

A GRENVILLIAN GRANULITE BELT IN THE COLOMBIAN ANDES AND ITS RELATION TO THE GUIANA SHIELD¹

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ABSTRACT

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Precambrian high-grade metamorphic rocks emplaced tectonically in the Central and Eastern Cordillera of Colombia define a granulite belt which is lithologically, petrologically, and geochronologically distinct from the adjacent part of the Guiana Shield. This Garzón – Santa Marta Granulite Belt was formed at the western border of the Early to Mid Proterozoic nucleus of the Shield by an orogenic event around 1.2-1.4 Ga. The Nickerie Metamorphic Episode, characterized in the whole western part of the Guiana Shield by mica age resetting around 1.2 Ga, extensive mylonitization along prominent ENE-WSW shear zones, and low-grade metamorphism, is brought into relation with this orogenic event. A continental collision model and a relationship with the Grenville Orogeny are suggested for this orogeny.

INTRODUCTION

At present considerable attention is being paid to the earliest history of Alpine and Circumpacific orogenic belts, as recorded by outcrops of Precambrian basement amidst Phanerozoic rocks. In the Andes, Precambrian rocks have been reported e.g. from Peru (BARD ET AL., 1974; STEWART ET AL., 1974; COBBING ET AL., 1977; DALMAYRAC ET AL., 1977); Bolivia (LEHMANN, 1978) and Ecuador (TROUW, 1976). Interpretation and correlation are complicated by widely differing radiometric ages and large distances to the nearest shield areas. In the Colombian Andes, scattered outcrops of high-grade metamorphic rocks occur which since long have been suspected to be of Precambrian age (GROSSE, 1935; TRUMPY, 1943), which was finally confirmed by MACDONALD & HURLEY (1969). Earlier reviews of the Precambrian in the Colombian Andes are given by IRVING (1971, 1975), ESTRADA (1972) and ALVAREZ (1981). New data discussed below show that lithological, petrological, and geochronological characteristics

define a consistent pattern that allows for a tentative reconstruction of the Precambrian history of the Colombian Andes and its relation to the Guiana Shield.

The Colombian Andes essentially consists of three separate mountain chains, the Western, Central and Eastern Cordilleras (Fig. 1). Geophysical investigations by CASE ET AL. (1971) and MEISSNER ET AL. (1976) have shown that the Western Cordillera, which consists mainly of Cretaceous tholeiitic basic volcanics and deep sea sediments, is underlain by oceanic crust. The Central and Eastern Cordilleras are underlain by continental crust. The suture between those provinces is formed by the Romeral Fault (Falla de Romeral) or Dolores Mega shear, generally considered as a Cretaceous subduction zone, possibly affected by later transcurrent faulting (TOUSSAINT & RESTREPO, 1976). While the Central Cordillera, now the site of extensive volcanism, emerged already during the Caledonian orogeny in the Mid-Paleozoic (IRVING, 1971, 1975), the non-volcanic Eastern Cordillera was uplifted only at the end of the Pliocene during the Andean orogeny (VAN DER HAMMEN ET AL., 1973; HOWE, 1974; VAN HOUTEN, 1976). Further details of the tectonic history are discussed by IRVING (1971, 1975).

Precambrian high-grade metamorphic rocks crop out in fault-bounded upthrust masses both in the Central and the Eastern Cordillera. Already the earliest authors cited above,

