

## IGNEOUS AND METAMORPHIC COMPLEXES OF THE GUIANA SHIELD IN SURINAME<sup>1</sup>

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### ABSTRACT

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The crystalline basement of Suriname was formed essentially in the Lower Proterozoic during the Trans-Amazonian orogeny around 2000 to 1870 Ma ago. Two belts of high-grade metamorphic rocks probably developed as intracratonic basins within an older, possibly Archaean continent. A greenstone belt with basic and intermediate volcanics, volcanoclastic greywackes and coarse-clastic (molassic?) sediments is supposed to have formed in an island-arc-back-arc marginal basin environment at the northern margin of the older continent. Deformation and metamorphism took place around 2000 Ma ago. Extensive acid magmatism around 1870 Ma represents a subsequent stage in the Trans-Amazonian Orogenic Cycle, marked by acid ignimbritic volcanism, and next by granitoid and gabbroic intrusions. Most of the older basement was remobilized and reworked during this stage.

Cratonization of the region was completed before the deposition of the Roraima Formation sandstones and pyroclastics around 1650 Ma and the intrusion of the Avanavero and Käyser Dolerites. Metamorphism, mylonitization and mica age resetting occurred around 1250 Ma in western Suriname during the Nickerie Metamorphic Episode. The intrusion of the Permo-Triassic Apatoe Dolerite around 230 Ma marks the beginning of the separation of South America and Africa.

### INTRODUCTION

Suriname occupies a central place within the Guiana Shield, of which it is also one of the best explored parts. The systematic geological survey of the country by the Geological and Mining Service of Suriname started in 1943 and culminated in 1977 with the publication of the Geological Map of Suriname 1:500 000 in two sheets. The accompanying explanation (BOSMA ET AL., 1977), which until now was only available as an internal report, is being published presently (DE VLETER, in press). A simplified version of the map (Fig. 1) is included as a separate enclosure to this issue of *Geologie en Mijnbouw*.

The map and the explanation compile the knowledge obtained from (1) 35 years of field work; (2) a hard-rock sample collection that covers the entire area and that consists of about 100 000 specimens (1 sample per km<sup>2</sup>), of which more than 50 000 thin sections were made; (3) a nearly complete coverage by aerial photographs (O'HERNE, 1966) and a complete coverage by aeromagnetic total intensity contour maps. Additional information was obtained from about 700 drill cores covering most of the rock units distinguished. About 300 Rb-Sr, K-Ar, and U-Pb whole-rock and mineral age determinations were performed by the ZWO Laboratory of Isotope Geology at Amsterdam. The wealth of data more or less compensates for the very poor exposure due to intensive weathering and the dense tropical vegetation.

The crystalline basement of Suriname consists essentially of two high-grade metamorphic belts of Archaean (?) and Lower Proterozoic age, the Falawatra and Coeroeni Groups; a Lower Proterozoic greenstone belt (Marowijne Group) and a vast Lower Proterozoic granitoid-volcanic complex. It carries a few remnants of an once extensive cover of flat-lying Middle Proterozoic continental sediments (Roraima Formation) and is cut by abundant Middle Proterozoic and Permo-Triassic

