks, with rhythmically bedded packets as much as 50 m thick of feldspathic sandstone, siltstone, and black shale. Locally, tuffaceous breccia, manganiferous phyllite, with intercalated dacitic to basaltic tuff, breccia, and lava flows, and chert are also present. The overall thickness of this formation is about 1,000 m (Menendez, 1968, 1972; Benaim, 1972; Day and others, this volume). Rocks of the Yuruari Formation are typically greenschist-facies chlorite-sericite±calcite schist. Hornblende-hornfels and pyroxene-hornfels facies, with biotite, sillimanite or andalusite, chloritoid, tourmaline, and garnet, developed in aureoles of granitic intrusions. Only locally are rocks of the Yuruari Formation intruded by granite of the Supamo Complex. The upper contact does not crop out, but the contact with the overlying Caballape Formation is apparently an angular unconformity and (or) a tectonic disconformity (Menendez, 1968). Low hills and plains with a rectangular drainage pattern and a varicolored (light to dark yellow, reddish yellow, and several shades of red) clayey residual soil have developed on the Yuruari Formation. Savanna-type vegetation is characteristic (Benaim, 1972; Menendez, 1972).

The greenstone-belt rocks of the Pastora Supergroup are strongly deformed and record at least two episodes of deformation. Recumbent isoclinal folds with folded axial planes are characteristic, and the axial planes are commonly parallel to subparallel to the borders of the granitic intrusions of the Supamo Complex (Menendez, 1972). Thus, the greenstone-belt rocks of the Pastora Supergroup typically form synforms that wrap around granitic domes of the Supamo Complex with annular shapes. Foliation is commonly developed in rocks of the greenstone belt, and it is parallel to subparallel to the primary stratification. Foliation is best developed close to contacts with the Supamo Complex. Cleavage parallel to the axial plane of the folds is also well developed in these rocks. Major shear zones as much as 1 km wide and 35 km long cut the rocks of the Pastora Supergroup (Menendez, 1972, 1974).

Geology of the Botanamo Group

Rocks in the Caballape and Los Caribes Formations of the Botanamo Group discordantly overlie the Pastora Supergroup. The Caballape Formation includes mafic to felsic lava and pyroclastic flows and breccia interbedded with epiclastic and turbiditic sedimentary rocks. Menendez (1968) estimated that graywacke, conglomerate, and siltstone comprise 80 percent of the unit in the El Callao-Guasipati area, the remainder being andesitic to rhyodacitic pyroclastic tuff and breccia. However, Benaim (1972) noted that only the basal part of the formation crops out in this area. Day and others (1989) determined that the Caballape Formation in the Anacoco area consists of about 80 percent basaltic to dacitic volcanic flows (some with pillow lavas) and associated pyroclastic rocks and about 20 percent volcanic breccia and graywacke with thin (1 to 5 cm thick) horizons of shale. The basal contact of the Caballape Formation is discordant to unconformable with the Pastora Supergroup, and the upper contact is reportedly concordant with the Los Caribes Formation (Benaim, 1972). Menendez (1968) estimated that the minimum thickness of this formation is about 5,000 m. Granites of the Supamo Complex do not intrude rocks of the Caballape Formation, and thus amphibolites are not present in this formation, in contrast to the Pastora Supergroup (Cox and others, in preparation). The Caballape Formation consists of greenschist-facies schists only with chlorite, epidote, sericite, quartz, calcite, biotite, and opaque oxide minerals, which are only moderately folded into broad synclines. The terrain underlain by this formation is flat, with low hills elongated parallel to the trend of the beds, and characterized by a rectangular or dendritic drainage. The rocks weather to form a bleached soil (Benaim, 1972; Menendez, 1972).

The Los Caribes Formation consists of intercalated red phyllite and sandstone, polymict conglomerate, and siltstone with minor felsic tuff breccia and lava flows of intermediate composition. This unit is excluded from the greenstone-belt sequence by some authors and is referred to as pre-Roraima metasedimentary rocks or pre-Roraima foliated sandstone (Ghosh, 1985). It has even been suggested that this formation is time correlative with rocks of the Cuchivero Group. It is likely that rocks of both pre-Cuchivero and post-Cuchivero ages have been included within the Los Caribes Formation by various authors because some rocks mapped as Los Caribes Formation contain fragments of unmetamorphosed felsic tuff typical of the Cuchivero Group and not greenschist-facies metavolcanic rocks (Cox and others, in preparation). Thus, the name should be restricted to only that area near the type section in the Cuyuni River where Benaim (1972) mapped the contact between the Caballape and Los Caribes Formations as concordant and interdigitated.

Sedimentary rocks of the Los Caribes Formation have been metamorphosed to the greenschist facies, in contrast to sedimentary rocks of the Roraima Group that are unmetamorphosed or only weakly thermally metamorphosed as shown by the presence of pyrophyllite and andalusite (Ghosh, 1985). Minerals such as chlorite, muscovite, epidote, chloritoid, and recrystallized sheared quartz in the Los Caribes Formation are representative of the greenschist facies. Also, in contrast to rocks of the Roraima Group, folds in conglomerate, sandstone, and phyllitic shale of the Los Caribes Formation are isoclinal or chevron in shape, and the rocks are foliated with a fracture cleavage at a high angle to bedding (Benaim, 1972; Ghosh, 1985; Lira and others, 1985). Some conglomeratic units are as thick as 60 m; however, the total thickness of this formation has not been determined. The Los Caribes Formation probably represents environments transitional from marine to continental during the terminal stages of the Trans-Amazonian orogeny.

Rocks of the Los Caribes Formation are probably correlative with those of the Cinaruco Formation in the Amazon Federal Territory, and the Muruwa, Rosebel, and Orapu Formations in Guyana, Suriname, and French Guiana, respectively (Ghosh, 1985). These rocks also resemble a molassic sequence known as the Tarkwaian Series in the eastern West African craton (Black, 1980; Bonhomme and Bertrand-Sarfati, 1982; Cohen and Gibbs, 1989). The Tarkwaian Series consists of Early Proterozoic (2,180 to 2,000 Ma) clastic metasedimentary rocks about 2,800 m thick that are folded within the Birrimian greenstone-belt rocks (Black, 1980; Norman and Appiah, 1989).

Geology of the Real Corona-El Torno assemblage

Supracrustal rocks, including basal feldspathic quartzite and conglomerate, tholeiitic basalt, gabbro, and thin beds of shale, chert, and ferruginous quartzite, form an east-trending structural basin about 100 km southwest of Ciudad Bolívar (pl. 1). The basin, or syncline, is about 45 km long and 16 km wide and is underlain both on the north and south by a gneissic basement about 2,240 Ma in age (Kalliokoski, 1965; Sidder and others, 1991). The basal quartzite is in depositional contact with the basement of granitic gneiss. The thickness of the quartzite is as much as 150 m; thicknesses of the other units are not known. These rocks have been penetratively deformed, with well-developed foliation, mineral lineation, and S-C mylonitic fabric, and metamorphosed to the amphibolite facies. Hills underlain by quartzite and chert rise as much as 200 m above the generally flat gneissic terrain. Vegetation in the area is savanna-like.

Age, chemistry, and origin of the greenstone-belt rocks

The greenstone belts of the Guayana Shield formed during the Early Proterozoic. They closely resemble in structure, lithostratigraphy, composition of their metavolcanic and metasedimentary rocks, and areal extent others of Early Proterozoic age such as those associated with the Penokean orogen in the Lake Superior region (Sims and others, 1989). Geochronological data, including uranium-lead zircon and whole-rock samarium-neodymium and rubidium-strontium isochron dates, prove that the metavolcanic greenstone-belt rocks and their associated granitic rocks were emplaced throughout the Guayana Shield between about 2,250 and 2,100 Ma (Gibbs and Olszewski, 1982; Gruau and others, 1985). These ages are the same as those obtained from the most detailed geochronological study of the Venezuelan greenstone-belt rocks, which determined an age of less than 2,300 to about 2,050 Ma for the emplacement of the metavolcanic-metasedimentary greenstone-belt sequence and the crystallization of the granites of the Supamo Complex (Klar, 1979). A sample of dacitic tuff from the Yuruari Formation in the Lo Increible mining district (pl. 2) has a uranium-lead zircon age of 2,131 ± 10 Ma (Day and others, this volume), which coincides with the published ages of the greenstone-belt rocks.

The chemistry of the greenstone-belt rocks in the Guayana Shield has not been studied systematically. Those investigators who have conducted geochemical studies on the greenstone-belt rocks note that the original chemical composition of the igneous rocks has been altered by weathering, hydrothermal alteration (spilitization and potassium metasomatism), and greenschist- and amphibolite-facies regional metamorphism. Recent studies by Gibbs (1987) and Renner and Gibbs (1987) in Guyana and Day and others (1989) in Venezuela provide data for representative areas of the Guayana Shield. Both tholeiitic and calc-alkaline differentiation trends are common in the volcanic rocks. Low-potassium subalkaline basalt and basaltic andesite are the dominant rock types, with lesser subequal proportions of andesite, dacite, and rhyolite. Gibbs (1987) noted that few samples from throughout the Guayana Shield contain silica contents in the range from 68 to 63 weight percent and concluded that the overall distribution is bimodal. Day and others (1989) reported a compositional continuum with systematic variations in the major and trace elements forming a cogenetic mafic to felsic calc-alkaline magmatic series for rocks of the Caballape Formation in the Anacoco area, Venezuela.

Discriminant diagrams used to define the tectonic setting of volcanic rocks are not consistent in specifying the tectonic environment of deposition of the greenstone-belt rocks. The volcanic rocks were erupted predominantly in a submarine environment, and their chemistry shows some characteristics of modern ocean floor basalts, island-arc rocks, and continental arc rocks. Initial $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of 0.7019 and 0.51002, respectively, as well as an ε_{Nd} value of 2.1 (Gruau and others, 1985), indicate that the volcanic rocks are derivatives of mantle melts and do not contain any contamination from Archean continental crust. It is possible that Early Proterozoic magmatism in the Guayana Shield developed as juvenile additions to the crust. Ambiguous geochemical signatures may reflect this evolutionary history and record environments as diverse as young island arc, back-arc marginal basin, and mature (thickened) island arc or continental arc. The Trans-Amazonian orogeny resulted in the amalgamation of these new crustal components (Choudhuri, 1980; Bosma and others, 1983; Gibbs, 1987; Renner and Gibbs, 1987; Teixeira and others, 1989; Liégeois and others, 1991).

Supracrustal rocks of the Real Corona-El Torno assemblage were deposited in a submarine environment within or marginal to the craton, possibly as a back-arc marginal basin inboard from the Pastora island arc, or during an early cratonic rifting phase associated with the Trans-Amazonian orogeny. Closure of the basin and regional compressive tectonism associated with the later phases of the Trans-Amazonian orogeny produced the penetrative deformation and metamorphism and variably thrust the basaltic rocks over the basal quartzite. The age of the basement gneiss places a maximum age on the rifting of 2,240 Ma (Sidder and others, 1991).

Mineral deposits of the greenstone-belt rocks

The greenstone-belt rocks of the Guayana Shield contain deposits of low-sulfide gold-quartz veins (Berger, 1986). Several deposits in Venezuela are currently being mined, such as those in the El Callao, Lo Increible, and Botanamo districts (Sidder, 1990). Mafic metavolcanic rocks of the El Callao Formation are the most common ore host in the El Callao district, which is the largest in Venezuela with production of about 200 metric tons of gold; however, all rock types in the greenstone belts throughout the shield, except those in the Los Caribes Formation, are known to host ore (Korol, 1961; Carter and Fernandes, 1969; Menendez, 1972; Dahlberg, 1975; Blanc and others, 1980; Barnard, 1990). Ore throughout the greenstone belts is localized by faults and shear zones (Menendez, 1972). Quartz veins typically range in thickness from 2 centimeters (cm) to more than 10 m. Quartz is milky white to gray and locally banded. Native gold and minor to trace amounts of pyrite with lesser amounts of tetrahedrite, chalcopyrite, bornite, molybdenite, scheelite, and sphalerite are the most typical metallic minerals in the quartz veins. Carbonate (commonly ankerite) in the quartz veins and carbonate alteration as much as 30 m into the wall rocks are common in some districts such as El Callao. In addition to carbonate alteration, the wall rocks are intensely silicified, sericitized, and propylitized (with epidote and chlorite) as much as several tens of meters away from the veins, and tourmaline and mariposite (chrome mica) are variably present in the alteration assemblage (Macdonald, 1968; Banerjee and Moorhead, 1970; Barron, 1973; Menendez, 1974).

The Vuelvan Caras deposit (pl. 2) is the only gold-bearing vein deposit in the Venezuelan Guayana Shield known to occur in both granitic rocks and metavolcanic and metasedimentary rocks (Graterol, 1974; Wynn and Sidder, 1991). It is similar to gold deposits in Guyana, such as those at Aurora, Omai, and Mahdia, that are in stockwork veins within and at the periphery of granitic plutons that range in age from about 2,100 to 1,800 Ma (Macdonald, 1968; Barron, 1969; Carter and Fernandes, 1969; Berrange, 1977; Elliot, 1986; Barnard, 1990). Although in Venezuela the association of granitic intrusions with gold-bearing quartz veins is not well documented, several authors have noted that gold deposits in greenstone-belt rocks in Guyana, Suriname, and French Guiana are spatially associated, if not genetically related, to granitic intrusions (Carter and Fernandes, 1969; Banerjee and Moorhead, 1970; Dahlberg, 1975, Blanc and others, 1980).

Metals other than gold have not been produced in any significant quantity from the greenstone-belt rocks of the Guayana Shield. Small occurrences of manganese in Venezuela, such as San Cristobal and La Esperanza, and iron prospects in banded iron-formation have not been systematically worked or evaluated. The manganese prospects in Venezuela are similar to the Serra do Navio manganese deposit in Amapa Federal Territory, Brazil, which has reserves of about 21 million tons of 39 percent manganese (Lima, 1984), and to Matthews Ridge in Guyana, which produced about 1.5 million tons with a grade of about 39.5 percent manganese from 1961 to 1968 and has ore reserves of about 318,000 tons of 37 percent manganese (Barron, 1973).

Undiscovered deposits such as those of Algoma-type banded iron-formation, Homestake-type gold, and Cuban-type (island arc) volcanogenic manganese are possible in the metavolcanic and metasedimentary rocks of the greenstone belts. Volcanogenic massive sulfide deposits have not been discovered in the Guayana Shield, although the tectonic and volcano-sedimentary environments appear favorable for volcanic-hosted kuroko-type massive sulfide deposits, and prospects with anomalous copper are known in Guyana (Barron, 1973; Sidder, this volume). Porphyry copper ± gold ± molybdenum deposits may be hosted by Trans-Amazonian age or younger (post-Supamo) Early Proterozoic granitic rocks that intrude the greenstone-belt rocks, such as those at Vuelvan Caras. Platinum-group elements (PGE), chromium, and nickel-copper deposits may be associated with mafic-ultramafic complexes in the greenstone belts. Anomalous abundances of PGE have been discovered in mafic rocks at Piston de Uroy and in the Real Corona-El Torno assemblage (Sidder, this volume; Wynn, Page, and others, this volume). PGE are also present in gold lode and placer deposits (Dahlberg, 1975; Sidder, 1990). Sidder (this volume) reviews in detail mineral occurrences and deposits associated with the greenstone belts and other rocks of the Venezuelan Guayana Shield.