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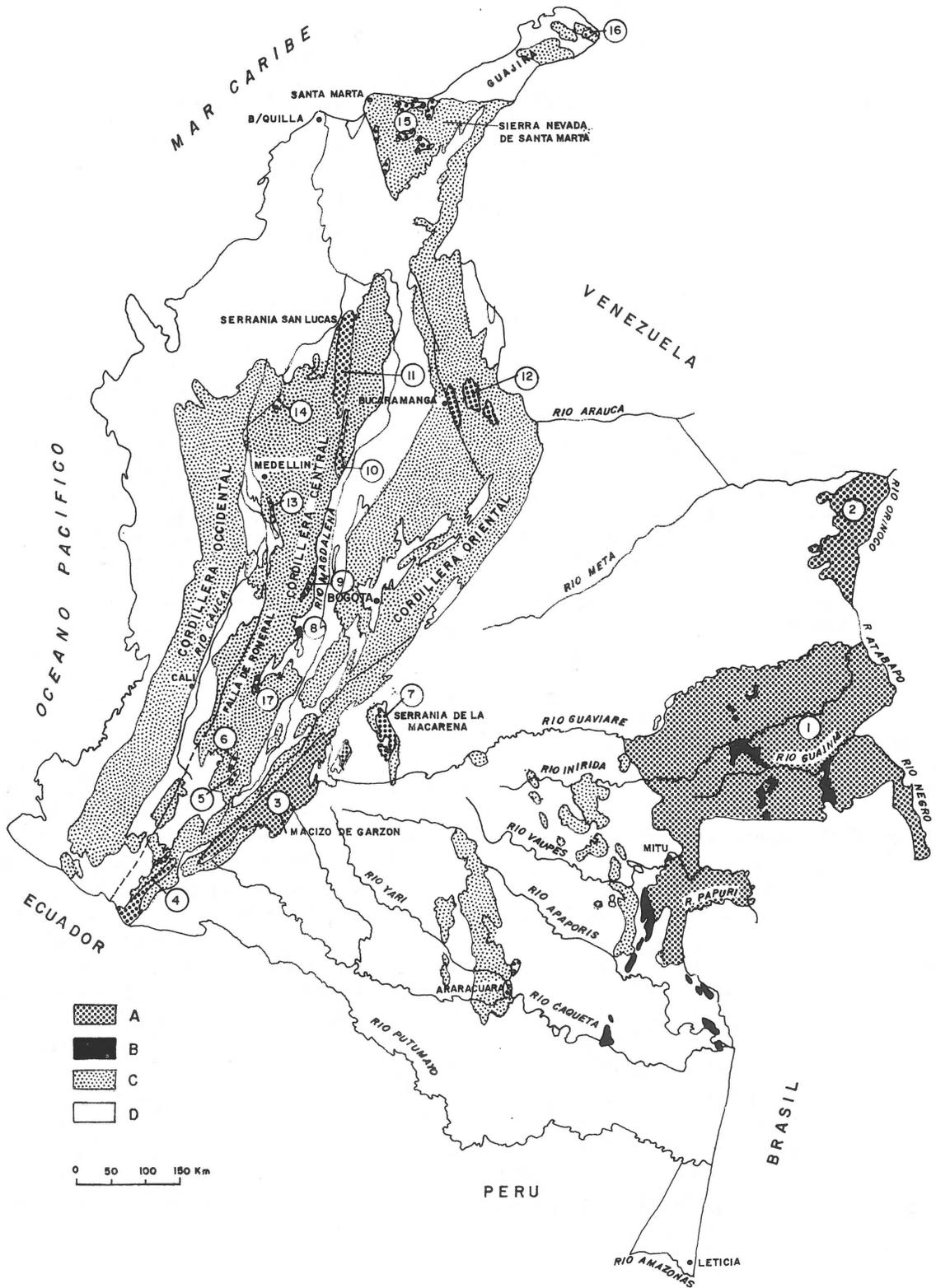


Fig. 1. Geological sketch map of Colombia. Legend: A – Precambrian basement; B – Precambrian (meta)sandstone covers; C – Paleozoic and Mesozoic; D – Cenozoic. Outcrops of Precambrian basement: (1) Mitú Migmatitic Complex; (2) Parguaza Rapakivi Granite; (3) Garzón Massif; (4) Alisales – Guamués; (5) Serranía de las Minas; (6) La Plata Massif; (7) Serranía de la Macarena; (8) Payandé; (9) Léri-da – Venadillo; (10) Puerto Berrío; (11) Serranía de San Lucas; (12) Bucaramanga Gneiss; (13) C aldas – La Miel; (14) Puquí Gneiss; (15) Sierra Nevada de Santa Marta; (16) Guajira; (17) Mendarco – Ambeima.

correlated these rocks with the Guiana Shield. The Guiana Shield is usually defined as the cratonic area between the Orinoco and Amazon rivers. Its present northern and eastern boundaries were formed when South America started to drift apart in the Mesozoic; its southern margin is the intracratonic Amazon sedimentary basin. Along its western margin in Colombia the basement disappears below the sediments of the Andean Foredeep which reach thicknesses of over 6000 m in some areas. Nevertheless, drilling by oil companies and geophysical studies indicate its continuity below these sediments, and therefore the Andean Precambrian can be considered to represent the westernmost extension of the Guiana Shield. Andean Precambrian outcrops are only 300 km away from the nearest Precambrian outcrops in the shield area of eastern Colombia; hence, correlation is easier than in other Andean countries in which this distance is often more than 1000 km. Therefore, the Precambrian of the Colombian Andes offers a unique opportunity to study the early history of the western continental margin of the Gondwana supercontinent since its cratonization.