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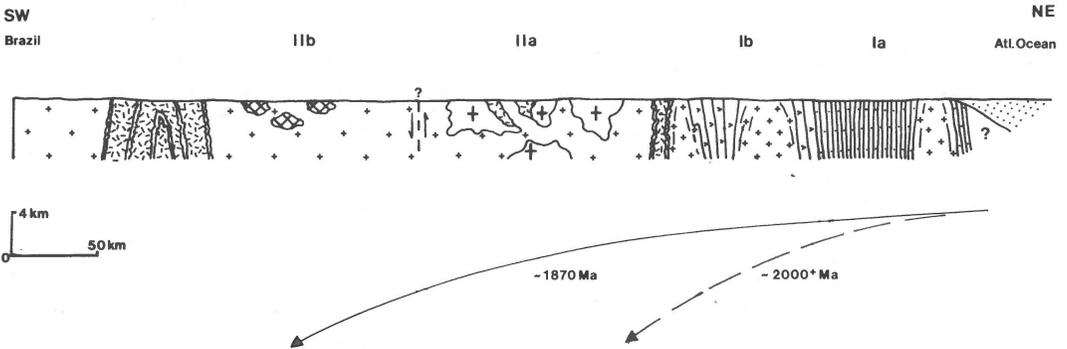
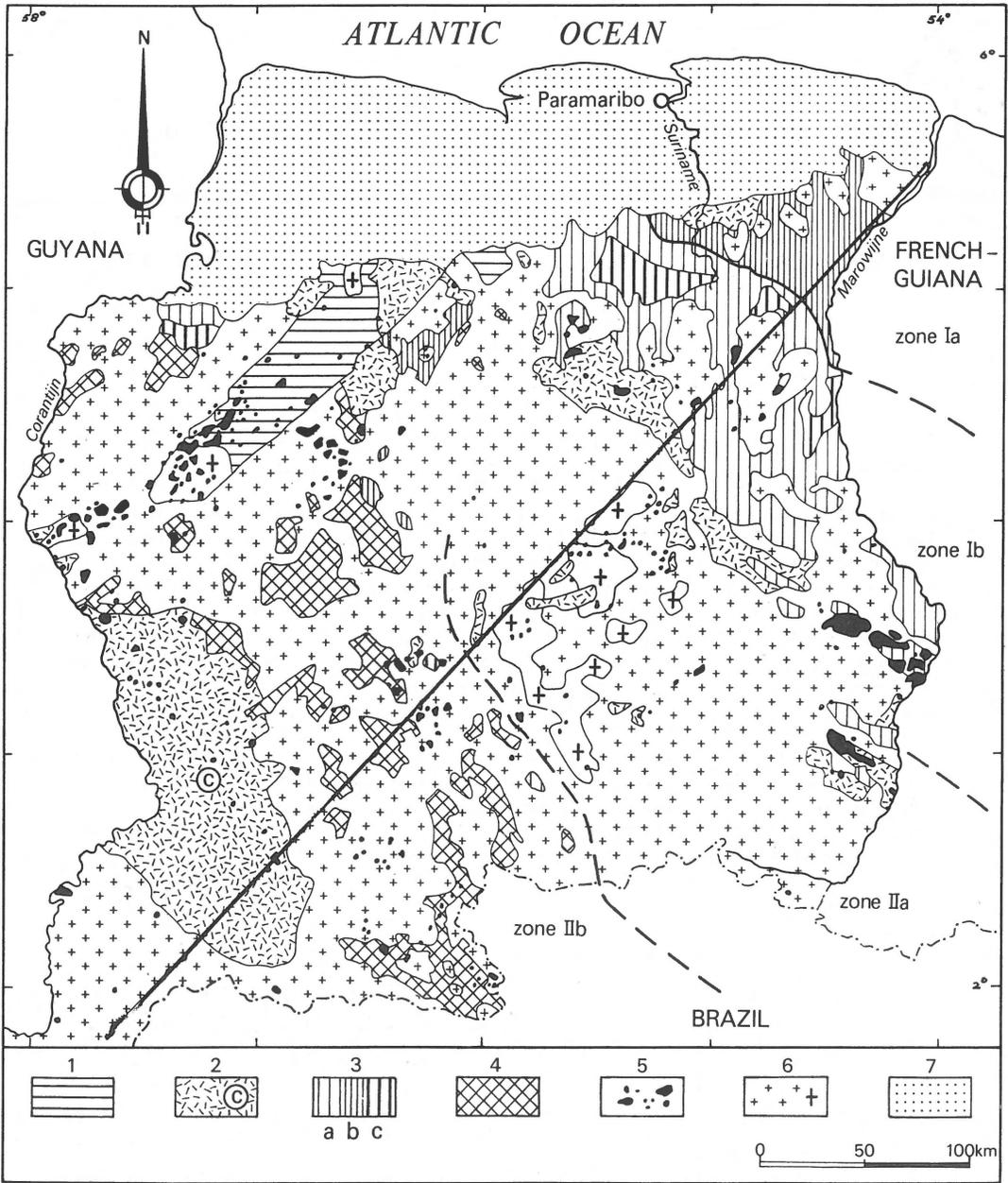
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dolerite dykes (Fig. 1 & 2). Figure 3 shows the geological setting of Suriname in relation to the Guiana Shield.