SUPAMO COMPLEX

The Supamo Complex includes paragneiss, schist, migmatite, and granitic rocks such as tonalite, granodiorite, and trondhjemite. Quartz monzonite and granite that intrude trondhjemite and the greenstone-belt rocks of the Pastora Supergroup have also been included within the Supamo Complex by some authors (Menendez, 1972). The plutonic rocks of the Supamo Complex are massive to foliated, generally form domes, and metamorphic grade in the country rocks increases from greenschist to amphibolite facies within about 6 km of the intrusions. The marginal facies of the intrusive bodies are generally concordant with the supracrustal rocks that they intrude. The granitic rocks generally underlie a savanna with small, rounded, isolated hills and a dendritic drainage pattern. The soil is sandy with minor clay and has a bleached or whitish color (Menendez, 1972, 1974; Benaim, 1974). Rocks of the Supamo Complex are not known to host any mineral deposits.

The age of the Supamo Complex is commonly described as ranging from 2,700 to 2,100 Ma, with the younger aged rocks said to be "remobilized Supamo". Recent uranium-lead isotopic data for zircons indicate that trondhjemite of the Supamo Complex crystallized between about 2,200 and 2,050 Ma (Klar, 1979). Moreno and Mendoza (1975) suggested that the potassic granitic rocks may be associated with younger granites of the Cuchivero Group (table 1). However, the age of emplacement of quartz monzonite plutons into the Imataca Complex and the greenstone-granite terrane ranges from about 2,200 to 2,050 Ma based on uranium-lead zircon dates (Klar, 1979) and possibly to 1,958 Ma as indicated by rubidium-strontium data for biotite (Onstott, Hargraves, York, and Hall, 1984). These dates are older than those for granites in the Cuchivero Group (table 1). The reinterpreted age of gneissic rocks in the Supamo Complex is about 2,230 Ma, which is consistent with an age of 2,227 Ma for the apparently correlative Bartica Gneiss in Guyana (Gibbs and Olszewski, 1982).

TRANS-AMAZONIAN OROGENY

The Trans-Amazonian orogeny was a major orogenic cycle of greenschist- to upper amphibolite- and granulite-facies metamorphism, deformation, and magmatic activity that occurred in the Guayana Shield during the Early Proterozoic. It was a period of continental collision and amalgamation of assorted Archean and Early Proterozoic terranes into the Amazonian craton, their subsequent common deformation, and the first development of continental environments on much of the craton. Paleomagnetic and $^{40}Ar/^{39}Ar$ data indicate that the Guayana and Guaporé Shields and possibly the West African craton were combined as a single tectonic plate during the Trans-Amazonian orogeny (Gibbs and Wirth, 1986; Renne and others, 1988; Teixeira and others, 1989). The Imataca Complex was thrust over the Pastora-Supamo greenstone-granite terrane during the Trans-Amazonian orogeny, and continued oblique compression between these two terranes resulted in left slip along major fault zones such as the Guri shear zone (Swapp and Onstott, 1989). The Guri fault zone, and its inferred continuation in the West African craton the Sassandra-Trou Mountain fault zone, may be a suture between Archean rocks (the Imataca Complex in Venezuela) and the Early Proterozoic greenstone-belt rocks. The Eburnean orogeny in the West African craton was a period of igneous and metamorphic activity between about 2,200 and 2,000 Ma ago (Hedge and others, 1975; Onstott and Dorbor, 1987; Cohen and Gibbs, 1989; Liégeois and others, 1991), coincident with the Trans-Amazonian orogeny in the Guayana Shield.

The Trans-Amazonian orogeny in the Guayana Shield occurred between about 2,150 and 1,960 Ma, and possibly continued to about 1,730 Ma. The wide range in ages is apparently the result of time transgressive tectonic activity that crossed the shield from northeast to southwest (Gaudette and Olszewski, 1985). Alternatively, the range in ages spans two distinct orogenic episodes that have been combined as the Trans-Amazonian orogeny, a predominantly collisional and metamorphic event with intrusive magmatic activity throughout the shield from about 2,150 to 1,960 Ma and a period of intense metamorphism, deformation, and intrusion between about 1,860 and 1,730 Ma in the Amazon Federal Territory of Venezuela, which is in the westernmost part of the shield (Klar, 1979; Gibbs, 1980; Bosma and others, 1983; Teixeira and others, 1984; Gaudette and Olszewski, 1985). Post-orogenic and (or) anorogenic magmatic activity that emplaced rocks of the Cuchivero Group and its equivalents with minor uplift, but little or no deformation or metamorphism from about 1,930 to about 1,790 Ma is not considered here to be part of the Trans-Amazonian orogeny. Kimberlite, at least in the western Guayana Shield of Venezuela, also may have been intruded at about 2,000 Ma (Nixon and others, 1989). Model ages from neodymium isotopic data define an age of about 2,060 to 1,950 Ma for the intrusion of diamond-bearing kimberlitic dikes and sills in the Quebrada Grande area of the Guaniamo mining district (pl. 2; Nixon, 1988; Nixon and others, 1989).

Rocks of the Imataca Complex reveal a history of prograde metamorphism and retrograde cooling and uplift associated with the Trans-Amazonian orogeny. Detailed rubidium-strontium isotopic studies of the age of granulite-facies metamorphism in the Imataca Complex indicate an age of 2,022 ± 67 Ma for the Trans-Amazonian orogeny (Montgomery and Hurley, 1978). This date apparently predates the peak pressure associated with the orogeny and postdates the peak temperature (Swapp and Onstott, 1989). Plateau dates from $^{40}Ar/^{39}Ar$ analyses of hornblende and biotite in the Imataca Complex range from about 2,044 to 1,760 Ma and are interpreted to record decompression, uplift, and cooling following peak metamorphism of the Trans-Amazonian orogeny (Onstott and others, 1989; Swapp and Onstott, 1989). The Imataca Complex was uplifted from a depth of about 32 to about 16 km during southward thrusting over the greenstone-belt rocks within about 30 m.y. after the initiation of uplift (after reaching peak pressure conditions at about 2,000 Ma) (Swapp and Onstott, 1989). Additional vertical readjustments over about a 20 m.y. interval uplifted the Imataca Complex to about a 15 km depth, at which time isobaric cooling ensued. Extremely slow cooling rates implied by plateau dates of biotite from granulite-facies rocks in the core of the Imataca Complex, potassium feldspar, and plagioclase indicate that substantial uplift of the Imataca Complex had ceased by about 1,962 Ma and that rocks in the complex cooled isobarically at intermediate crustal levels of about 15 km until about 1,100 Ma (Onstott and others, 1989; Swapp and Onstott, 1989). All argon-bearing mineral systems were closed by 1,100 Ma, which could reflect renewed uplift associated with the Nickerie or K'Mudku episode (table 1; Onstott and others, 1989). In contrast, metamorphic rocks in the Carajas region, Brazil, of the Guaporé Shield cooled rapidly and attained stable magnetization by about 1,910 Ma (Renne and others, 1988). Paleomagnetic and $^{40}Ar/^{39}Ar$ data preclude the possibility of any subsequent regional metamorphism to even the lowest greenschist facies after the Trans-Amazonian orogeny in the Guaporé Shield.

The Trans-Amazonian orogeny in the Guayana Shield is defined here to consist of deformation, metamorphism, and magmatic activity between about 2,150 and 1,960 Ma. Deformation in rocks of the Pastora Supergroup indicates that two pulses or episodes of tectonic activity took place within this interval, whereas rocks of the Botanamo Group were affected by just the second pulse of deformation. It is possible that subduction jumped to the southwest (present orientation) of the greenstone-belt rocks following collision and amalgamation of the island-arc greenstone-belt rocks with the Imataca Complex. Post-collisional magmatism and subsequent continental-arc magmatism resulted in the eruption and intrusion of the Cuchivero Group and its equivalents. The Cuchivero Group is regarded here to be post-collision and post-Trans-Amazonian in age, even though some of the Cuchivero Group may be arc-related rocks, which are considered orogenic. Rocks of the Cuchivero Group are generally unmetamorphosed and relatively undeformed and their character is sufficiently different from that of the greenstone-belt rocks such that they should be considered part of an unnamed thermomagmatic event. This post-Trans-Amazonian magmatic activity ensued until about 1,790 Ma.

Metamorphism, deformation, and magmatic activity between about 1,860 and 1,730 Ma in the Amazon Federal Territory must be considered as part of yet another orogenic event (see section on undivided Proterozoic rocks). Gaudette and Olszewski (1985) correlated this younger orogenic episode in the Amazon Federal Territory with the older Trans-Amazonian event (2,150 to 1,960 Ma). However, the age of 1,900 ± 200 Ma reported for the Trans-Amazonian orogeny (Moreno and others, 1977; Gaudette and Olszewski, 1985), which is based on potassium-argon and whole-rock rubidium-strontium dates for an intrusion in the Imataca Complex and rocks of the Cuchivero Group, is not compatible with the recent and more accurate uranium-lead and argon-argon dates for metamorphism and deformation of the Trans-Amazonian orogeny. As noted in the section on undivided Proterozoic rocks in the Amazon Federal Territory, geologic mapping, geochemical sampling, and geochronologic dating are insufficient for a rigorous interpretation of the geology in this complex area.

CUCHIVERO GROUP

Early to Middle Proterozoic supracrustal rocks were emplaced in and deposited on the older greenstone-granite terrane in the southern, central, and western parts of the Venezuelan Guayana Shield (pl. 1). They include a thick pile (greater than 3 km in thickness) of felsic to intermediate and mafic volcanic, subvolcanic, and plutonic rocks, and associated volcanogenic sedimentary rocks of the Cuchivero Group; sandstone and conglomerate with lesser siltstone, shale, chert, and interlayered felsic volcanic rocks (jasper) of the Roraima Group; continental tholeiitic dikes, sills, inclined sheets, and small irregular intrusive bodies of the Avanavero Suite; and rapakivi granite of the Parguaza Province (Rios, 1972; Mendoza and others, 1975; Ghosh, 1985; Gibbs, 1986; Sidder and Martinez, 1990).

The Cuchivero Group includes the relatively older volcanic rocks of the Caicara Formation and the younger granites of Guaniamito, San Pedro, and Santa Rosalia (Rios, 1972; Mendoza and others, 1975). The granites crop out principally in the northern part of the province, whereas the volcanic rocks predominate in the southern part. Broad, open folds are common, and structures such as faults and lineaments generally strike northwest to north-northwest and north-northeast. The El Viejo Formation, the volcanic suite of the Parucito Valley, and other relatively unmetamorphosed volcanic and plutonic rocks in the Amazon Federal Territory, the Uatuma Supergroup (including the Surumu and Iricoumé Formations and the granodiorite of Serra do Mel) in northern Brazil, the Kuyuwini and Burro-burro Groups in Guyana, and the Dalbana Formation in Suriname correlate with the Cuchivero Group (Mendoza and others, 1975; Montalvao, 1975; Talukdar and Colvée, 1975, 1977; Berrange, 1977; Mendoza and others, 1977; Tepedino, 1985; Gibbs, 1987; Sidder and Martinez, 1990; Machado and others, 1991). Rocks equivalent to the Cuchivero Group are not present in French Guiana or the West African craton.

Caicara Formation

The Caicara Formation consists of subaerially deposited pyroclastic rocks such as variably welded ash-flow tuff and breccia with minor lava flows and intercalated volcaniclastic rocks. The rocks are aphyric to porphyritic, with both crystal-rich and crystal+lithic-rich varieties. Vitroclastic and eutaxitic textures with devitrified glass shards and collapsed pumice fragments are common (Rios, 1972; Mendoza, 1977b; Sidder and Martinez, 1990). The Caicara Formation is comprised dominantly of rhyolite, with subordinate rhyodacite and dacite and minor proportions of andesite, basaltic andesite, and basalt. On a total alkali-silica diagram, some rocks of the Caicara Formation are classified as trachyte and trachydacite. The silicic rocks are mainly tuffs, whereas andesite and basalt occur as lava flows and dikes. Together, these rocks form a comagmatic calc-alkaline series (Talukdar and Colvée, 1975, 1977; Mendoza, 1977b; Sidder and Martinez, 1990). Briceño and others (1989) described felsic to intermediate volcanic and volcaniclastic rocks near Ichun tepui (pl. 1), named them the Ichun Formation, and suggested that they were part of the Roraima Group. However, these rocks are chemically and lithologically similar and have the same stratigraphic position as those of the Caicara Formation to the north and south along the Paragua River. Moreover, the basal conglomerate and overlying sandstone of the Roraima Group in this area appear to overlie the volcanic rocks conformably (Sidder, unpublished data, 1988). Stephen D. Olmore (U.S. Geological Survey, oral commun., 1990) has mapped a similar conformable contact between rocks of the Caicara Formation and the overlying Roraima Group in the Amazon Federal Territory, and Amaral and Halpern (1975) reported common intercalations of volcanic tuff of the Surumu Formation near the base of the Roraima Group in Brazil within 80 km south of the Brazil-Venezuela-Guyana junction (fig. 1). The contact between the Caicara Formation and the Roraima Group at the base and in the cliff-face of Ichun tepui below the waterfalls of Salto Espuma and in other areas needs to be studied in more detail to verify the conformable relation.

Granites of the Cuchivero Group

Granites associated spatially and temporally with the volcanic rocks of the Caicara Formation include the granites of San Pedro, Santa Rosalia (including the granite of Las Trincheras), and Guaniamito. They are hypabyssal biotite granite, quartz monzonite, and granodiorite (Rios, 1972; Mendoza, 1974; Tepedino, 1985) bodies that are in intrusive and fault contact with the volcanic rocks. The rocks are generally equigranular to porphyritic, and medium- to coarse-grained. The granite of San Pedro is dominantly a fine-grained leucocratic granite that has been interpreted as a marginal border phase of the coarser grained biotite granite of Santa Rosalia (Mendoza, 1974). The granite of Guaniamito is a porphyritic, medium to coarsely crystalline, biotite granite. All of these granites are generally massive in texture but locally foliated, especially near the intrusive contact of granite with the volcanic rocks of the Caicara Formation (Rios, 1972). Primary minerals of the granites include potassium feldspar (orthoclase and microcline; 20-60 modal percent), quartz (10-40 percent), plagioclase (albite-oligoclase; 5-40 percent), biotite (<1-10 percent), and accessory sphene, apatite, zircon, muscovite, hornblende, allanite, and iron-titanium oxide minerals (magnetite and lesser ilmenite). Secondary alteration minerals are epidote, clinozoisite, and white mica in plagioclase and potassium feldspar, chlorite after biotite, and hematite after magnetite. Aplite dikes and barren quartz veins commonly cut these granitic bodies (Rios, 1972; Mendoza, 1974; Tepedino, 1985; Sidder, unpublished data, 1988). Bosma and others (1983) and De Roever and Bosma (1975) described hypabyssal biotite granite and leucogranite in Suriname that are associated with and intrude rhyolitic volcanic rocks of the Dalbana Formation. The hypabyssal granites are considered to be comagmatic equivalents of the volcanic rocks (Mendoza, 1977b; Bosma and others, 1983).