THE GARZON MASSIF

The largest outcrop of Precambrian rocks in the Colombian Andes, the Garzón Massif, forms the backbone of the southern part of the Eastern Cordillera, reaching 3500 m in altitude and covering an area of about 10,000 km² (Fig. 1). It forms an elongate block uplifted at the end of the Pliocene along NE-SW high-angle reverse faults as a result of subduction-generated compression. It is unconformably overlain by Upper Palaeozoic sediments and Triassic volcanics and has been intruded by Jurassic granites and lamprophyre dykes (KROONENBERG, 1981 a, b; KROONENBERG & DIEDERIX, 1982). The western part of the Garzón Massif has been studied by the author as part of a geological mapping project, undertaken while teaching post-graduate photogeology courses at the Interamerican Centre for Photo Interpretation CIAF at Bogotá, Colombia.

Lithology and Metamorphism

Two major rock units have been distinguished in the Garzón Massif, a banded sequence of granulites and related rocks; the Garzón Group, and homogeneous hornblende-biotite augengneiss bodies; the Guapotón and Mancagua Gneisses. Contacts between the augengneisses and the Garzón Group granulites are conformable and parallel to the prevailing schistosity; the augengneisses therefore are considered to be metamorphosed syntectonic granites.

The Garzón Group forms the main part of the massif. It consists mainly of granulites, gneisses, amphibolites, ultramafic and calcsilicate rocks, alternating on decimetre-to decametre-scale. A migmatitic character is common in the granulites and gneisses; earlier descriptions of the Garzón

Massif rocks concentrated on this aspect (RADELLI, 1962). Banding and schistosity are usually parallel, with predominating NW to N strikes, making an angle with the NE-SW trend of the Eastern Cordillera. Locally isoclinal to tight folding is to be seen, but usually the banding is straight. Crosscutting pegmatites with abundant magnetite or biotite locally are common, and are probably related to the syntectonic granite bodies.

Charnockitic to enderbritic granulites form the bulk of the Garzón Group sequence. They are dark-grey to greenish granoblastic rocks of granitic to tonalitic composition with orthopyroxene as the most characteristic mineral, both in the melanosomes and the leucosomes. The mineral paragenesis is quartz + plagioclase (antiperthite) ± (meso) perthite ± orthopyroxene ± clinopyroxene ± hornblende ± biotite. Inclusions of hornblende in pyroxenes suggest prograde metamorphism to the granulite facies according to the reactions proposed by DE WAARD (1965). Granulite-facies metamorphism is also evident from the strongly perthitic, mesoperthitic or antiperthitic character of the feldspars, and the deep colours of biotite and hornblende. Secondary alteration to actinolite and sericite is widespread.

Garnetiferous charnockitic granulites of the Garzón Group; they show the mineral paragenesis quartz + mesoperthite ± plagioclase (antiperthite) + garnet + orthopyroxene + biotite. Calcium-bearing ferromagnesian minerals are absent, suggesting a semipelitic bulk chemical composition. This paragenesis is thought to have formed through the reaction biotite + quartz = orthopyroxene + garnet + potassium feldspar, but reaction textures are essentially retrogressive, as shown by biotite + quartz + garnet rims around orthopyroxene.

Pelitic gneisses and granulites of the Garzón Group show the mineral paragenesis quartz + mesoperthite ± plagioclase ± garnet ± sillimanite ± biotite ± graphite. They occur only locally as intercalations in other types of granulites. Green spinel is a characteristic accessory. Biotite and sillimanite inclusions in garnet testify of the prograde reaction biotite + sillimanite + quartz = garnet + K feldspar. In a few instances cordierite + magnetite + orthopyroxene ± spinel rims have been found to replace garnet and quartz and those suggest a second metamorphic event, equally of granulite facies conditions but at higher temperatures and lower pressure (cf. BERG, 1977; SCHREYER & ABRAHAM, 1978; KORIKOVSKI, 1979). As these samples have not been found in situ, their importance for the regional metamorphic zonation cannot be evaluated.

Mafic granulites and amphibolites of the Garzón Group form darker greyish to greenish bands not exceeding a few metres in width, within the charnockitic-enderbitic granulites. The most common paragenesis is plagioclase ± orthopyroxene ± clinopyroxene ± hornblende ± biotite ± quartz. Garnet is fairly common, especially in quartz-free mafic granulites. In some specimens there is evidence for the reaction orthopyroxene + plagioclase = clinopyroxene + garnet + quartz, but other reactions involving also hornblende and garnet but no quartz have been observed too. These rocks await further study, but the evidence for a higher-pressure clinopyroxene + garnet + quartz subfacies remains inconclusive at present.