In this paper the Precambrian igneous and metamorphic complexes are described and their geologic evolution is discussed. Geochemical characteristics and their interpretation will be dealt with in detail in a separate paper (BOSMA ET AL., in prep.).

## THE HIGH-GRADE METAMORPHIC BELTS

### *Structural setting*

In western Suriname two high-grade metamorphic complexes have been distinguished. *The Falawatra Group* in northwestern Suriname forms a NE-SW trending fault-bounded structure, the Bakhuis Mountains Horst, which consists of an elongated core of charnockitic granulites of possibly Archaean age, surrounded by Lower Proterozoic granulite-facies and amphibolite-facies gneisses and intruded by pyroxene granites of similar age. *The Coeroeni Group* in southwestern Suriname forms an elongated NW-SE trending lowland zone consisting mainly of amphibolite-facies and granulite-facies gneisses. Both complexes show a more or less concentric structural and isograd pattern suggesting a domal structure (DAHLBERG, 1975; DE ROEVER, 1975a; KROONENBERG, 1976). The two high-grade metamorphic belts continue into southern Guyana, where they join near the Rewa River, going further west as a single belt, the Central Guiana Granulite Belt (KROONENBERG, 1976) into Brazil (Fig. 3). Scattered outcrops of similar rocks occur in unknown structural setting within the granitic area of central and south Suriname.

### *Age (Table I)*

Radiometric dating of both complexes indicates that the main phase of high-grade metamorphism took place during the Trans-Amazonian Orogeny around 2000 Ma ago (PRIEM ET AL., 1977, 1978). The complexes, however, might be of pre-Trans-Amazonian origin. Such an origin is inferred for the charnockitic core of the Falawatra Group from the presence of cross-cutting granulite-facies metadolerite dikes which do not continue in the surrounding gneisses nor have been found in the Coeroeni Group. An Archaean origin was determined for the high-grade Imataca Complex in NW Venezuela (MONTGOMERY & HURLEY, 1978; MONTGOMERY, 1979) but was never demonstrated geochronologically for any part of the whole Central Guiana Granulite Belt. From the

Brazilian part of the belt, the Suite Metamórfico Anauá, some Archaean K-Ar ages were reported (MANDETTA, 1970; cited in SANTOS, 1980) but these may be due to excess argon (GIBBS, 1980). An Archaean Rb-Sr isochron age for four samples of the Falawatra Group and two of the Supamo Group in Venezuela (GAUDETTE ET AL., 1976) appears to be due to a fortuitous arrangement of too few data points, as was shown by extensive Rb-Sr and U-Pb dating on the Falawatra Group by PRIEM ET AL (1978). The Archaean Supamo U-Pb zircon ages of GAUDETTE ET AL. (1976) have been reinterpreted by GIBBS (1980) and GIBBS & OLSZEWSKI (1982) to be Trans-Amazonian as well. Rb-Sr data for the Kanuku and Kwitaro Groups in Guyana, the equivalents of the Falawatra and Coeroeni Groups respectively, show similar Trans-Amazonian ages (SPOONER ET AL., 1971; BERRANGÉ, 1977). Recently obtained Sm-Nd data on these groups also reveal a Trans-Amazonian age (C.N. BARRON, pers. comm.). The wide scatter in the Rb-Sr data for the Falawatra Group (PRIEM ET AL., 1978) and the Kanuku Group (SPOONER ET AL., 1971) is the only geochronological argument that can be maintained for an Archaean age of these rocks.