Granitic and volcanic rocks of the Cuchivero Group and its equivalents throughout the Guayana Shield are generally unmetamorphosed. Reports of lower greenschist-facies metamorphism apparently refer to local contact metamorphic aureoles in volcanic and volcaniclastic rocks close to intrusions. For example, field and petrographic evidence of metamorphism is not present in samples of volcanic rocks from the upper Caura or Paragua River areas (Sidder, unpublished data, 1990; Sidder and Martinez, 1990). Indeed, as noted above, vitroclastic and eutaxitic textures are abundant. Minor alteration in the volcanic rocks and granites, such as partial replacement of feldspar by fine-grained sericite and epidote, chlorite alteration of biotite, and thin veinlets of quartz or epidote+chlorite, is indicative of deuteric and local hydrothermal alteration. Rios (1972) recognized that the volcanic rocks of the Caicara Formation were thermally metamorphosed in restricted zones close to intrusions. It is significant to note that Rios (1972) called primary flow bands developed during the extrusion and emplacement of the volcanic rocks "foliación", or foliation. He did not recognize any effects of regional metamorphism. However, subsequent authors have referred to the Caicara Formation as a sequence of metavolcanic rocks (Tepedino, 1985), and others have called the rocks metavolcanic, but noted that the rocks had suffered contact metamorphism ("thermal-regional or plutono-metamorphism") only due to intrusions of the granitic batholith of the Cuchivero Group (Mendoza, 1977b). Similarly, Bosma and others (1983) referred to rhyolitic rocks of the Dalbana Formation in Suriname as metavolcanic. However, they noted that "*distinctly recrystallized metavolcanics form broad marginal zones along the granites.... The recrystallization, without significant foliation or folding, is spatially related to granite intrusions and probably took place at shallow depth under hornblende-hornfels facies conditions.*" Thus, the volcanic rocks of the Caicara Formation and the granites of the Cuchivero Group and similar rocks throughout the Guayana Shield are not regionally metamorphosed, but they are contact metamorphosed or hydrothermally altered in proximity to intrusions, faults, dikes, and veins (De Roever and Bosma, 1975; Sidder and Martinez, 1990).

Age and origin of the Cuchivero Group

Whole-rock rubidium-strontium dates reported for rocks of the Cuchivero Group and its equivalents throughout the Guayana Shield range from 1,930 to 1,640 Ma, with the majority between 1,930 and 1,790 Ma (table 2; Hurley and others, 1977; Moreno and others, 1977; Bosma and others, 1983; Schobbenhaus and others, 1984; Teixeira and others, 1989; Machado and others, 1991). Initial $^{87}Sr/^{86}Sr$ ratios vary from 0.698 for the granites of Guaniamito, San Pedro, and Santa Rosalia to 0.721 for volcanic rocks of the Surumu Formation in Brazil (table 2). The former initial ratio is not geologically reasonable because basaltic achondrite meteorites have an initial ratio of 0.69897 (Faure, 1986). The latter is extremely high due to scatter of the data, with a mean squares weighted deviation (MSWD) of 60.9 and a 1-sigma error of 0.017 in the calculated initial ratio. A majority of the initial ratios for rocks of the Cuchivero Group and its equivalents ranges between about 0.705 and 0.707, which is between those inferred for Proterozoic crust (>0.708) and mantle-derived magmas (<0.7045) (Priem, 1987; Riciputi and others, 1990) and is a further indication of some contribution of continental crust in the generation of the magmas. Those initial ratios that are as high as 0.712 may reflect melts derived directly from crustal material.

Rocks of the Cuchivero Group and its equivalents have been considered as both orogenic related to the Trans-Amazonian collision and deformation and as anorogenic (De Vletter and Kroonenberg, 1984). Supporters of the orogenic interpretation suggest that the contact between the felsic

Table 2. Rubidium-strontium whole-rock isochron dates for volcanic and plutonic rocks of the Cuchivero Group and its equivalents, Guayana Shield.

COUNTRY	UNIT	AGE (Ma)	$(^{87}Sr/^{86}Sr)_o$	MSWD	REF.
Venezuela	Caicara Formation	1,700 ± 220 (n = 3)	0.709	1.72	1
Venezuela	Granites of Santa Rosalia and San Pedro	1,880 ± 88 (n = 7)	0.698	24.3	1
Guyana	Kuyuwini Group	1,800 ± 420 (n = 4)	0.705	20.9	2
Suriname	Felsic volcanic rocks (Dalbana Formation)	1,930 ± 48 (n = 18)	0.705	2.25	3
Suriname	Granitoid rocks	1,850 ± 40 (n = 14)	0.707	2.58	3
Suriname	Granitic and volcanic rocks together*	1,880 ± 31 (n = 32)	0.706	2.64	3
Brazil	Surumu Formation	1,800 ± 94 (n = 6)	0.721	60.9	4
Brazil	Surumu Formation	1,640 ± 55 (n = 6)	0.714	18.2	5
Brazil	Surumu Formation (includes four samples analyzed by Amaral and Halpern, 1975)**	1,820 ± 55 (n = 10)	0.712	45.7	4
Brazil	Granite of Serra do Mel	1,790 ± 62 (n = 4)	0.706	4.63	4

[1]Gaudette and others, 1978
[2]Berrange, 1977
[3]Priem and others, 1971
[4]Basei and Teixeira, 1975
[5]Amaral and Halpern, 1975
*As reported by Priem and others, 1971
**As reported by Basei and Teixeira, 1975

volcanic rocks and rocks of the underlying greenstone belt is conformable and therefore include the Cuchivero Group and its equivalents as a second, dominantly magmatic, stage of the Trans-Amazonian orogeny between about 2,000 and 1,870 Ma (Bosma and others, 1983; De Vletter and Kroonenberg, 1984; Teixeira and others, 1984). However, as noted above, deformation and metamorphism in the Cuchivero Group are significantly different from that in the greenstone-belt rocks, and, therefore, a conformable contact is considered extremely unlikely. Those who suggest that the predominantly felsic igneous rocks of the Cuchivero Group and its equivalents are anorogenic note that the contact with the greenstone-belt rocks is a profound angular unconformity and crustal extension, as evidenced by widespread intrusion of mafic dikes and sills of the Avanavero Suite, was penecontemporaneous with the deposition of the volcanic rocks (Montalvao, 1975; Gibbs, 1980; Gibbs, 1986; Gibbs and Olszewski, 1982). However, as presented below, the age of the Avanavero Suite (about 1,650 Ma; table 1) is younger than that of the Cuchivero Group and these units are not coeval.

The volcanic and plutonic rocks of the Cuchivero Group are referred to here as post-collisional, post-Trans-Amazonian because they do not have a clear association with any orogenic belt, they are not regionally metamorphosed, and they are weakly deformed, lacking a pervasive penetrative fabric. Any deformation that they underwent may be attributed to younger post-Trans-Amazonian events. Granites formed in post-collisional tectonic settings commonly postdate the collisional event by about 25 to 75 m.y. (Sylvester, 1989), which is the approximate time interval between the termination of uplift of the Imataca Complex (collision with the greenstone-belt rocks) and magmatism in the Cuchivero Group. Limited geochemical data suggest that the granite of Santa Rosalia and volcanic rocks of the Caicara Formation are transitional; they plot between within-plate (anorogenic) granite and volcanic-arc granite on several discriminant diagrams and approximately in the field of post-collision granite on the rubidium versus yttrium + niobium diagram (fig. 3; Pearce and others, 1984; Sylvester, 1989; Sidder, unpublished data, 1990). The variously indicated tectonic settings may result from transitional mantle and crustal sources; post-collision within-plate crustal magmatism may have been followed by renewed subduction and mantle-derived continental arc magmas. Additional field, geochemical, isotopic, and petrographic data are needed from throughout the shield in order to determine the origin of the Cuchivero Group and its equivalents.

Mineral resources in the Cuchivero Group

Major mineral deposits have not been discovered to date in the Cuchivero Group. Quartz veins with silver and gold occur locally in the volcanic rocks of the Caicara Formation, and isolated areas of rhyolite contain trace amounts of disseminated cassiterite (Sidder, 1990; Sidder and Martinez, 1990). Although epithermal and bonanza-type precious metal vein deposits are uncommon in Precambrian rocks (Hutchinson, 1987), the felsic to intermediate composition and pyroclastic character of the volcanic rocks in addition to geochemical anomalies of silver, bismuth, and molybdenum in some quartz-sulfide veins and gold in panned concentrates are suggestive of epithermal precious-metal deposits in these rocks (Sidder and Martinez, 1990). Mineralized epithermal systems in the Guayana Shield may have been preserved by burial of the Cuchivero Group volcanic rocks shortly after their deposition by sedimentary rocks of the Roraima Group, as exhibited by locally conformable contacts.

Field and geochemical evidence indicates that shallow porphyritic granitic intrusions into volcanic rocks of the Caicara Formation in western Bolívar State and the Amazon Federal Territory and possibly equivalent rocks in Brazil have moderate potential for associated porphyry molybdenum-type deposits. Molybdenite is a relatively common mineral in contact zones between felsic volcanic rocks of the Caicara Formation and biotite granite of the Cuchivero Group in Venezuela (Mendoza and others, 1977). In northern Brazil, molybdenite is disseminated in biotite granite and in small

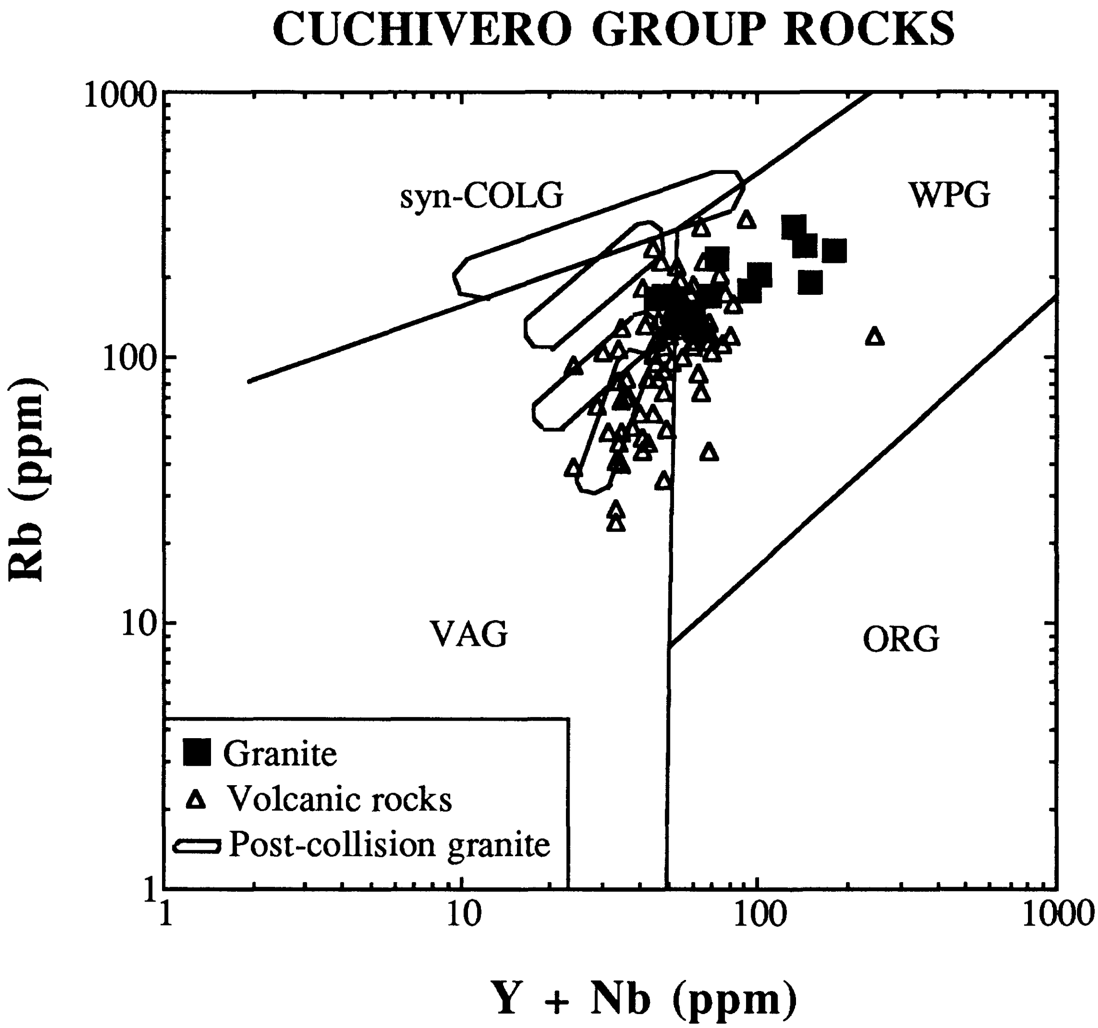

Figure 3. Rb vs. (Y + Nb) diagram of Cuchivero Group rocks. Fields of post-collision granite from Pearce and others (1984). VAG, volcanic arc granite; ORG, ocean ridge granite; WPG, within-plate granite; syn-COLG, syn-collision granite. Data from Sidder and Martinez, 1990, and Sidder, unpublished data, 1990.

quartz veins at the faulted contact between granite and volcanic rocks of the Surumu Formation (Montalvao and others, 1975; Berrange, 1977; Schobbenhaus and others, 1984).

Cassiterite and wood tin are sparsely disseminated in some samples of high-silica rhyolite in the Caicara Formation and its equivalent rocks of the Iricoumé Formation in Brazil (Jones and others, 1986; Sidder, 1990). Cassiterite is also present in panned concentrates, for example, from creeks that drain into the upper Paragua River near the Brazil-Venezuela border (pl. 2; Sidder, 1990). These occurrences are typical of rhyolite-hosted tin deposits (Duffield and others, 1990); however, occurrences of economic significance are not yet known.

The carbonatite at Cerro Impacto (within the Cuchivero Province; pl. 2), which occurs near the intersection of large northeast- and northwest-striking fractures, is enriched in niobium, thorium, barium, cerium, and other metals and rare earth elements (Aarden and others, 1978; Premoli and Kroonenberg, 1981). The northwest-striking fractures may be coextensive with those along which kimberlite was emplaced in the Quebrada Grande area, and they are parallel to large regional fractures that apparently controlled the emplacement of pegmatitic dikes into granites of the Parguaza Province. These fractures extend throughout the western part of the Guayana Shield in Bolívar State, the Amazon Federal Territory, and into Brazil. Mendoza and others (1977) suggested that the carbonatitic complex intruded plutonic rocks of the Cuchivero Group during the Mesozoic between 150 and 80 Ma; however, dates of about 1,900 to 2,060 Ma and 850 Ma reported by Nixon (1988) and Nixon and others (1989) for kimberlitic rocks in the Quebrada Grande area suggest that the carbonatite at Cerro Impacto may be much older than Mesozoic. It may correspond in age with either of the Proterozoic kimberlites of the Quebrada Grande area, which are only slightly older and younger, respectively, than carbonatites emplaced elsewhere in the world between about 1,800 and 1,650 Ma, and between 1,000 and 900 Ma (Meyer, 1988).