On the other hand there are also amphibolites without orthopyroxene, especially along the peripheries of the Garzón Massif, indicating that locally granulite-facies conditions were not attained.

Ultramafic rocks of the Garzón Group occur as conformably intercalated bands and lenses up to 20 m in thickness. They are mainly

orthopyroxene hornblendites with pargasitic hornblende and locally clinopyroxene, olivine, phlogopite and green spinel. Occasionally phlogopites are found with large mica flakes of commercial quality. The metamorphic character is evident from preferred orientation especially of orthopyroxene and phlogopite. Reaction textures involving pyroxenes, hornblende and spinel have been observed.

Calcsilicate rocks are very scarce in the Garzón Group. They form concordant bands not exceeding 1 m in width, consisting mainly of calcite, forsterite, phlogopite and dolomite. Reaction shells against neighbouring quartzofeldspathic rocks contain complex parageneses with additionally diopside, tremolite, clinohumite, scapolite, grossularite and phlogopite. Neither wollastonite nor vesuvianite have been found. Locally there are thin magnetite-garnet-rich bands with some sulphidic minerals (pyrite, chalcopyrite).

The intercalation of rocks of undoubted metasedimentary origin such as calcsilicate rocks and pelitic gneisses demonstrate that at least part of the Garzón Group is of metasedimentary origin. However, the bulk of the Garzón Group consists of quartzofeldspathic rocks the origin of which is more difficult to explain. WINDLEY (1977) succinctly discusses the pros and cons of metasedimentary, metavolcanic and metaplutonic origin of quartzofeldspathic metamorphic rocks in general. On account of data from Greenland, he prefers a metaplutonic ancestry adopting the Sierra Nevada batholith of California as a protolith-model for charnockitic granulites. The Garzón Massif clearly shows two different suites of quartzofeldspathic rocks, the banded granulites and the homogeneous Mancagua and Guapotón augengneiss bodies. Therefore, I prefer a supracrustal origin for the banded sequence of the Garzón Group. The apparent calc-alkaline affinity of the sequence can be explained in terms of the Cordilleran model proposed by WINDLEY (1977), assuming the banded quartzofeldspathic rocks to represent ensialic basalt-andesite-rhyolite volcanics, not unlike the Cenozoic and Jurassic volcanic suites of the Colombian Andes. Geochemical studies are being carried out at present to test this hypothesis. A metaplutonic origin of the ultramafic rocks is thought to be probable on behalf of their association with ilmenite-magnetite-apatite segregates elsewhere in Colombia (see below).

Metamorphism mainly took place in the granulite facies, probably at intermediate pressures, in view of the scarcity of cordierite and the absence of the olivine-plagioclase paragenesis on the one hand, and the general stability of the orthopyroxene-plagioclase paragenesis as compared with the scarcity for evidence for the clinopyroxene-garnet-quartz assemblage, on the other hand. The observed reaction textures seem to record local rather than regional P-T variations within the granulite facies. Retrogradation to actinolite- and sericite-bearing assemblages testify to a later low-grade event.

Geochronology

ALVAREZ & CORDANI (1980; see also ALVAREZ, 1981) obtained a four-points Rb-Sr isochron of 1180 Ma. ($\lambda = 1.42 \cdot 10^{-11} \text{ a}^{-1}$)

with an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.704 on granulites of the Garzón Group. A fifth sample gave a modal age of 601 ± 56 Ma. No mineral ages are available. A detailed study is being carried out.

OTHER OUTCROPS OF ANDEAN PRECAMBRIAN

Sierra Nevada de Santa Marta

The Sierra Nevada de Santa Marta constitutes an isolated triangular massif rising from the Caribbean coast to 5800 m. The geology of this area was reported by TSCHANZ ET AL. (1969, 1974). Twelve outcrops of Precambrian rocks separated by huge Jurassic batholiths have been mapped here. TSCHANZ ET AL. (1969, 1974) distinguish quartz-perthite granulites, intermediate, mafic, ultramafic, calcareous and garnetiferous granulites. Mineral parageneses are similar to those in the Garzón Massif, except for the absence of pelitic rocks. Concordant bands of anorthosite (An 20-50) of great lateral continuity have been reported from various sites, sometimes associated with concordant lenses and small dykes of magnetite-ilmenite-apatite rocks (TSCHANZ ET AL., 1969, 1974).