Both high-grade metamorphic complexes show the effects of the Nickerie Metamorphic Episode, viz. low-grade metamorphism resulting in resetting of mica and hornblende ages, and shearing and mylonitization along ENE fault zones (PRIEM ET AL., 1971, 1977, 1978; DE ROEVER & BOSMA, 1975; KROONENBERG, 1976). The ENE trending mylonitized border faults of the Bakhuis Mountains Horst are parallel to the Trans-Amazonian schistosity and to the banding of the granulites. The faults probably were formed during the Trans-Amazonian updoming of the Bakhuis Mountains (BOSMA ET AL., in press) and were reactivated during the Nickerie Metamorphic Episode, and possibly also during the Phanerozoic (ALEVA, 1970; BOSMA & DE ROEVER, 1975).

### *Lithology and metamorphism*

(1) *The Falawatra Group* (DE ROEVER, 1975b) – The charnockitic granulites of the core of the complex show a compositional banding on a centimetre-to metre-scale, mainly of leucoenderbite, enderbite, norite and pyroxene amphibolite. This generally subvertical banding is considered to be of supracrustal origin in view of the intercalations of quartzite, calcsilicate rock and graphite-bearing granulite. The banding is enhanced by concordant leucoenderbite leucosomes produced by incipient anatexis. The mineral composition is orthopyroxene ± clinopyroxene ± hornblende ± biotite + plagioclase ± perthite ± quartz, indicative of the granulite facies. Metamorphism took place at rather low pressures in view of the absence of coeval garnet and the common occurrence of cordierite in pelitic gneisses infolded into and surrounding the charnockitic core of the complex. Metamorphic conditions were estimated around 800-900° at 8-9 kbar.

Fig. 2 (facing page).

Sketch map and cross-section of the main structural units of the Precambrian basement of Suriname. Legend: (1) Archaean (?) granulite belt (2) Trans-Amazonian high-grade belts (3) Trans-Amazonian greenstone belt (a. metabasalts etc.; b. meta greywackes; c. meta-arenite and conglomerates); (4-5-6) Trans-Amazonian granitoid-volcanic complex: (4) acid-intermediate metavolcanics; (5) metagabbros; (6) granitoid rocks: (big crosses: pyroxene granites); (7) unconsolidated Cenozoic sediments. Dolerites and Roraima sandstones omitted. Environmental zonation: (Ia) outer turbidite arc; (Ib) main basic volcanic arc; (IIa) deep-level acid magmatism; (IIb) shallow-level acid magmatism.