UNDIVIDED PROTEROZOIC ROCKS

Many Proterozoic rocks in the Amazon Federal Territory have not been studied or have been examined in reconnaissance fashion and are herein included as an undivided group of rocks (pl. 1). They consist predominantly of granitic and associated volcanic rocks, mafic and alkaline intrusive rocks, and medium- to high-grade gneisses of both igneous and sedimentary protoliths. Mendoza and others (1977) and Gaudette and Olszewski (1985) informally named some of these rocks, such as the Minicia gneiss or migmatite, the Macabana augen gneiss, the granites of Atabapo, San Carlos, and Sipapo, as well as many other local names, after the area where they were mapped. Barrios and others (1985) grouped these locally named units into two provinces, the Ventuari and Casiquiare dominions, based on similar structural, petrologic, and geochronologic characteristics. The Ventuari dominion, primarily north and east of the Orinoco River in the Amazon Federal Territory (pl. 1), consists of volcanic and plutonic rocks similar to the Cuchivero Group, the Parguaza granite, sedimentary rocks of the Roraima Group, isolated metasedimentary sequences, and massive alkaline and mafic intrusions. Topographic relief in this province is high, and elevations are as much as 2,000 m above sea level on the tops of some vertically cliffed plateaus, which are called tepuis in Venezuela. The Casiquiare dominion, generally south of the Orinoco River in the Amazon Federal Territory (pl. 1), includes granite, gneiss, migmatite, and scarce outcrops of the Roraima Group, without volcanic rocks or alkaline or mafic intrusive bodies. Elevation rarely exceeds 500 m above sea level in this province (Barrios and others, 1985). Priem and others (1982) identified similar granitic and metamorphic rocks in southeastern Colombia near the Colombia-Venezuela border and used the name "Complejo migmatítico de Mitú" (Mitú migmatitic complex). Notably, all of these authors commented on the complexity of the relations between the rocks, the poor exposures in the jungle, and the intense weathering of the rocks. Most of the mapped and sampled outcrops form discontinuous and isolated exposures along rivers.

The undivided Proterozoic intrusive rocks in the Amazon Federal Territory range in composition from biotite granite to tonalite and diorite. They are generally medium to coarse grained, equigranular to porphyritic, and weakly foliated. The plutonic rocks have been moderately deformed by small-scale faults and shears, and cataclastic textures are common. Aplite dikes of more than one intrusive episode cross cut the plutonic rocks (Mendoza and others, 1977; Priem and others, 1982; Gaudette and Olszewski, 1985). Granitic rocks of the Ventuari dominion, such as the granite of Padamo and unnamed plutonic rocks along the Orinoco, Ventuari, and Paru Rivers, are similar to those of the granite of Santa Rosalia. Associated volcanic rocks of the El Viejo Formation, the volcanic suite of the Parucito Valley, and similar locally named units such as the felsic to intermediate volcanic rocks of Yaví, Asita, Autana, and others in the Ventuari dominion are probably equivalent to the Caicara Formation or to volcanic rocks associated with the Parguaza granite (Talukdar and Colvée, 1975, 1977; Mendoza and others, 1977; Gaudette and Olszewski, 1985). Some granitic rocks in the Casiquiare dominion are similar to those of the Parguaza granite (Barrios and others, 1985; Gaudette and Olszewski, 1985).

The undivided Proterozoic metamorphic rocks vary from poorly foliated and mildly tectonized gneiss to well-foliated gneiss and migmatite with cataclastic texture. Phyllite and quartzite are weakly metamorphosed metasedimentary rocks. Granitic gneiss, or metamorphosed plutonic rocks, ranges in composition from granite to granodiorite, tonalite, and diorite. The intensity of metamorphism reaches the greenschist and amphibolite facies with assemblages of chlorite ± muscovite ± epidote ± chloritoid and plagioclase-hornblende ± garnet, respectively (Mendoza and others, 1977; Gaudette and Olszewski, 1985).

Geochronological data indicate that peak metamorphism and magmatism of the undivided Proterozoic rocks in the Venezuelan Amazon Federal Territory occurred between about 1,860 and 1,730 Ma. Gaudette and Olszewski (1985) correlated this metamorphic and magmatic activity with the Trans-Amazonian orogeny, but it is probably part of a younger unnamed event, as discussed above. Low initial $^{87}Sr/^{86}Sr$ ratios of about 0.703 in paragneiss implies that the protolith of the metasedimentary rocks was not considerably older. Strongly deformed and metamorphosed plutonic rocks of about 1,860 Ma, in addition to moderately to weakly deformed plutonic rocks with an age of about 1,730 Ma[3], indicate that plutonism and metamorphism may have been synchronous from about 1,860 to 1,730 Ma. Unmetamorphosed, undeformed granitic rocks about 1,600 Ma old represent post-orogenic plutonic activity in the Amazon Federal Territory, and the Parguaza rapakivi granite (pl. 1) typifies magmatic activity at about 1,545 Ma. In general, dates determined for granitic rocks in the Ventuari dominion are older than for those to the southwest in the Casiquiare dominion (Barrios and others, 1985; Gaudette and Olszewski, 1985; Gibbs and Wirth, 1986).

Geochronological data from the Amazon Territory of Brazil and the Amazonas region of southeastern Colombia exhibit ages of metamorphic and magmatic activity similar to those in the Casiquiare dominion of the Amazon Federal Territory of Venezuela. Tassinari (1984) utilized whole-rock rubidium-strontium and lead-lead dating methods to date granitic to granodioritic gneiss and migmatite of the Rio Negro-Juruena Province, which truncates the Maroni-Itacaiunas belt (and the Ventuari dominion) in the Amazon Federal Territory and southeastern Colombia (Cordani and Brito Neves, 1982; Teixeira and others, 1989). He determined that a magmatic arc and new continental crust were formed in this province between about 1,750 and 1,600 Ma from magmas generated in the upper mantle (initial $^{87}Sr/^{86}Sr$ ratio of 0.7030).

Priem and others (1982) applied whole-rock rubidium-strontium and uranium-lead zircon data to discern that the granite-gneiss basement of the Amazonas region of southeastern Colombia has a minimum age of about 1,850 Ma. A maximum age of about 1,450 Ma was established for the high-grade metamorphism and resetting of the isotopic systems. Priem and others (1982) concluded that the Complejo migmatítico de Mitú was formed about 1,560 to 1,450 m.y. ago by large-scale granitic plutonism during the Parguaza episode and metamorphic reconstitution of rocks with a minimum age of about 1,850 Ma.

Gaudette and Olszewski (1985) suggested that a tectonic zone or boundary is present along the Orinoco River south of about 4°00' N based on the above radiometric data. This zone marks the contact between the Ventuari and Casiquiare dominions and the Maroni-Itacaiunas and the Rio Negro-Juruena mobile belts (Barrios and others, 1985; Teixeira and others, 1989). The evolution of a northeast-facing subduction zone between about 1,900 to 1,450 Ma and a change from compressional horizontal tectonics to tensional vertical tectonics with the end of subduction may account for the geologic relations present in the Proterozoic undivided rocks of the Amazon region of Venezuela-Colombia-Brazil (Priem and others, 1982; Barrios and others, 1985; Gaudette and Olszewski, 1985).

RORAIMA GROUP

The Roraima Group is a generally flat-lying (dips less than 20°) suite of sedimentary rocks deposited in fluvial, deltaic, shallow marine, and lacustrine or epicontinental environments. It originally covered an area of at least 250,000 km^2, possibly as much as 1,200,000 km^2, that stretched about 1,500 km east to west from Suriname to Brazil and the Amazon Federal Territory of Venezuela; French Guiana and the West African craton do not have rocks equivalent to the Roraima Group (Gansser, 1954; Ghosh, 1985). Quartz arenite is the predominant rock type; subordinate ones include feldspathic arenite, conglomerate, quartzite, arkose, argillaceous siltstone, shale, jasper, and chert. This suite of rocks is generally 700 to 1,000 m thick and in some areas is more than 3,000 m thick (Ghosh, 1985; Dohrenwend and others, this volume). The basal contact is not seen in all places; however, the Roraima Group has been reported to overlie unconformably the Early Proterozoic greenstone-granite terrane, the Caicara Formation, the Parguaza granite, and undivided Proterozoic rocks in the Amazon Federal Territory (De Loczy, 1973; Ghosh, 1985). As noted above, rocks of the Roraima Group locally lie conformably on volcanic rocks of the Caicara Formation. Rocks that overlie the Roraima Group are not common. Fluvial sedimentary rocks about 30 m thick, possibly Miocene to Pliocene in age, cover the Roraima Group in parts of Guyana and Brazil (De Loczy, 1973). However, Late Proterozoic or Phanerozoic sedimentary rocks are not known to overlie the Roraima Group in Venezuela (Ghosh, 1985; George, 1989).

Rocks of the Roraima Group in Venezuela form startling, vertically cliffed tepuis that rise 1,000 m or more above the surrounding jungle. The tops of the tepuis are commonly saucer-shaped, with dips about 20 to 45° toward the center (Gansser, 1974; Ghosh, 1985). The cause of this topography has been attributed to: 1) inverted topography, with the tepuis situated on the axis of synclines; 2) isostatic depression; 3) buckling related to vertical basement tectonics; and 4) faults along the hinge zones between the marginal rims and the central plateaus that formed central graben and marginal horst blocks (Gansser, 1974; Ghosh, 1985). Karst features, such as large caves, shafts, underground streams, karren, and dolines, are locally developed on the tops of some tepuis (Szczerban and Urbani, 1974), and several species of plants are native only to the tops of individual tepuis (George, 1989).

Rocks of the Roraima Group generally are unmetamorphosed; most samples do not exhibit any textural or mineralogical evidence of metamorphism (Ghosh, 1985). Pyrophyllite and andalusite in some rocks are interpreted as metamorphic minerals that formed from very low grade burial metamorphism (Urbani, 1977). However, these minerals are also distributed in localized contact metamorphic aureoles around diabasic and gabbroic intrusions of the Avanavero Suite or of the Mesozoic dike swarms (Gansser, 1974; Urbani, 1977; Ghosh, 1985; Gibbs, 1986). It is possible that rocks interpreted to be affected by burial metamorphism are in fact metamorphosed by an unexposed intrusion. Structural features in the Roraima Group generally are broad, open folds and block faults that strike northeast and north-northeast to north-northwest throughout Venezuela and the Guayana Shield (Gansser, 1954; Ghosh, 1985). Dohrenwend and others (this volume) recognized a deformational gradient from south to north in the Gran Sabana area of southeastern Venezuela with relatively tight folds and conspicuous axial planar foliation within the lower part of the Roraima Group in the south and relatively undisturbed gently dipping to horizontal strata without foliation in the north. The foliation imposes a conspicuous ridge and valley topography in the south, whereas the less deformed and undeformed rocks in the north underlie the high plateaus (Dohrenwend and others, this volume).

Reid (1974a) divided the Roraima Group in the Gran Sabana area of Venezuela into four formations, from lower to upper, the Uairén, Kukenán, Uaimapué, and Matuaí Formations. Elsewhere in the Guayana Shield, the Roraima Group has been subdivided into lower (generally equivalent to the Uairén Formation), middle (the Kukenán and Uaimapué Formations), and upper (Matuaí Formation) members (Gansser, 1954; Bateson, 1966; Priem and others, 1973; Ghosh, 1985). The stratigraphy of the Roraima Group is complex, although it may appear to be simple in some areas. Units are not continuous; rather they appear to grade both laterally and vertically and few marker beds have been established for regional correlation in the shield. For example, conglomerate, arkose, and jasperoid tuffaceous rocks, which are distinctive in the Gran Sabana area of Venezuela, Brazil, and Guyana, are not present in tepuis in the Amazon Federal Territory (Ghosh, 1985). Moreover, the stratigraphic sequences in several tepuis of the Amazon Federal Territory do not correlate with each other. Rocks in the Amazon Federal Territory are included in the Roraima Group because of their abundant thick sequences of cross-bedded, fine- to medium-grained quartz arenite and feldspathic arenite with lesser interbedded layers of shale. Possibly these rocks are time-transgressive with those of the Roraima Group in the Gran Sabana area (Ghosh, 1985).

Alberdi and Contreras (1989) identified a 128 m thick sequence of graywacke, siltstone, and shale that underlies the basal sandstone and conglomerate of the Uairén Formation north of the Gran Sabana area. They suggested that these rocks be included in the Roraima Group as the Urico Formation. The Urico Formation is apparently correlative with the Wailan Formation, which is composed of silty to sandy shales and argillaceous sandstones and is transgressed by conglomerate of the Roraima Group, in northern Brazil and Guyana (Gansser, 1954). However, Gansser (1954) considered the Wailan Formation to be equivalent to the Haimarakka Formation, which is correlative with the Caicara Formation.

The Uairén Formation consists of about 800 to 900 m of quartzitic sandstone, conglomerate, and minor shaly siltstone. Thin lenses and beds (less than 50 cm to about 10 m thick) of quartz-pebble and polymict conglomerate and thin beds and laminae of shaly siltstone are intercalated with the sandstone (Reid, 1974a; Reid and Bisque, 1975). Dohrenwend and others (this volume) subdivided the Uairén Formation into a lower member about 600 m thick and an upper member about 100 to 300 m thick. The former consists of well-sorted, coarse- to medium-grained quartz sandstone that is cross-stratified with trough and festoon cross-beds and is intercalated with conglomerate and shaly siltstone; the latter includes medium-grained sandstone with abundant trough cross-stratification and intercalated channel gravels (Reid, 1974a; Reid and Bisque, 1975; Dohrenwend and others, this volume). The lower member is moderately bedded to massive and underlies high cliffs and extensive dip slopes of several cuestas along the southern margin of the Gran Sabana. The upper member forms conspicuously benched scarp slopes and irregular ridges (Dohrenwend and others, this volume).

The Kukenán (also spelled Cuquenan) Formation is comprised of sandstone interbedded with siltstone, claystone, and shale. The sandstone is well-bedded to massive and fine- to medium-grained, and the siltstone, claystone, and shale are medium- to thin-bedded, laminated, and variegated in color. The formation has a maximum thickness of about 100 m in the Gran Sabana area (Reid, 1974a; Reid and Bisque, 1975; Dohrenwend and others, this volume).

The lower part of the Uaimapué Formation is similar to the Uairén Formation in that it consists of sandstone and conglomerate with interbedded siltstone and mudstone. However, abundant beds of jasper, chert, and arkose characterize the upper part of the formation (Gansser, 1954; Reid, 1974a; Reid and Bisque, 1975; Dohrenwend and others, this volume). The total thickness of the Uaimapué Formation in the Gran Sabana area is about 250 m. Sandstone in the lower part of the formation is fine- to coarse-grained and pervasively channelled with trough cross-stratification. Clasts in the conglomerate are predominantly quartz pebbles. Red arkose, green and red jasper, and green, red, and gray chert are interbedded in the upper part of the formation (Reid, 1974a; Reid and Bisque, 1975). The arkose contains pyroclastic material, and jasper contains distinct shards of devitrified volcanic glass (Gansser, 1974; Reid, 1976; Ascanio and others, 1985). The jasper beds, which are about 20 cm in thickness and are interbedded with siltstone and sandstone forming sequences about 10 m thick, are interpreted as volcaniclastic tuff (Ascanio and others, 1985); they are marker beds for correlating throughout the Guayana Shield and have been radiometrically dated.