The Sierra Nevada de Santa Marta is the only other area in the Colombian Andes for which Rb-Sr isochron data are available. MACDONALD & HURLEY (1969) reported a six-point reference isochron of 1270-1370 Ma with an initial strontium isotope ratio of 0.703 (all cited Rb-Sr ages have been recalculated for a decay constant of $1.42 \cdot 10^{-11} \text{ a}^{-1}$) on gneisses from this area. Two single whole-rock Rb-Sr data of 1273 and 736 Ma have been reported by TSCHANZ ET AL., (1969, 1974) on granulites, as well as a hornblende K-Ar age of 949 ± 30 Ma. MACDONALD & HURLEY (1969) obtained a hornblende K-Ar age of 250 Ma. A 1250 Ma U-Pb zircon age was reported from the Jojoncito leucogranite gneiss in the Guajira peninsula 200 km to the NE (CASE & MACDONALD, 1973).

Bucaramanga Gneiss

In the Eastern Cordillera 300 km N of Bogotá low-pressure amphibolite-facies pelitic gneisses, gneisses hornblende and related rocks have been mapped in the Santander Massif (WARD ET AL., 1973). A single whole rock Rb-Sr age of 680 ± 140 Ma and a hornblende K-Ar age of 945 ± 40 Ma were obtained by GOLDSMITH ET AL., (1971).

Central Cordillera

Along the eastern flank of the Central Cordillera Precambrian granulites migmatitic gneisses, amphibolites, etc. have been reported from various sites, viz. from the Serranía de San Lucas (BOGOTÁ & ALUJA, 1981) near Puerto Berrío (FEININGER ET AL., 1971), Lérica-Venadillo (VESGA & BARRERO, 1978) Payandé (BARRERO, 1969), Mendarco-Ambeima (MU-

ÑOZ & VARGAS, 1981), Serranía de las Minas and La Plata Massif (KROONENBERG, 1981a; KROONENBERG & DIEDERIX, 1982), and Alisales-Guamues (PONCE, 1979). The only radiometric age available is a K-Ar hornblende age of 1360 ± 270 Ma from the Lérida-Venadillo area (VESGA & BARRERO, 1978).

Granulite xenoliths have been found in the lavas of the Nevado del Ruiz volcano (5400 m) in the central part of the Central Cordillera (JARAMILLO, 1978, 1980).

Garnetiferous amphibolites from Caldas, Antioquia in the western flank of the Central Cordillera yielded a single K-Ar hornblende age of 1670 ± 500 Ma and an orthogneiss near La Miel showed a Rb-Sr age of 580 ± 40 Ma (RESTREPO & TOUSSAINT, 1978; TOUSSAINT, 1978). Both, in the western and the eastern flank of the Central Cordillera, migmatitic gneisses and amphibolites with Palaeozoic or Mesozoic mineral ages have been found, such as the Puquí Gneiss (Fig. 1), part of which may represent Precambrian rocks overprinted by Phanerozoic metamorphic events (ALVAREZ, 1979; KROONENBERG, 1981a).

Serranía de La Macarena

The Serranía de La Macarena is an isolated uplifted block amidst the Andean foredeep east of the Eastern Cordillera. Precambrian high-grade metamorphic rocks have been reported by TRUMPY (1943) and GANSSER (1954). Geochronological data are not available.

THE GARZÓN-SANTA MARTA GRANULITE BELT

The correspondence of the Rb-Sr isochron ages of the granulites of the Garzón Massif with those of the Sierra Nevada de Santa Marta supports the concept of a single granulite belt of Late Proterozoic age in the Colombian Andes. Many outcrops of high-grade metamorphic rocks in the eastern flank of the Central Cordillera are sufficiently similar lithologically and petrologically to be included in the granulite belt.

The Bucaramanga Gneiss, on the other hand, is predominantly pelitic, shows low-pressure amphibolite facies metamorphism, and hence its relation to the Garzón-Santa Marta Granulite Belt cannot be established until more radiometric data are available. The concentration of single Rb-Sr whole rock and K-Ar mineral ages around 940 and 700 Ma suggest younger events, the importance of which cannot be evaluated from the available data.

The present extension of the Garzón-Santa Marta Granulite Belt is restricted to the Andean part of Colombia. Recent studies in the Colombian Amazonas (HUGUETT ET AL., 1979; GALVIS ET AL., 1979; KROONENBERG, 1981a) show that acid quartzofeldspathic gneisses and granites predominate; intermediate hornblende-bearing gneisses are rare; ultramafic, anorthositic and calcsilicate rocks have never been found. The

metamorphic grade reached the upper amphibolite-facies; never the granulite facies. Therefore, the Garzón-Santa Marta Granulite Belt should be regarded as a separate lithological unit within the Guiana Shield.

In order to compare the geochronological characteristics of the granulite belt with those of the Guiana Shield, I will briefly review the main age provinces in the Shield.