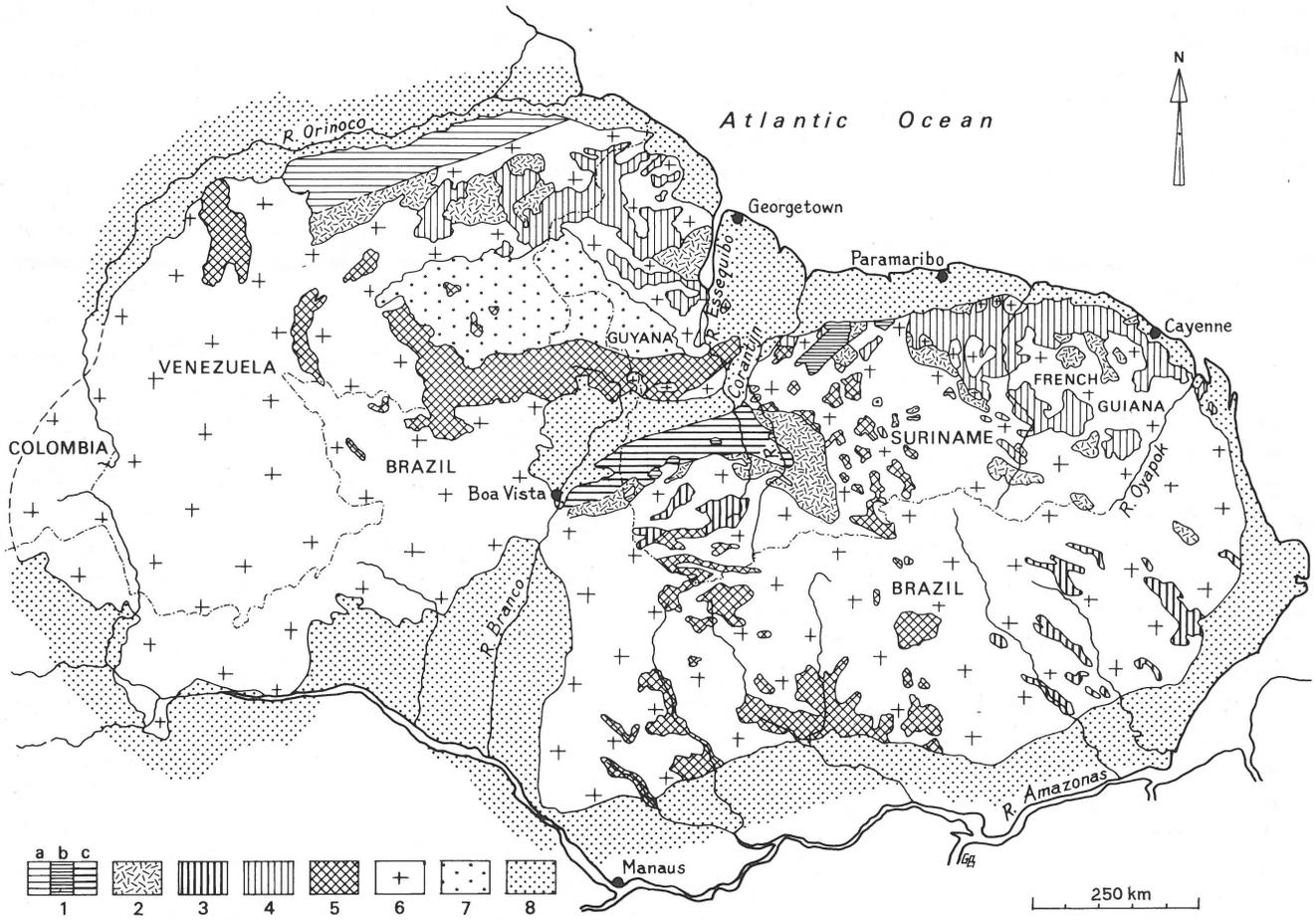


Fig. 3. Simplified geological map of the Guiana Shield (after various sources)

(1) Granulite belts (a. Imataca complex; b. Falawatra-Kanuku granulites; c. Kanuku Coeroeni migmatites); (2) Amphibolite-facies equivalents of 1; (3) Low-grade metasediments; (4) Greenstone belts; (5) Acid-intermediate metavolcanics; (6) Granitoid rocks; (7) Roraima sandstones; (8) Phanerozoic sediments.

Metamorphism and banding are synkinematic with isoclinal folds with steeply dipping axes, as well as with the domal structure in the Falawatra Group. A static overprint of higher-pressure metamorphism is evidenced by garnet poikiloblasts and rims of garnet + clinopyroxene + sodic plagioclase  $\pm$  quartz around orthopyroxene and hornblende and replacement of cordierite by biotite, sillimanite, kyanite, orthopyroxene, pyrope-rich almandine and rarely of sapphirine and surinamite (DAHLBERG, 1973; DE ROEVER, 1975a; DE ROEVER ET AL., 1976).

(2) *The Coeroeni Group* (KROONENBERG, 1976) – The Coeroeni Group consists mainly of quartzofeldspathic and pelitic gneisses with intercalations of amphibolites, quartzites, and calcsilicate rocks testifying to a supracrustal origin. They usually display a distinct schistosity enhanced by migmatitic banding, with predominating NW-SE trends. The metamorphism is synkinematic with tight to isoclinal folding, pinch and swell structures and boudinage. The metamorphic grade ranges from the sillimanite-muscovite zone of the amphibolite facies to the granulite facies. The common occurrence of cordierite in pelitic gneisses and cummingtonite + plagioclase in amphibolite-facies metabasites indicate rather low pressures during metamorphism. Like in the Falawatra Group, a second phase of static metamorphism at higher pressure is found that overprints the first

phase. The overprinting is clear from the replacement of cordierite by biotite, muscovite, andalusite, sillimanite, kyanite, staurolite, garnet, and ferrogdrite, and also by the development of garnet in metabasites. The metamorphic conditions in the first phase range from 650–700° at 5 kbar to 800° at 6–8 kbar, in the second phase between 680° at 5–7 kbar to 550° at 4 kbar.