The Mataui Formation, the youngest unit of the Roraima Group, forms the vertical cliffs of some tepuis and is dominantly cross-bedded, ripple-marked, and massive quartz sandstone and quartzite (Reid, 1974a; Reid and Bisque, 1975). Sandstone in the uppermost part of the formation, as seen on the tops of the tepuis, is less well cemented, friable, and thinner bedded with sandy shale horizons. The entire unit is 1,000 m or more thick (Gansser, 1954; Reid, 1974a; Reid and Bisque, 1975).

The Roraima Group in the Amazon Federal Territory, which is best observed in tepuis, includes quartz arenite, feldspathic arenite, and shale and generally comprises three members. However, the stratigraphic sequences cannot be correlated from one tepui to another (Ghosh, 1977, 1985). The lower member, about 300 to 500 m thick, consists of thinly graded beds of fine- to coarse-grained, cross-stratified, ripple-marked, and laminated quartz arenite with minor quartz wacke and thin conglomeratic beds (Mendoza and others, 1977; Ghosh, 1977, 1985). The middle member, about 100 to 200 m thick, includes medium-grained, cross-bedded quartz arenite, feldspathic arenite, and argillaceous quartz arenite. Dark gray to black shale units as much as 50 m thick are typical of the middle member. The upper member, which forms prominent cliffs, is composed of 500 to 700 m of medium- to coarse-grained quartz arenite with lesser feldspathic arenite and lenticular clay beds with thin carbonate-rich laminations (Mendoza and others, 1977; Ghosh, 1977, 1985). Major units of conglomerate, arkose, or jasper have not been observed in the Amazon Federal Territory (Ghosh, 1977, 1985).

Environment of deposition and age of the Roraima Group

Rocks of the Roraima Group were deposited in fluvial, deltaic, shallow coastal marine, and lacustrine or epicontinental environments, such as low sinuosity river channels and their flood plains, delta distributaries above tranquil interdeltaic lakes, coastal lagoons to interdeltaic bays, non-barred beach, and intertidal mud flats (Ghosh, 1985). The lateral and vertical distribution of the lithologic units depict an alluvial-deltaic complex near a wave-dominant, high energy coast line with abundant beaches, sandy flats, and subtidal bars, with less common mudflats and coastal lagoons (Ghosh, 1985). Cross-stratification, ripple marks, and pebble orientation within the Roraima Group throughout the shield indicate that the sediments were transported from a source to the northeast, east, and southeast (Gansser, 1954; Keats, 1974; Reid and Bisque, 1975; Ghosh, 1985). Rocks of the Roraima Group may have been deposited in several basins (fault-block basins?) across the Guayana Shield separated by basement highs (Ghosh, 1985).

The Roraima Group may be as old as about 1,900 Ma and as young as about 1,500 Ma (Ghosh, 1985). Correlation of the Roraima Group throughout the shield is problematic because radiometric dating of felsic pyroclastic rocks interbedded with sandstone of the middle part of the Roraima Group (Uaimapué Formation and its equivalents) and diabase dikes and sills that intrude the Roraima Group yield erratic dates. For example, felsic volcanic rocks have whole-rock rubidium-strontium isochron dates of about 1,730, 1,660, and 1,570 Ma (table 3) near Canaima in the northern Gran Sabana area, in Suriname, and near Santa Elena de Uairén in the southern Gran Sabana area, respectively (Gaudette and Olszewski, 1985; Priem and others, 1973; Pringle and Teggin, 1985, respectively). However, it should be noted that these dates are analytically indistinguishable (1,650 Ma) given the error and MSWD associated with each date (table 3). Diabase dikes that cut rocks of the Roraima Group throughout the Guayana Shield have been dated by $^{40}Ar/^{39}Ar$ and whole-rock and mineral rubidium-strontium and potassium-argon analyses. Mineral and whole-rock rubidium-strontium isochrons for doleritic[4] sills that intrude the Roraima Group in Guyana and Suriname yield dates of about 1,640 Ma and 1,670 Ma, respectively (table 4). The potassium-argon method does not give accurate ages for the diabase intrusions (fig. 4; McDougall, 1968), and $^{40}Ar/^{39}Ar$ analyses of biotite and plagioclase from one sample of diabase gave dates of about 1,800 and 1,470 Ma, respectively (Onstott, Hargraves, and York, 1984). Direct dating of the Roraima Group yields ages of about 1,650 Ma for the middle member (Uaimapué Formation), which rests on as much as 1,200 m of quartz arenite, and indirect dating of diabase dikes and sills indicates an age of at least 1,670 to 1,640 Ma (McDougall and others, 1963; Hebeda and others, 1973).

Both discordant and concordant contacts have been mapped between rocks of the Roraima Group and the Caicara Formation, which was deposited between about 1,930 and 1,790 Ma (table 2; Reid and Bisque, 1975; Amaral and Halpern, 1975; Sidder, unpublished data, 1988). In addition, Mendoza (1974) and Mendoza and others (1977) identified the contact between the Roraima Group and the Parguaza granite (1,545 Ma) to be an angular unconformity. In support of this interpretation, Ghosh (1985) noted that "*contact metamorphic minerals are conspicuous by their absence in the Roraima Group overlying the Parguaza granite*". In contrast, other Proterozoic units such as the Cinaruco Formation in the Amazon Federal Territory (equivalent to the Los Caribes Formation) contain andalusite in a contact aureole as much as 0.5 km from the intrusive contact (Ghosh, 1985). These geologic relations bracket the age of the Roraima Group as being as old as about 1,900 Ma and as young as about 1,500 Ma.

Sedimentary rocks of the Roraima Group apparently record a long period of sedimentation on a relatively stable crust. It has been proposed that the present crustal thickness of shields was not attained at the time of "stabilization", or the cessation of deformation and magmatism, but that continued passive underplating of the crust (intrusion of part of the Cuchivero Group and its equivalents) and subsequent subsidence and sedimentation may have extended for several hundred million years after initial stabilization (Rogers and others, 1984). Sandstones throughout the Guayana Shield presently considered to be part of the Roraima Group apparently record a long period of subsidence and continental-nearshore sedimentation that perhaps migrated successively westward in multiple basins on a stable craton possibly from as early as 1,900 to at least 1,545 Ma.

Mineral resources of the Roraima Group

Modern and paleo-placer deposits of gold and diamonds have been mined extensively in the Venezuelan Guayana Shield (pl. 2; Mendoza, 1985). Recent field work (Dohrenwend and others, this volume) in the southern Gran Sabana area identified three types of placer occurrences: 1) diamond placers within modern channels of major rivers; 2) gold and diamond placers in colluvial-alluvial deposits of low-order drainages; and 3) gold and diamond paleo-placers associated with conglomeratic lenses and beds within the lower 500 to 600 m of the Uairén Formation. These paleo-placer

Table 3. Rubidium-strontium whole-rock isochron dates for volcanic rocks within the Roraima Group, Guayana Shield.

COUNTRY	AREA	AGE (Ma)	$(^{87}Sr/^{86}Sr)_o$	MSWD	REF.
Venezuela	Canaima	1,730* ± 120 (n = 8)	0.708	11.2	1
Venezuela	Santa Elena de Uairén	1,570** ± 83 (n = 16)	0.721	79.8	2
Suriname	Tafelberg	1,660 ± 27 (n = 14)	0.708	1.84	3

1Gaudette and Olszewski, 1985

2Pringle and Teggin, 1985

3Priem and others, 1973

*These dates are recalculated from the original published data. The same decay constant, atomic ratios, and experimental errors were used. However, the data in the publication were reported as: 1,747 ± 49 Ma; initial ratio = 0.708; MSWD = 2.84.

**These dates are recalculated from the original published data. The same decay constant, atomic ratios, and experimental errors were used. However, the data in the publication were reported as: 1,579 ± 18 Ma; initial ratio = 0.720; MSWD = 19.95.

Table 4. Rubidium-strontium whole-rock isochron dates for diabase of the Avanavero Suite and hornfels formed from its intrusion into the Roraima Group, Guayana Shield.

COUNTRY	UNIT	AGE (Ma)	$(^{87}Sr/^{86}Sr)_o$	MSWD	REF.
Suriname	Dolerite of Avanavero Suite	1,670 ± 18 (n = 22)	0.704	4.24	1
Guyana	Dolerite of Roraima intrusive suite	1,640 ± 58 (n = 8)	0.704	11.9	2
Brazil	Hornfelsed sandstone of the Roraima Group next to a diabase dike	1,990* ± 170 (n = 3)	0.696	0.078	3
Guyana	Hornfelsed shale of the Roraima Group overlying a diabase sill	1,600* ± 44 (n = 2)	0.856		4

[1]Hebeda and others, 1973
[2]McDougall and others, 1963
[3]Basei and Teixeira, 1975
[4]Snelling and McConnell, 1969
*These ages are calculated with Model 1 of York (1969), which assumes that the only cause for scatter from a straight line are the assigned errors. However, the errors for $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ were not cited in the original references. Values of 2.0 percent and 0.1 percent, respectively, were used for the calculations.

K-Ar dates for Proterozoic diabase of the Guayana Shield

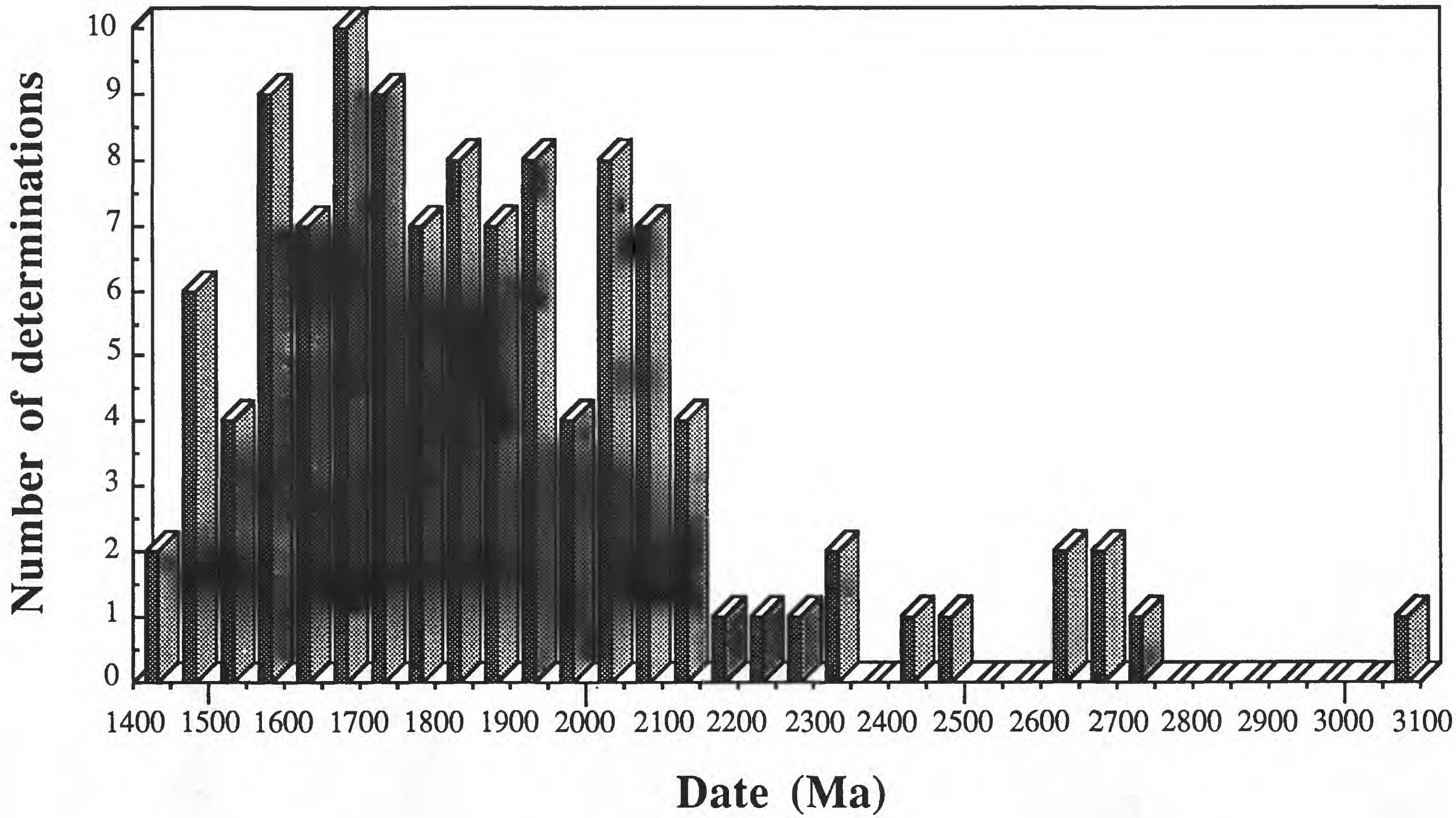

Figure 4. Potassium-argon dates for Proterozoic diabase of the Guayana Shield. Data from McDougall and others, 1963; Snelling, 1963; Snelling and McConnell, 1969; Hebeda and others, 1973; Frick and Steiger, 1974; Basei and Teixeira, 1975; Teggin and others, 1985.

deposits are the source of gold for modern placer and colluvial-alluvial gravel deposits (Reid and Bisque, 1975; Mendoza, 1985; Dohrenwend and others, this volume).

Conglomerates in the lower part of the Roraima Group have been proposed as the source of diamonds by many investigators (Gansser, 1954; Pollard and others, 1957; De Loczy, 1973; Briceño, 1984; Mendoza, 1985). Reid (1974b) suggested that kimberlite, possibly in Brazil or even west Africa, was the source for the paleo-placer deposits in the Roraima Group. Studies at San Salvador de Paúl (pl. 2; Briceño, 1984) and elsewhere along the Caroni River and in the Gran Sabana area (Reid, 1974b; Reid and Bisque, 1975; Dohrenwend and others, this volume) document that conglomerates of the Uairén Formation are the source of alluvial diamonds. Briceño (1984) stated that the conglomerates in the Uairén Formation are themselves paleo-placers and were the source for diamond-bearing gravels deposited about 8,000 years ago at San Salvador de Paúl. These Holocene paleo-placers appear to be the source of diamonds in some deposits in currently active drainages (Gansser, 1954; Briceño, 1984).

Kimberlite, a common source of diamonds, and its indicator minerals such as chrome pyrope and magnesian ilmenite have been identified in Venezuela only in the Quebrada Grande area (pl. 2; Baptista and Svisero, 1978; Malcolm McCallum, Colorado State University, oral commun., 1988). As many as a dozen diamond-bearing kimberlitic dikes and sills with chrome pyrope, titanium-rich phlogopite, chromite, and yimengite [$(K(Cr,Ti,Fe,Mg)_{12}O_{19})$, a rare alteration product of chromite previously recognized only in kimberlite from China] have been located there (Nixon, 1988; Nixon and Condliffe, 1989; Nixon and others, 1989). Rubidium-strontium whole rock isochron and argon-argon dates and neodymium model ages obtained from the kimberlitic and lamproitic or lamprophyric dikes indicate that these intrusions may have been emplaced at two different periods; one between about 2,060 and 1,900 Ma, and the other at 850 Ma (Nixon, 1988; Nixon and others, 1989). Although neither kimberlite nor its indicator minerals have been identified elsewhere in Venezuela, it is possible that other diamond-bearing kimberlites intruded along north-northwest fractures that extend throughout the western part of the Guayana Shield in Bolívar State, the Amazon Federal Territory, and into Brazil. Sedimentary rocks of the Roraima Group may have incorporated diamonds from the older Proterozoic kimberlites during their transport and deposition.