AGE PROVINCES IN THE GUIANA SHIELD (Fig. 2)

Guriense (3.7-3.4 Ga)

The oldest ages in the Guiana Shield have been obtained from the Imataca complex, a belt of high-grade metamorphic rocks stretching ENE-WSW along the southern bank of the Orinoco river in northern Venezuela. Main rock types are charnockitic granulites, quartzofeldspathic gneisses, amphibolites and metamorphosed iron formation (KALLIOKOSKI, 1965). Rb-Sr and U-Pb studies by MONTGOMERY & HURLEY (1978) indicate a 3.7-3.4 Ga protolith age, overprinted by a regional granulite-facies metamorphic event at 2 Ga approximately. The older, Archaean event has been referred to as Guriense event by MARTÍN BELLIZZIA (1974).

Trans-Amazonian (2.2-1.8 Ga)

The bulk of the Guiana Shield was formed during the Trans-Amazonian Orogenic Cycle as defined by HURLEY ET AL. (1967). 2.2 Ga U-Pb-zircon ages from the greenstone belt that stretches along the northern coast of the Guianas are the most reliable data for the beginning of this event (GIBBS, 1980). Granitic and rhyolitic rocks that loom large in the central part of the Shield give slightly younger ages between 2000 and 1800 Ma. (DE ALMEIDA, 1981; PRIEM ET AL., 1971). The Central Guiana Granulite Belt, stretching NE-SW from the Surinam coast through Southern Guyana into northern Brazil (KROONENBERG, 1976), also seems of Trans-Amazonian age (PRIEM ET AL., 1978), although an Archaean protolith age has long been suspected (BOSMA ET AL., in press). Granulites from the Peruvian coast also show Trans-Amazonian ages (COBBING ET AL., 1977; DALMAYRAC ET AL., 1977).

Parguazan-Rio Negro-Juruena (1.75-1.4 Ga)

A third group of ages is revealed by granitic and migmatitic rocks in the western part of the Guiana Shield in southern Venezuela, eastern Colombia and northwestern Brazil. The Paraguaza Rapakivi granite in southern Venezuela was shown to be about 1500 Ma old by GAUDETTE ET AL. (1978). PRIEM ET AL. (1982) ascribed similar ages obtained from migmatitic and granitic rocks of the Mitú Migmatitic Complex in the Colombian Amazonas to the Parguazan Tectonomagmatic Event. TASSINARI (1981) included all rocks of the western part of the Guiana Shield in the Rio Negro-Juruena geochrono-