## THE GREENSTONE BELT

### Structural setting

Large areas in northern and eastern Suriname are occupied by low-grade metavolcanics and metasediments of Lower Proterozoic age which are known as the *Marowijne Group*. They form part of a nearly continuous E-W to SE-NW striking greenstone belt along the northeastern margin of the Guiana Shield (CHOUDHURI, 1980; GIBBS, 1980; see Fig. 3) which possibly has a continuation in western Africa on a pre-drift configuration. The stratigraphic succession observed in Suriname is as follows:

(1) *The Paramaka Formation*, which consists of a basal sequence of mafic metavolcanics associated with metagabbros, followed by intermediate volcanics. Intercalations of metacherts and phyllites increase from bottom to top; (2) *The Armina Formation*, volcaniclastic metagreywackes and phyllites; (3) *The Rosebel Formation*, consisting of meta-arenites and metaconglomerates. These greenschist-facies rocks pass into amphibolite-facies amphibolites, schists and quartzites, around diapiric granitoid intrusions. The thickness of the whole sequence is estimated at about 10 km.

Field data (O'HERNE, 1958; DE MUNCK, 1954) and the appearance of the greenstone belt on the geological map and LANDSAT photographs suggest a subdivision into (1) a southwestern part consisting mainly of Paramaka Formation metavolcanics, folded into open synclines, intruded by diapiric tonalite bodies and unconformably overlain by Rosebel Formation metasediments, and (2) a northeastern part consisting mainly of Armina Formation metasediments, folded into isoclinal synclines and intruded by bi-mica and biotite granite bodies. In the continuation of the belt into French Guiana these two 'synclinoria' become widely separated by a broad belt of tonalitic intrusions (MAROT & CAPDEVILA, 1980). The diapiric granitoid intrusions generally show concordant contacts with the steeply dipping schists and amphibolites.

The Marowijne Group has sharp, probably tectonic contacts with high-grade quartzofeldspathic gneisses to the southwest. Another gneiss belt occurs north of the greenstone belt, which is largely covered by coastal sediments. The greenstone belt is intersected by the Bakhuis Mountains Horst in the northwestern part of the country. Basic metavolcanics west of the horst, the Matapi Formation, have been correlated with those of the Paramaka Formation. The Ston Formation in western Suriname, consisting of metaquartzarenites and conglomerates, has been correlated with the Rosebel Formation, but differs from this formation in its much more mature composition and open style of folding. Moreover, it is conformably overlain by the Dalbana Formation metarhyolites (see below) and hence might better be correlated with the Muruwa Formation in Guyana, which is not included in the greenstone belt (BARRON, 1969).

#### Age

Rb-Sr whole-rock dating of metabasalts and metaquartzandesites from northeastern Suriname yielded an isochron age of  $1950 \pm 150$  Ma (PRIEM ET AL., 1980). According to these authors, this age probably approximates the time of the volcanism in view of the low initial  $^{87}\text{Sr}/^{86}\text{Sr}$  isotope ratio of about 0.702. A single metaquartzandesite from the Matapi Formation in northwestern Suriname gave an identical Rb-Sr whole-rock age of  $1955 \pm 60$  Ma. However, GIBBS & OLSZEWSKI (1982) consider that this age may represent the low-grade metamorphism of the metavolcanic rocks as a

result of accompanying remobilization of alkalis evidenced e.g. by VEENSTRA (1978). They assume these rocks to be coeval with metagreywackes and gneisses of the Guyana greenstone belt dated at about 2250 Ma by U-Pb zircon analysis. Their study implies also that the greenstone belt and the surrounding gneisses are of the same age. This age corresponds with their reinterpretation of the zircon ages (GAUDETTE ET AL., 1976) of the Supamo Group in Venezuela, which also belongs to the greenstone belt of the northeastern Guiana Shield.

The age of metamorphism appears from additional K-Ar analyses to be around 2000 Ma (Table 1; PRIEM, pers. comm.), i.e. identical to that of the high-grade belts, the Falawatra and Coeroeni Groups.