Radiometric anomalies have been measured in rocks of the Roraima Group on the south end of the Gran Sabana between Santa Elena de Uairén and Icabaru (pl. 2; Brooks and Nuñez, this volume). The apparent similarity of the basal conglomerate of the Roraima Group to the gold-uranium bearing conglomerates of the Witwatersrand, South Africa, Jacobina, Brazil, and Blind River, Canada (De Loczy, 1973; Bellizzia and others, 1981) and the reported occurrence of authigenic pyrite (Gallagher, 1976) have led to the proposal that the basal conglomerates of the Roraima Group are a viable exploration target for uranium as well as gold deposits (De Loczy, 1973; Mendoza, 1985). The uranium potential has not been evaluated systematically.

AVANAVERO SUITE

Unmetamorphosed mafic intrusive rocks of the Avanavero Suite (formerly known as the Roraima Intrusive Suite) are present throughout the Guayana Shield as dikes, sills, inclined sheets, and small irregular intrusive bodies such as laccoliths. The distribution of these rocks is similar to that of the Roraima and Cuchivero Groups and their equivalents in that they are present from western Venezuela to Suriname, but absent in French Guiana and west Africa (Gibbs, 1986). Sills are restricted to the Roraima Group, and they were fed by dikes and irregular intrusive bodies in the underlying basement rocks (Hawkes, 1966a; Gibbs, 1986). The sills are commonly intruded along the unconformity between the greenstone-granite terrane and the Roraima Group as well as throughout the lower and middle members of the Roraima Group (Hawkes, 1966b). The stratigraphically highest sill is apparently at the base of the upper member (Matauí Formation) (Bateson, 1966). On Mount Roraima, at the juncture between Venezuela, Guyana, and Brazil, a large gabbroic body forms the boundary between the middle and upper members (Gansser, 1954). The dikes trend north-south, ± 15°, or nearly east-west, and they are as much as 1,000 m thick and continue along strike for as much as 150 km (Bosma and others, 1983; Gibbs, 1986).

The diabasic rocks of the Guayana Shield range in composition from gabbro and norite to granophyre. They are typically medium- to coarse-grained and massive, with chilled margins developed locally (Hawkes, 1966a, Sial and others, 1986). Subophitic to ophitic textures are common, and the finer grained rocks are commonly porphyritic. Hawkes (1966b) recognized cumulate textures and rhythmic layering in the Tumatumari-Kopinang dike and sill complex in Guyana. Plagioclase (An_{35} to An_{70}), hypersthene, bronzite, augite, and pigeonite are the primary minerals, with accessory amounts of biotite, magnetite, ilmenite, corona-textured olivine, hornblende, and graphic intergrowths of quartz and potassium feldspar (micropegmatite), and trace amounts of apatite, zircon, pyrite, and chalcopyrite (Hawkes, 1966a, 1966b; Hebeda and others, 1973; Gibbs, 1986; Sial and others, 1986). The accessory minerals range in abundance from about 2 to as much as 15 modal percent. Minor amounts of secondary minerals such as hornblende and uralite replacing pyroxene, serpentine pseudomorphs of olivine, chlorite after biotite and hornblende, and sericitic and saussuritic alteration of plagioclase are also present. The diabases do not show any evidence of metamorphism (Hawkes, 1966a, 1966b; Hebeda and others, 1973; Sial and others, 1986).

The chemistry of the diabases throughout the Guayana Shield is similar to that of continental tholeiites. All samples of dikes and irregular bodies in the basement rocks and sills in the Roraima Group are tholeiitic, and major element concentrations are similar, although trace element abundances of Rb, Ba, Y, Sr, and Cr may vary (Hawkes, 1966a, 1966b; Teggin and others, 1985). Gabbroic rocks contain about 51 to about 54 weight percent silica, and granophyre has about 58 to 65 weight percent silica (Hawkes, 1966a; Teggin and others, 1985). Samples of diabase plot in the tholeiitic field on several discriminant diagrams such as the total alkali-silica, AFM ($Na_2O + K_2O$-FeO_t-MgO), and Jensen (cation percent ($FeO + Fe_2O_3 + TiO_2$)-Al_2O_3-MgO) plots (Teggin and others, 1985; Sial and others, 1986). Quartz and hypersthene are common normative minerals (Hawkes, 1966b; Teggin and others, 1985). The Proterozoic diabases are lower in total iron, titanium, vanadium, volatile content (water, carbon dioxide, fluorine, and chlorine as measured by loss on ignition), and possibly copper than the Mesozoic diabase suite (Teggin and others, 1985; Sial and others, 1986). It has been suggested, on the basis of these and other chemical differences between the Proterozoic and Mesozoic diabases, that the Proterozoic intrusions represent differentiates of parent magmas with the same composition that underwent pre-intrusive, shallow level (crustal) differentiation (Choudhuri, 1978) or that were derived from a shallower region in the mantle (Sial and others, 1986). In contrast, the Mesozoic dike swarms represent magmas derived directly from the mantle, possibly related to a hot spot or mantle plume, during the breakup of Gondwanaland and the formation of the Atlantic Ocean (Choudhuri, 1978; Sial and others, 1986).

Dating the Avanavero Suite is difficult. As noted above, diabase from throughout the Guayana Shield has been dated by argon-argon and whole-rock and mineral rubidium-strontium and potassium-argon analyses. The potassium-argon dates range from about 3,095 to 1,418 Ma (fig. 4), whereas two mineral and whole-rock rubidium-strontium isochrons yield dates of about 1,670 and 1,640 Ma (table 4). The $^{40}Ar/^{39}Ar$ integrated age dates for biotite and plagioclase in a diabase sill in Guyana are 1,798 and 1,468 Ma, respectively (Onstott, Hargraves, and York, 1984). The last 10 percent of $^{39}Ar_K$ released from plagioclase indicates an age of 1,823 Ma; the last 40 percent of $^{39}Ar_K$ released from biotite defines a plateau at 1,810 Ma, and individual fractions indicate an age of about 1,850 Ma. However, the dates for biotite are suspect due to the high percentage of atmospheric argon (>29 percent and as much as 91 percent in the fraction at 1,150°C) in 16 of 17 fractions of the biotite analysis. The $^{40}Ar/^{39}Ar$ data for plagioclase support the conclusion that younger ages in the diabases are caused by argon loss (McDougall, 1968; Onstott, Hargraves, and York, 1984).

The lack of a well-defined peak on the histogram of potassium-argon dates for 114 analyses of diabase (fig. 4) indicates that this method has not adequately distinguished the age of the diabasic intrusions of the Guayana Shield. Detailed studies of the distribution of radiogenic argon in samples of diabase prove that it is inhomogeneously distributed throughout the rocks and minerals by both excess argon contamination (Hebeda and others, 1973) and loss of argon (McDougall, 1968) since the crystallization of the diabases. These changes are attributed to a tectonothermal event known as the Nickerie or K'Mudku episode at about 1,200 Ma, which affected the entire Guayana Shield (Snelling and McConnell, 1969; Hebeda and others, 1973; Bosma and others, 1983). As stated by McDougall (1968), *"The spread in ages determined by the K-Ar method on the Roraima dolerites shows that little is to be gained by undertaking further measurements by this technique on these rocks. The question as to the age or ages of emplacement of the dolerites probably will only be resolved by detailed and precise Rb-Sr whole-rock measurements on many samples."*

Rubidium-strontium isochrons for samples of hornfelsed sandstone and shale collected adjacent to diabase intrusions yield disparate results (table 4). The initial $^{87}Sr/^{86}Sr$ ratio determined for these samples (table 4) indicates that these isochrons may not be representative of the true age of emplacement of the diabases. The small number of analyses precludes a rigorous interpretation of these data.

Paleomagnetic analyses of Proterozoic diabase from Venezuela, Guyana, and Suriname define at least two separate groups with remanence orientations approximately opposite in declination (Hargraves, 1968; Veldkamp and others, 1971; Onstott, Hargraves, and York, 1984). However, the radiometric age determinations do not distinguish separate periods of diabase intrusion (table 4; fig. 4; Gibbs, 1986). At present, the age of diabase intrusion in the Guayana Shield can only be estimated to be about 1,650 Ma, with the possibility of intrusion(s) as old as about 1,850 Ma.

PARGUAZA GRANITE

Granitic rocks in the Parguaza Province constitute a batholith that covers at least 10,000 km^2, and possibly as much as 30,000 km^2, in the Amazon Federal Territory (pl. 1). These granites were emplaced predominantly in the Ventuari dominion into rocks equivalent to those of the Cuchivero Group. Granites of similar composition and age are present to the south and southeast into Brazil and westward into Colombia (Mendoza, 1975; Kovach and others, 1976; Gaudette and others, 1978; Priem and others, 1982); these include the Agua Boa and Madeira plutons, which host the world-class tin deposit at Pitinga, as well as the Surucucus, Abonari, Velho Guilherme, and other intrusive suites in Brazil (Dall'Agnol and others, 1975; Dall'Agnol, 1982; Jones and others, 1986; Dall'Agnol and others, 1987; Issler and Lima, 1987). Volcanic rocks, such as the rhyodacite of Guayapo, are associated with the Parguaza granite (Mendoza and others, 1977). Some felsic to intermediate tuffs in the Amazon Federal Territory identified as correlative with the Caicara Formation may also be related to the Parguaza granite.

Granitic rocks of the Parguaza Province include massive, coarsely crystalline, porphyritic granite and biotite granite, commonly with rapakivi (wiborgite-type) texture. They contain quartz (5-34 modal percent), potassium feldspar (microcline perthite, 25-55 percent), plagioclase (oligoclase, 15-31 percent), biotite (3-17 percent), and hornblende (1-24 percent), with accessory clinopyroxene, apatite, sphene, zircon, ilmenite, and magnetite (Mendoza, 1974, 1975; Gaudette and others, 1978). Rapakivi and less commonly antirapakivi textures, with ovoids of potassium feldspar mantled by plagioclase and plagioclase mantled by microcline, respectively, are characteristic of these granitic rocks. The Parguaza granite is relatively unmetamorphosed and unaltered. Epidote is rarely present as a secondary mineral in plagioclase, and chlorite is not observed, which is in contrast to the granitic rocks of Santa Rosalia (Mendoza, 1974; Gaudette and others, 1978).

The granitic rocks of the Parguaza Province have a tholeiitic affinity (Mendoza, 1975). Silica ranges from about 66 to 74 weight percent, and Na_2O and MgO are low to moderate in abundance (2.9 to 3.9 weight percent and 0.2 to 0.7 weight percent, respectively). Concentrations of total iron as Fe_2O_3, TiO_2, and CaO are relatively high, with 2.6 to 7.2, 0.4 to 0.9, and 1.0 to 3.1 weight percent, respectively (Mendoza, 1975). The major and trace element contents of the Parguaza granite are similar to those of granophyre from the Duluth and Skaergaard Complexes, to Nigerian charnockite, to other rapakivi granite such as that in Finland, and to Middle Proterozoic (1.48 to 1.35 Ga) granite in the granite-rhyolite terranes of the midcontinent of the United States (Mendoza, 1975; Gaudette and others, 1978; Sims and others, 1987).

Age and origin of the Parguaza granite

The Parguaza granite was intruded about 1,545 m.y. ago in the Ventuari dominion of the Amazon Federal Territory (Gaudette and others, 1978). Other granitic rocks in the westernmost part of the Guayana Shield and southward beneath alluvial cover of the upper Amazon Basin have similar ages and compositions (table 5). Together, these granites have been interpreted to represent widespread anorogenic magmatism from about 1,570 to 1,480 Ma (Dall'Agnol and others, 1975; Kovach and others, 1976; Gaudette and others, 1978; Priem and others, 1982; Gibbs and Barron, 1983; Teixeira and others, 1989).

Generation of the Parguaza granitic magmas has been characterized as a rift-related event (Gaudette and others, 1978; Gaudette and Olszewski, 1985; Jones and others, 1986). A tectonic environment represented by within-plate crustal extension accompanied by a high thermal gradient due to intrusion of mantle-derived basaltic magmas may explain the origin of the Parguaza granite. The Parguaza granite is similar in age, composition, and tectonic setting to the Middle Proterozoic (1,480 to 1,450 Ma) granite-rhyolite terrane of the St. Francois Mountains in southeastern Missouri of the United States (Kisvarsanyi and Kisvarsanyi, 1989). The formation of rocks in the St. Francois terrane has been explained as a failed cratonic rift or an anorogenic extensional tectonic setting at a passive continental margin (Kisvarsanyi, 1975; Windley, 1989), or possibly by orogenic/accretionary processes related to the early stages of the adjoining Grenville orogen (Patchett and Ruiz, 1989). As noted by Patchett and Ruiz (1989), the lack of: 1) alluvial sediment fill; 2) minor to major quantities of basalt; and 3) basalt erupted peripherally to the rift indicate that the granite-rhyolite terrane was not formed in a classic rift environment. A similar argument may be made against a rift setting for the Parguaza granite. Indeed, the Parguaza granite may be related to orogenic/accretionary processes associated with the 1,200 Ma Garzón-Santa Marta granulite belt in Colombia, which has been correlated with the Grenville orogenic belt (Kroonenberg, 1982; Priem and others, 1989).

Ratios such as Na/K, Ba/Sr, and K/Rb indicate that fractional crystallization was an important process during the formation of the Parguaza rapakivi granite (Mendoza, 1974, 1975). The low initial ratio of $^{87}Sr/^{86}Sr$ (table 5), neodymium isotopic data ($^{143}Nd/^{144}Nd$ = 0.51160), and a high average content of nickel (about 12 ppm) suggest that the granitic magmas may have been derived from crustal material of trondhjemitic or charnockitic composition, with a component of undifferentiated mantle material (Mendoza, 1974, 1975; Gaudette and others, 1978; Allègre and Ben Othman, 1980). However, the lack of trace element and isotopic data does not allow the source to be defined more specifically.

Mineral occurrences in the Parguaza granite

Placer, eluvial, and lode occurrences of tin in the Amazon Federal Territory and Bolívar State are spatially associated with the Parguaza granite. Cassiterite in lodes is associated with

Table 5. Rubidium-strontium whole-rock isochron dates for granitic rocks of the Parguaza Province and its equivalents, Guayana Shield.