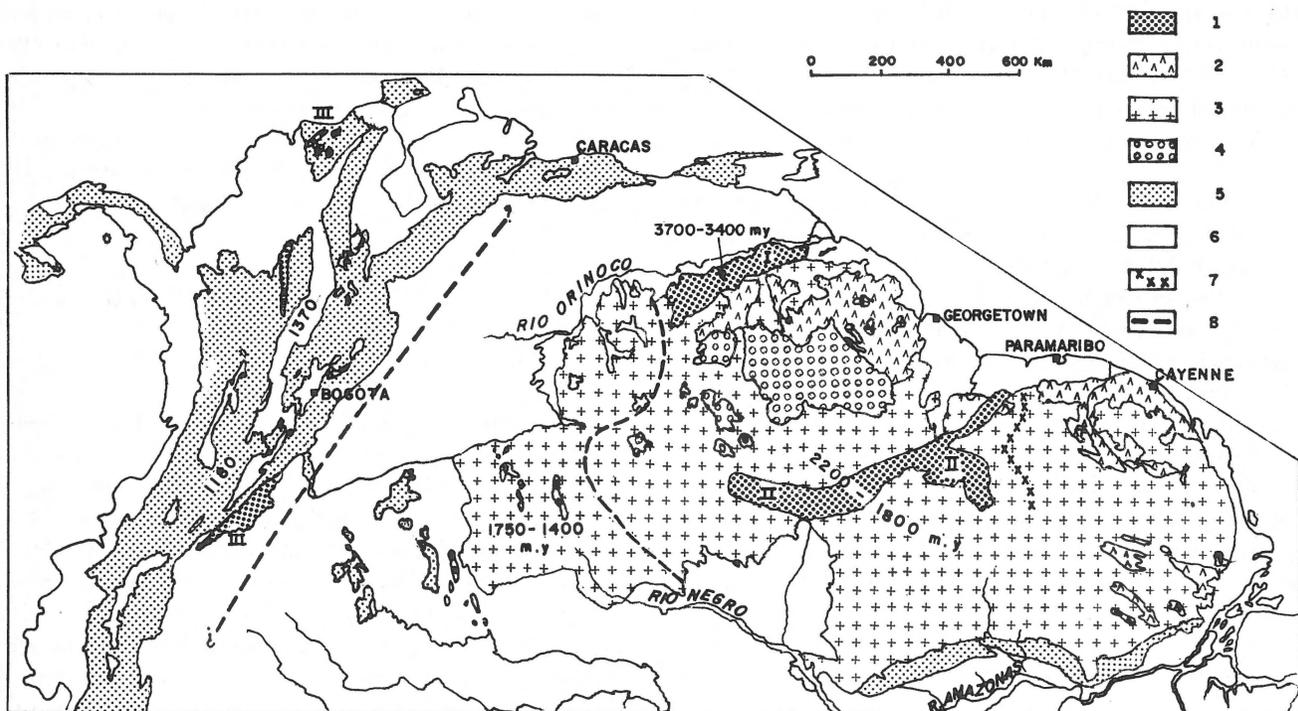


Fig. 2. Main structural and age provinces of the Guiana Shield. Legend: (1) Granulite belts (I – Imataca Complex; II – Central Guiana Granulite Belt; III – Garzón – Santa Marta Granulite Belt); (2) Greenstone belts; (3) Granitoid, migmatitic and acid metavolcanic rocks; (4) (Meta) sandstone covers (Roraima, Tunuf, Cinaruco, Guainía etc. Formations); (5) Paleozoic and Mesozoic; (6) Cenozoic; (7) Eastern limit of Nickerie mica age resetting in Suriname (Priem et al., 1971); (8) Limits between age provinces.

logical province, stretching from southern Venezuela into the corresponding part of the Brazilian Shield south of the Amazonas Basin. Acid pyroclastic rocks intercalated in the Roraima sandstones that cover extensive portions of the basement partly show ages within this time span (PRIEM ET AL., 1973).

THE NICKERIE METAMORPHIC EPISODE (1.3-1.1 Ga)

The age provinces in the Guiana Shield described in the preceding paragraph are based essentially on Rb-Sr whole-rock isochron and U-Pb-zircon studies. However, mineral ages in all three provinces often are considerably younger, between 1100 and 1300 Ma. In the early days of geochronological research in the Guiana Shield, before the application of Rb-Sr isochron techniques, the supposed age of 1200-1300 Ma of many shield areas was based precisely on such K-Ar and Rb-Sr mineral ages e.g. in eastern Colombia (PINSON ET AL., 1962). Barron, in a paper read to the 7th Guiana Geological Conference held in Paramaribo, Surinam, in 1966, was the first to recognize these ages as overprint ages, related to mylonitization along ENE-WSW shear zones in already cratonized areas. He referred to this event as the K'Mudku Mylonite Episode. This paper did not appear in print until

1969 (BARRON, 1969), and in the meantime PRIEM ET AL (1968) had published a similar hypothesis as regards Surinam mineral ages, terming the event the Nickerie Metamorphic Episode (see also BERRANGÉ, 1977).

Later the effects of the Nickerie Metamorphic Episode were also recognized in Venezuela, where MARTÍN BELLIZZIA (1974) referred to it as Orinoquense event, eastern Colombia (PRIEM ET AL., 1982), and in northern Brazil (Jarí-Falsino event, DE ALMEIDA, 1981). The effect of the Nickerie Metamorphic Episode, therefore, extends over the whole western part of the Guiana Shield. Its eastern boundary has been established in central Surinam along a N-S line dividing the Surinam part of the Shield in two halves; east of this line mineral ages are Trans-Amazonian in accordance with Rb-Sr isochron ages (PRIEM ET AL., 1971).

Mica age resetting in the Guiana Shield is often accompanied by low grade metamorphic effects in the pumpellyite-prehnite facies to greenschist facies (DE ROEVER & BOSMA, 1975; KROONENBERG, 1976), and may also be found in rocks which do not show any sign of mylonitization. Low-grade metamorphism is known to be sufficient to cause mineral age resetting (e.g. PURDY & JÄGER, 1976; ANDRIESEN, 1978; VERSCHURE ET AL., 1980). The Nickerie Metamorphic Episode was therefore a regional tectono-thermal event, the cause of which has not been explained up to now.