COUNTRY	UNIT	AGE (Ma)	$(^{87}Sr/^{86}Sr)_o$	MSWD	REF.
Venezuela	Parguaza granite	1,490* ± 120 (n = 4)	0.701	2.09	1
Venezuela	Granite of San Carlos de Rio Negro (Casiquiare dominion)	1,567 ± 25 (n = 4)	0.704	0.93	2
Colombia	Granites of the Inírida and Guaviare Rivers (Ventuari? dominion)	1,485 ± 35 (n = 8)	0.706	1.6	3
Brazil	Surucucus granite	1,520* ± 140 (n = 6)	0.696	22.2	4,5
Brazil	Granite of the Upper Amazon Basin	1,530** ± 25 (n = 3)	0.706	0.29	6
Brazil	Agua Boa-Madeira plutons, Pitinga area	1,700*** ± 34 (n = 9)	0.701	5.98	7

[1]Gaudette and others, 1978
[2]Gaudette and Olszewski, 1985
[3]Priem and others, 1982
[4]Basei and Teixeira, 1975
[5]Dall'Agnol and others, 1975
[6]Kovach and others, 1976
[7]Macambira and others, 1987

*The errors for $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ were not cited in the original references. Values of 1.5 and 0.085 percent (H.E. Gaudette, University of New Hampshire, oral commun., 1990), and 2.0 and 0.1 percent, respectively, were used for the calculations of the dates of the Parguaza and the Surucucus granites, respectively. The Parguaza granite has a uranium-lead zircon age of 1,545 ± 20 Ma (Gaudette and others, 1978).
**These three samples are several hundred kilometers from one another and may not be comagmatic. Their model ages, assuming an initial ratio of 0.706, are: 1541, 1536, and 1528 Ma.
***This date is recalculated from the original published data. The same decay constant and atomic ratios were used. However, the date in the publication was reported as: 1,689 ± 19 Ma; initial ratio = 0.707; MSWD = 1.48, which is apparently a Model 1, and not a Model 3, date.

quartz veins that cut the granite, and anomalous values of tantalum, niobium, zirconium, and titanium, contained in tantalum-rich rutile or struverite, Ta-Nb-Fe-Mn-bearing rutile, tantalite-columbite, stanniferous tantalite or ixiolite, and zircon (Aarden and Davidson, 1977), are present in pegmatites associated with the granite (Rodriguez and Perez, 1982; Perez and others, 1985). The best known tin prospect is that near Caño Aguamena (pl. 2).

The Parguaza granite is equivalent in composition and approximately equal in age (table 5) with that in the Agua Boa and Madeira plutons, which host the Pitinga deposit in Brazil. Pitinga is one of the world's largest tin deposits, with reserves of 18.7 x 10^6 m^3 at 1.2 kg/m^3, and potential reserves of 37,000 tonnes of tin (Schobbenhaus and others, 1984; Thorman and Drew, 1988). Greisenized granite, locally called apogranite, hosts the primary tin ore and is the source of the alluvial deposits (Jones and others, 1986; Macambira and others, 1987; Thorman and Drew, 1988). Alkaline granite with rapakivi texture in the Surucucus area of northernmost Brazil is about 1,520 Ma and has potential reserves of 20,000 tonnes of tin (Dall'Agnol and others, 1975; Schobbenhaus and others, 1984; Jones and others, 1986). Thus, the Parguaza granite has high potential for identification of undiscovered tin deposits.

The similarity in age, composition, and tectonic environment between the Parguaza granite and the granite-rhyolite terrane of the St. Francois Mountains suggests that Olympic Dam-type iron-copper-uranium-gold-REE deposits are a favorable exploration target in the Parguaza province (Sims, 1988). Aeromagnetic and radiometric data could help locate potential prospects.

NICKERIE OROGENY

Potassium-argon, argon-argon, and rubidium-strontium dates of about 1,350 to 1,100 Ma for micas and feldspars from Archean and Early Proterozoic rocks of the Guayana Shield are indicative of partial resetting and overprinting due to the Nickerie metamorphic episode (Priem and others, 1968; Kroonenberg, 1982; Onstott and others, 1989). Loss of argon and strontium due to recrystallization resulted in the abnormally young Middle Proterozoic dates for Early Proterozoic and Archean rocks, and increase of argon in diabase of the Avanavero Suite caused the aberrant old dates (fig. 4). Rocks affected by this episode extend from western Suriname through Guyana to Venezuela, Colombia, and northern Brazil. The eastern boundary of reset mica ages is in central Suriname (Priem and others, 1971; De Vletter and Kroonenberg, 1984). East of this boundary, Early Proterozoic rocks show Trans-Amazonian, not Nickerie, mineral ages. In Venezuela, this event is also called the Orinoquean orogenesis (Mendoza, 1977a; Moreno and others, 1977); in Guyana, it is named the K'Mudku mylonite episode (Barron, 1969; Singh, 1974); and it is known as the Jari-Falsino event in Brazil (Kroonenberg, 1982; Gibbs and Barron, 1983).

Reactivation of east-northeast-striking faults, such as the Guri shear zone, and minor uplift throughout the central and western portions of the Guayana Shield characterize the Nickerie episode. Cataclastic textures and locally mylonite zones and pseudotachylite developed along some faults (Priem and others, 1968; Barron, 1969). Mendoza (1977a) suggested that minor aplite and pegmatite dikes were emplaced coincident with faulting. Extremely low-grade to medium-grade metamorphism due to cataclasis and mylonitization in the central Guayana Shield during the Nickerie episode produced minerals such as pumpellyite, prehnite, epidote, albite, muscovite, chlorite, biotite, stilpnomelane, sphene, actinolite, and garnet (De Roever and Bosma, 1975). In the western part, high-grade metamorphism generated charnockitic and enderbitic granulite, mafic granulite, amphibolite, and augen gneiss (Priem and others, 1989).

The Nickerie metamorphic episode commonly has been described as a regional tectonothermal event (Priem and others, 1968; Barron, 1969; De Roever and Bosma, 1975; Mendoza, 1977), but without a known cause for the tectonism or increased heat flow. Recent geochronological studies of the Garzón massif in the Andes of Colombia indicate that a quartzo-feldspathic, calc-alkaline (continental arc) sequence of rocks along the western margin of the Guayana Shield was metamorphosed to the granulite facies about 1,172 Ma (Priem and others, 1989). This metamorphism and associated deformation are attributed to continental collision (Kroonenberg, 1982; Priem and others, 1989). The reset mineral ages in rocks of the Guayana Shield to the east are herein interpreted to be the result of thermal and tectonic effects of this proposed collision in the hinterland during the Nickerie orogeny.

MESOZOIC DIABASE DIKES

Narrow (<200 m), thin (<50 m), long (as much as 250 km) unmetamorphosed diabase dikes, that trend approximately east-northeast in Venezuela and north-northwest in the eastern part of the Guayana Shield, are related to the opening of the Atlantic Ocean (MacDonald and Opdyke, 1974; Gibbs, 1986). Because the field appearance and chemistry of this diabase are similar to that of the Avanavero Suite, the Mesozoic dikes have been grouped with those of the Avanavero Suite (unit Ya) on Plate 1. The dike rocks are fine- to medium-grained, with subophitic to ophitic texture (Hargraves, 1978), and contain plagioclase (commonly labradorite) and augite with minor pigeonite, relict olivine cores in pyroxene, biotite, green amphibole, apatite, opaque minerals such as titaniferous magnetite, ilmenite, rare chalcopyrite and pyrrhotite, and minor interstitial granophyric intergrowths of quartz and microcline microperthite (Hawkes, 1966a; Hargraves, 1978; Choudhuri and others, 1984). These rocks are quartz-saturated tholeiite with a continental basalt affinity (Choudhuri and others, 1984), and they generally have a higher concentration of titanium, total iron, vanadium, volatile content (water, carbon dioxide, fluorine, and chlorine as measured by loss on ignition), and possibly copper than those in the Avanavero Suite (Choudhuri, 1978; Teggin and others, 1985). Their chemistry suggests that the Mesozoic dike swarms were derived directly from an undepleted mantle source, possibly related to a mantle plume and hot spot, during the breakup of Gondwanaland and the separation of South America from Africa (Choudhuri and others, 1984).

The age of these younger diabase dikes, which occur throughout the Guayana Shield, has not been determined precisely. As shown in the histogram in Figure 5, potassium-argon dates for 59 samples of diabase range from about 550 to 130 Ma. The majority of dates ranges between about 230 and 170 Ma, with a peak at about 210 Ma (fig. 5). Dikes with different potassium-argon dates have magnetic poles similar to those characteristic of Permo-Triassic rocks (Veldkamp and others, 1971; Hargraves, 1978). However, scatter of the paleomagnetic pole positions does not allow the age of the dikes to be distinguished more accurately. Diabase dikes in Liberia, west Africa, that intruded Proterozoic basement rocks range in age between about 1,222 and 177 Ma and contain large and variable amounts of excess ^{40}Ar, which resulted in anomalously old dates (Dalrymple and others, 1975; Mauche and others, 1989). However, dikes that intruded Paleozoic sandstone range in age from about 201 to 177 Ma. Those dikes that cut sandstone may also contain small amounts of extraneous ^{40}Ar (Dalrymple and others, 1975; Mauche and others, 1989). Thus, dates for the diabase dikes in the Guayana Shield, all of which intrude Proterozoic or Archean rocks, may not be representative of their time of emplacement and crystallization. All of the dikes are probably latest Triassic-earliest Jurassic, about 210 to 200 Ma, in age. It is not known whether emplacement of the dikes marked the initiation of or predated opening of the Atlantic Ocean.

MESOZOIC-CENOZOIC UPLIFT, EROSIONAL SURFACES, AND ALLUVIUM

Uplift of the Imataca Complex and other rocks in the northern Guayana Shield of Venezuela occurred just prior to or during the separation of South America from Africa (Onstott and others, 1989). Additional uplift may also have been associated with mid-Cenozoic orogeny in the Caribbean area (Olmore and Estanga, 1989; Olmore and Garcia-Gerdes, 1990). These uplifts caused erosion of the Guayana Shield with subsequent deposition in a basin north of the Orinoco River

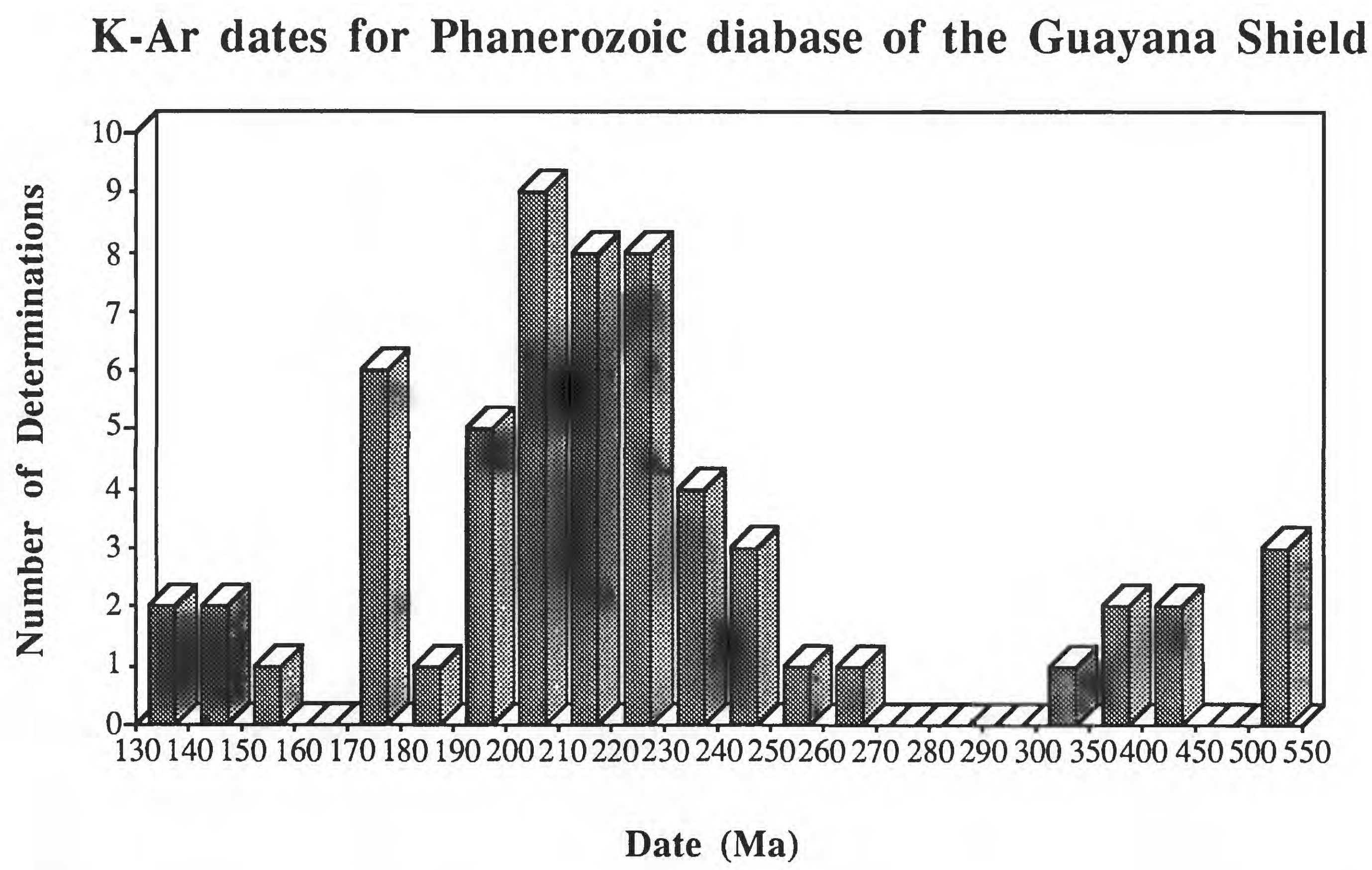

Figure 5. Potassium-argon dates for Phanerozoic diabase of the Guayana Shield. Data from Priem and others, 1968; Frick and Steiger, 1974; MacDonald and Opdyke, 1974; Schobbenhaus and others, 1984; Teggin and others, 1985.

(Schubert and others, 1986; Olmore and Garcia-Gerdes, 1990). Geomorphic and geologic evidence of Cenozoic tectonism has not been observed in the Gran Sabana area. However, slow, broad regional upwarping may not have generated a recognizable geomorphic expression (Dohrenwend and others, this volume).

At least six planar geomorphic surfaces, marked by distinct elevations, have been identified in the Venezuelan Guayana Shield (not shown on pl. 1). They are, from oldest to youngest: 1) Auyan-tepui (2,000-2,900 m); 2) Wonken or Kamarata-Pakaraima (900-1,200 m); 3) Imataca-Nuria (600-700 m); 4) Caroni-Aro (200-450 m); 5) Llanos (80-150 m); and 6) Orinoco floodplain (0-50 m) (Short and Steenken, 1962; Menendez and Sarmentero, 1985; Schubert and others, 1986; Briceño and Schubert, 1990; Dohrenwend and others, this volume). The age of the oldest two surfaces is not well known. Schubert and others (1986) speculated that they are Mesozoic in age. The others range in age from Early Tertiary to Holocene (Schubert and others, 1986; Briceño and Schubert, 1990). The Imataca-Nuria surface is important economically because bauxite and enriched deposits of BIF are developed on it (Menendez and Sarmentero, 1985; Schubert and others, 1986). All of the planation surfaces except for Auyan-tepui have been correlated with similar surfaces in Brazil, Guyana, Suriname, and (or) French Guiana (Short and Steenken, 1962; Schubert and others, 1986; Briceño and Schubert, 1990).

Tertiary-Quaternary paleo-placer deposits and the lower Roraima Group are the source of diamonds and gold in Holocene alluvium (Briceño, 1984; Dohrenwend and others, this volume).

SUMMARY OF THE VENEZUELAN GUAYANA SHIELD

The Guayana Shield of Venezuela consists predominantly of Archean and Early to Middle Proterozoic age rocks. The Archean Imataca Complex (fig. 6) includes gneiss, granulite, amphibolite, and banded iron-formation. Amphibolite- to granulite-facies metamorphism and refolded isoclinal folds are characteristic of the Imataca Complex. The Early Proterozoic greenstone-belt rocks are submarine sequences of mafic volcanic rocks at the base, with a middle section of basalt to rhyolite, and an upper section of turbiditic graywacke, volcaniclastic rocks, and chemical sedimentary rocks. Tholeiitic and calc-alkaline differentiation trends are common in the volcanic rocks. Layered mafic complexes are also found in the greenstone belts. Rocks of the greenstone belts were formed between about 2,250 and 2,100 Ma. The greenstone-belt rocks were metamorphosed to the greenschist facies and locally the amphibolite facies near granitic domes of the Supamo Complex, which intruded the greenstone-belt rocks between about 2,230 and 2,050 Ma. Major deposits of low-sulfide gold-quartz veins are hosted by rocks of the greenstone belts in shear zones. The Imataca Complex and the greenstone-granite terranes were deformed and metamorphosed during the Trans-Amazonian orogeny, which represents a period of continental collision between about 2,150 and 1,960 Ma. Post-collisional, post-Trans-Amazonian magmatism between about 1,930 and 1,790 Ma produced volcanic and plutonic rocks of the Cuchivero Group. Undivided Proterozoic rocks in the Amazon Federal Territory include granitic rocks, gneiss, and migmatite. Peak metamorphism and intrusion occurred between about 1,860 and 1,730 Ma.

Unmetamorphosed rocks of the Roraima Group were deposited in fluvial, deltaic, shallow coastal marine, and lacustrine or epicontinental environments. The Roraima Group is possibly as old as about 1,900 Ma and as young as about 1,500 Ma. Conglomeratic lenses and beds in the lower 500 to 600 m of the Roraima Group contain paleo-placers and some are the source of diamonds and gold in modern placer deposits. Mafic dikes, sills, and irregular intrusive bodies of the Avanavero Suite cut all earlier rocks of the Guayana Shield. These continental tholeiitic intrusions are about 1,650 Ma in age, and possibly as old as about 1,850 Ma. Middle Proterozoic, 1,500 Ma, rapakivi granite of the Parguaza Province hosts occurrences of tin in quartz veins. Continental collision during the Nickerie orogeny in the westernmost part of the Guayana Shield reset

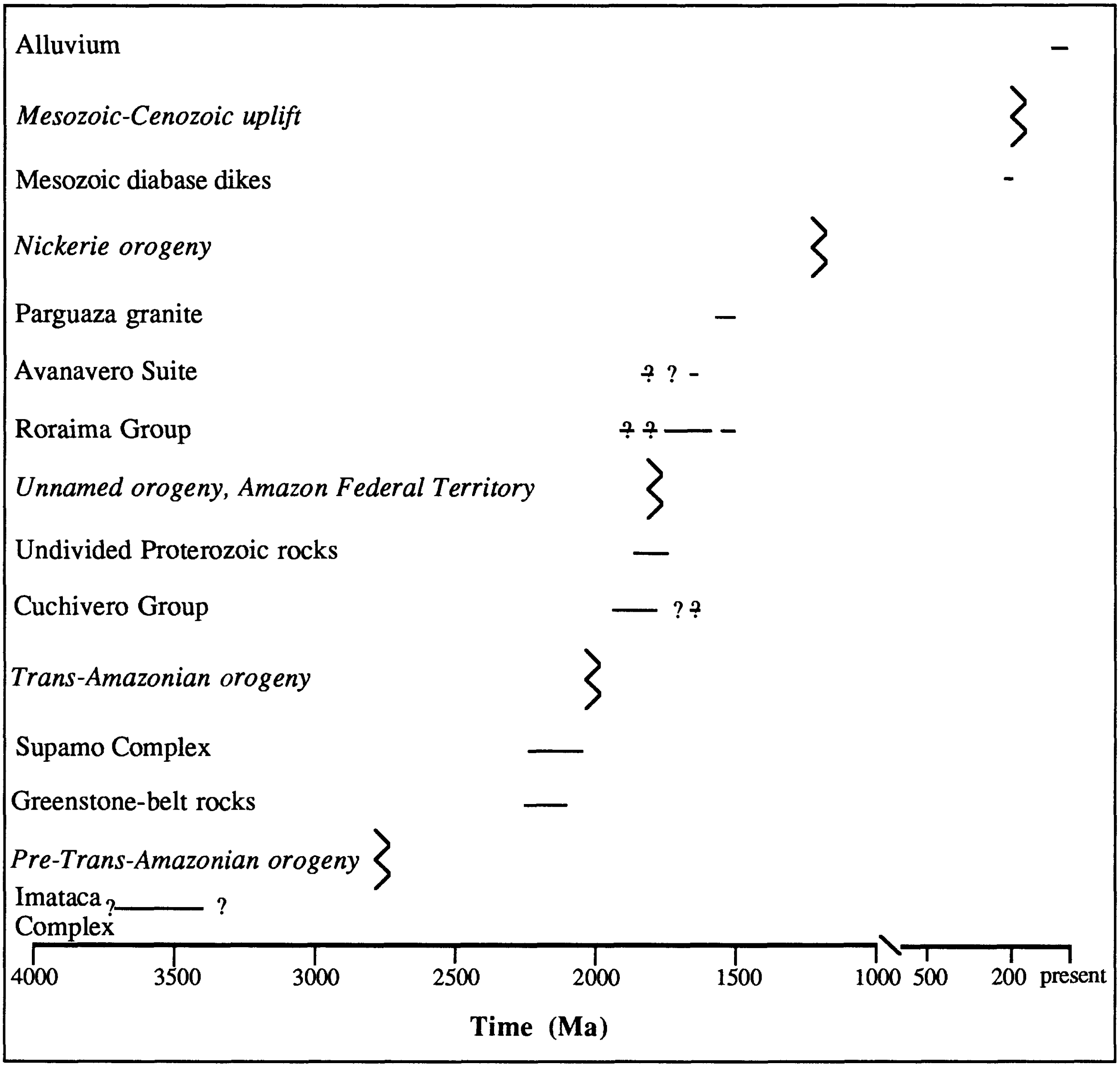

Figure 6. Chronologic history of the Venezuelan Guayana Shield.

mineral ages in Archean and Early Proterozoic rocks of the central and eastern parts to about 1,200 Ma.

Diabase dikes intruded the Guayana Shield during the opening of the Atlantic Ocean about 210 to 200 Ma. Six planar geomorphic surfaces developed at distinct elevations in the Guayana Shield during the Mesozoic and Cenozoic eras. Deposits of bauxite and enriched BIF were formed on the Imataca-Nuria surface. Gold and diamond placers are found in modern major river channels and in colluvial-alluvial deposits of low-order drainages.

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1. All rubidium-strontium isochron dates reported here have been recalculated with the decay constants and isotopic abundances recommended by Steiger and Jäger (1977): ^{87}Rb decay constant = 1.42 x 10^{-11} yr^{-1}; atomic ratio $^{85}Rb/^{87}Rb$ = 2.59265; atomic ratio $^{86}Sr/^{88}Sr$ = 0.1194; atomic ratio $^{84}Sr/^{86}Sr$ = 0.056584. A best-fit line has been calculated by the method of York (1969). Dates reported are those from Model 3, which assumes that the scatter of data is due to a combination of the assigned analytical error plus a normally distributed variation in the initial $^{87}Sr/^{86}Sr$. All potassium-argon dates have been recalculated (where sufficient data are available) using the decay constants and isotopic abundances recommended by Steiger and Jäger (1977): $\lambda^{40}K_e + \lambda'^{40}K_e = 0.581 \times 10^{-10}/yr$; $^{40}K_\beta = 4.962 \times 10^{-10}/yr$; ^{40}K = 0.01167 atomic percent (1.167 x 10^{-4} mol/mol); or by conversion with the critical table for conversion of K-Ar ages from old western constants to new IUGS constants (Dalrymple, 1979).

2. For simplicity, the meta-igneous and metasedimentary rocks in the greenstone belts are referred to by their precursor rock type name, eg., pyroxenite rather than metapyroxenite, basalt instead of metabasalt, graywacke for metagraywacke.

3. This date is recalculated from the original published data. The same decay constant, atomic ratios, and experimental errors were used. The results determined here are: 1,730 ± 71 Ma; initial ratio = 0.705; MSWD = 73.3. However, the data in the publication (Gaudette and Olszewski, 1985) were reported as: 1,793 ± 79 Ma; initial ratio = 0.704; MSWD = 18.4.

4. Dolerite is a British term for diabase. The two are used synonymously here, with the mafic intrusions in Guyana and Suriname generally referred to as dolerite (per the original usage) and those in Venezuela and Brazil called diabase.

Plate 2. Principal mining districts, mines, and mineral occurrences in the Guayana Shield, Venezuela. The major metal produced (or prospective for occurrences), as shown on Plate 2, is listed in bold in parentheses below. Other metals listed have minor or no production and are not shown on Plate 2.

1 Wausa (**Au, Al**)
2 La Linea (**Fe**)
3 San Juan de Macuro (**Fe**)
4 Rio Acure (**Al**)
5 Rio Aroi (**Al**)
6 Manoa or Cerro Yaguasimoina (**Fe**)
7 Piacoa or Catalino (**Fe**)
8 Morocota (**Fe**)
9 Caruachi (**diamonds**)
10 Las Grullas (**Fe**)
11 El Palmar (**Al**; Mn)
12 Guacuripia (**Mn**)
13 La Planada (**Au**)
14 El Manganeso (**Mn**)
15 Upata (**Al**; Mn)
16 El Pao (**Fe, Mn**)
17 Playa Blanca (**diamonds**)
18 Rio Claro (**diamonds**)
19 Cerro Maria Luisa (**Fe**)
20 El Merey (**diamonds**)
21 Potosi (**Au**)
22 Nuria (**Al**)
23 San Cristobal (**Mn**)
24 Bochinche (**Au**)
25 Vuelvan Caras (**Au**)
26 Marwani I (**Au**)
27 Marwani IV (**Au**)
28 Rio Marwani (**Au**)
29 Agua Negra (**Au**; diamonds)
30 Macapa (**Au**; diamonds)
31 Marwani-Los Caribes (**Au**)
32 San Antonio (**Au**)
33 Botanamo (**Au**)
34 Carmen Rosa (**Au**)
35 Carmen Rosa (**diamonds**)
36 Sua-Sua (**Au**)
37 El Callao (**Au**)
38 Lo Increible (**Au**)
39 Cicapra (**Au**)
40 Mandingal (**Au**)
41 Paviche (**diamonds**)
42 La Estrella (**Fe**)
43 Cerro Azul (**Au**)
44 El Grillero (**Au**)
45 Cerro Arimagua (**Fe**)
46 Cerro Toribio (**Fe**)
47 Cerro Redondo (**Fe**)
48 Ciudad Piar (**diamonds**)
49 Cerro Altamira (**Fe**)
50 Cerro Frontera (**Fe**)
51 San Isidro (**Fe**)
52 Cerro Bolivar (**Fe**)
53 Los Barrancos (**Fe**)
54 Rio Aro (**diamonds**)
55 Real Corona (**Fe**)
56 La Esperanza (**Mn**)
57 Rio Aro (**diamonds**)
58 Cerro La Pinto (**Au**; PGE)
59 El Trueno (**Fe**)
60 Cerro Etuna (**Fe**)
61 Sipao (**Au**)
62 Guaniamo (**diamonds**)
63 Caño Aguamena (**Sn, Nb, Ta, REE**)
64 Los Pijiguaos (**Al**)
65 Rio Suapure (**diamonds**)
66 Quebrada Grande (**diamonds**)
67 Cerro Impacto (**Nb, REE**; Th, Ba)
68 Rio Nichare (**Ti**)
69 Veri (**diamonds**)
70 Dori (**diamonds**)
71 Manaima or Los Picachos (**Au**)
72 Enei (**diamonds**)
73 El Casabe (**diamonds**; Au)
74 El Pao de La Fortuna (**diamonds**)
75 La Libertad (**diamonds**)
76 Asa (**diamonds**)
77 Leoncio or Felipe (**diamonds**)
78 Campo Grande (**diamonds**)
79 Los Guaicas (**Al**; Ti)
80 Caroni (**diamonds**)
81 San Salvador de Paúl (**diamonds**)
82 San Pedro de Las Bocas (**diamonds**)
83 Guariche (**Au**)
84 Parapapoy (**Au**)
85 La Estrella (**Au**)
86 Guatuaima (**Au**)
87 Guaito (**Au**)

88 Payapal (**Au**)
89 El Placer (**Au**)
90 La Lombriz (**Au**)
91 La Camorra (**Au**)
92 Canaima (**Au**)
93 La Lira (**Au**)
94 Aponao (**Au**)
95 El Foco (**Au**)
96 Chivao (**Au**)
97 Chicanan (**diamonds**)
98 Piston de Uroy (**Au**)
99 Km 88-Las Claritas (**Au**)
100 Cristina-Bizkaitarra (**Au**)
101 Venamo (**Au**)
102 Salto Araguai (**Au**)
103 San Juan (**diamonds**)
104 El Pauji (**Au**)
105 Gran Sabana (**Al**)
106 Gran Sabana (**Al**)
107 Gran Sabana (**Al**)
108 Larinal (**diamonds**; Au)
109 Kamarata (**diamonds**; Au)
110 Barrialon (**diamonds**)
111 Chiguao (**diamonds**; Au)
112 Kamu (**diamonds**; Au)
113 Karum (**Au**; diamonds)
114 Caura (**diamonds**)
115 La Paragua (**diamonds**)
116 Pao (**Au**)
117 Parupa (**diamonds**; Au)
118 Guacharo (**diamonds**)
119 La Sabanita (**diamonds**)
120 Avequi (**diamonds**)
121 Guacharaquito (**diamonds**)
122 Capaura (**diamonds**)
123 Los Frijoles (**diamonds**)
124 Yiguiripin (**diamonds**)
125 Conoroto (**diamonds**; Au)
126 Gran Sabana (**diamonds**)
127 Gran Sabana (**diamonds**)
128 Gran Sabana (**diamonds**)
129 El Loco (**diamonds**)
130 Flora Blanca (**diamonds**)
131 Divina Pastora (**Al**)
132 Santa Elena de Uairen (**diamonds**)
133 La Peña (**diamonds**; Au)
134 Chiricayen (**Au**)
135 La Faisca (**diamonds**; Au)
136 El Polaco (**diamonds**; Au)
137 La Hollada or Surukun (**diamonds**; Au)
138 Cinco Ranchos (**diamonds**; Au)
139 Icabaru (**Au, diamonds**)
140 Uaiparu (**diamonds**; Au)
141 Los Caribes (**diamonds**)
142 La Bandera (**diamonds**; Au)
143 Hacha (**diamonds**; Au)
144 San Luis (**diamonds**; Au)
145 Uonan (**diamonds**; Au)
146 Pereden (**diamonds**)
147 Pumpiri (**Au**)
148 Maijia (**diamonds**)
149 Alto Paragua (**Sn**)
150 Paramichi (**diamonds**)
151 Merevari (**Au**; Ag)
152 Churuata (**U**; Th, REE)