SIGNIFICANCE OF THE GARZON-SANTA MARTA GRANULITE BELT

In earlier reviews of the Precambrian of Colombia (IRVING, 1971, 1975; ESTRADA, 1972) Rb-Sr isochron data for the Sierra Nevada de Santa Marta and Rb-Sr and K-Ar mineral data for the Colombian Amazonas were used indiscriminately to postulate continental accretion around 1200 Ma around an older nucleus in the Guiana Shield. As the latter ages are caused by resetting, this interpretation is obviously in error. ALVAREZ & CORDANI (1980; in the abstract of their paper that was available until now) interpreting the Garzón ages, recognized the Andean Precambrian as a younger age province, but do not refer to mica resetting in the Amazonian hinterland, nor to the lithological and petrological differences between the Andean Precambrian and the adjacent shield area.

The Rb-Sr whole-rock isochrons obtained from the Garzón Massif and the Sierra Nevada de Santa Marta suggest an important granulite-facies metamorphic event around 1200 Ma along the western border of the Guiana Shield. Such an event has not been demonstrated anywhere else in the Guiana Shield. The two main granulite belts in the Shield were metamorphosed both around 2000 Ma in the Trans-Amazonian Orogenic Cycle, as shown above. The low initial strontium isotope ratios in the Sierra Nevada de Santa Marta and the Garzón Massif preclude a large premetamorphic crustal history, as MACDONALD & HURLEY (1969) and ALVAREZ (1981) already concluded, so correlation with the Imataca granulite belt, as envisaged by TSCHANZ ET AL. (1974) is highly improbable.

I conclude therefore that the protolith rocks of the Garzón-Santa Marta Granulite Belt were formed after the cratonization of the main part of the Guiana Shield. As stated above, the lithology of the belt roughly matches (1) an ensialic calc-alkaline volcanic suite with minor pelitic, semipelitic, and calcareous sedimentary intercalations, probably deposited in a shallow marine environment, and (2) small ultramafic and anorthositic intrusions. Data are insufficient as yet to establish whether these rocks indeed are underlain by older continental crust. In any case, the small quantity of mafic rocks precludes a predominantly oceanic origin. A complicating factor is that the transition between the Andean granulite belt and the Amazonian part of the shield is hidden below the sediments of the eastern Andean foredeep.

Granulite-facies metamorphism and contemporaneous intrusion of granites occurred around 1200-1300 Ma as borne out by the geochronological data. Now the coincidence of this metamorphic event with the Nickerie Metamorphic Episode in the whole western part of the Guiana Shield suggests a common cause. The disappearance of mica rejuvenation east of central Surinam also suggests that this phenomenon originated in the western part of the Shield.

What kind of orogenic event could have caused granulite-facies metamorphism at a continental margin and at the same

time regional heating and shearing over more than 2000 km in the adjacent craton? The main phases of Mesozoic and Cenozoic orogeny in the Andes are generally assumed to have been caused by subduction of oceanic crust below the South-American continent; this type of orogeny is clearly insufficient to cause regional heating of such an extent, because no traces of these events are recorded geochronologically in the Guiana Shield.

Faulting over thousands of kilometres has been recorded from continental collision orogens especially the Himalayas (Tibetan model of DEWEY & BURKE, 1973; cf. also MOLNAR & TAPONNIER, 1975). Could a continental collision have occurred at the Western border of the Guiana Shield around 1200-1300 Ma ago?

THE GARZON-SANTA MARTA BELT AND THE GRENVILLE PROVINCE

ALVAREZ & CORDANI (1980) were the first to hint at the geochronological similarity between the Andean Precambrian and the Grenville Province at the eastern margin of the Canadian Shield. Indeed, Rb-Sr whole-rock isochrons around 1100 Ma and mineral ages around 900 Ma are typical of the Grenville Province. But there is also a strong resemblance in lithology and metamorphic grade. Anorthosites, ilmenite-magnetite-apatite rocks, ultramafic rocks and charnockitic granulites are widespread in the Grenville Province; the metamorphic grade is usually in the granulite facies, often of intermediate pressure (BOURNE, 1978; SHARMA ET AL., 1978). Even typical problems in interpreting the significance of garnet in mafic granulites in the Adirondacks (DE WAARD, 1965; WHITNEY, 1978), are encountered in the Garzón Massif as well.

The strong similarity of both belts and their occurrence at opposite margins of older basement cores raises the question whether a continental collision between the western side of the Guiana Shield and the eastern side of the Canadian Shield around 1200 Ma is plausible. A continental collision origin for the Grenville Province is supported by DEWEY & BURKE (1973), BURKE ET AL., (1977) and YOUNG (1980), but rejected by MCELHINNY & MCWILLIAMS (1977). The discussion hinges on the interpretation of paleomagnetic results. Establishing a possible relation between the Garzón-Santa Marta Belt and the Grenville Province, therefore, first awaits paleomagnetic studies in the Colombian Andean Precambrian.

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