#### Lithology and metamorphism

(1) *The Paramaka Formation* – The metabasalts of the Paramaka Formation are actinolite-epidote-chlorite-sodic plagioclase greenschists and greenstones with commonly relict porphyritic, amygdaloidal and fluidal textures and some possible pillow structures. Greenschist facies metagabbros and metadolerites with relict magmatic structures occur as small intrusive bodies within the metabasalts. Intermediate volcanics that overlie the metabasalts are blastoporphyritic sericite- and chlorite-rich schists. They range in composition from andesite to dacite and locally to rhyolite. Tuffaceous, agglomeratic and matrix-rich volcaniclastic sediments occur intercalated between the metavolcanics. Intercalations of finely laminated phyllites increase in importance towards the top of the sequence. The metacherts may contain finely dispersed carbonaceous or ferruginous material.

The metamorphism of these rocks is mainly in the greenschist facies and took place probably at fairly high pressures, as indicated by the occurrence of kyanite and chloritoid. Lower-grade pumpellyite-prehnite-facies metabasalts have also been observed. Amphibolite-facies equivalents include common amphibolites, clinopyroxene-garnet-bearing metabasalts, banded ironstones (itabirites), spessartite quartzites (gondites), schists with chloritoid, paragonite, staurolite, kyanite and garnet, and some calcisilicate rocks. The main metamorphic foliation is parallel to the axial plane of generally tight chevron folds on a mesoscopic to microscopic scale, with steeply dipping axes.

(2) *The Armina Formation* – Along the northeastern margin of the main belt of mafic to intermediate metavolcanics a metagreywacke sequence is found, which is characterized by a conspicuous rhythmic alternation of graded greywacke layers and phyllite layers, with a great lateral continuity. A regional variation has been observed from a predominance of greywacke layers, ranging from decimetres to metres in thickness with scarce mudstone intercalations, to a predominance of phyllites with thin but very continuous greywacke laminae. The metagreywackes consist mainly of quartz, altered plagioclase and fragments of intermediate metavolcanic rock. The greywacke beds have sharp basal contacts, occasionally with bottom-loading structures. Thick layers frequently contain angular mudstone fragments near the base. Local irregular intraformational folding may be due to slumping. The sedimentary structures indicate that the greywackes were deposited by turbidity currents.

The metagreywacke sequence shows regional transitions from lower to upper greenschist-facies metamorphism, with local garnet or chloritoid. Near intrusions of bi-mica granite these rocks pass into garnet-bearing staurolite-biotite schists with local kyanite. As in the Paramaka Formation, the metamorphic foliation is parallel to the axial planes of tight folds with steeply dipping axes. These folds appear to be superimposed on km-sized, isoclinal fold structures.

Small-scale folding (e.g. kink bands) and crenulation of the main foliation indicate a third folding phase.

(3) *The Rosebel Formation* – In northeastern Suriname low-grade metamorphic immature sandstones and conglomerates alternating with phyllites and in a few cases intermediate metavolcanics unconformably overlie the mafic to intermediate metavolcanics of the Paramaka Formation. The metasandstones are medium- to coarse-grained lithic meta-arenites, grading into arenitic greywackes. They show well-preserved sedimentary structures, predominantly micro- and mega-ripple cross-bedding. The poorly sorted polymict metaconglomerates form lenses of a few metres to tens of metres in thickness, locally with erosional bottoms. The rounded pebbles are mainly derived from the underlying Paramaka Formation. Phyllites, present in varying amounts throughout the sequence, display a fine horizontal lamination and contain flasers of fine meta-arenite. The dominant metamorphic minerals are sericite, chlorite, and locally chloritoid.

The Rosebel Formation shows km-sized, isoclinal fold structures with near-horizontal axes. A pervasive schistosity is not always visible, but pebbles often display a tectonic elongation of over 100%. The schistosity within the pebbles commonly deviates from that of the matrix, indicating a phase of metamorphism and folding prior to the deposition of the Rosebel Formation. The predominance of very immature coarse and fine clastics points to a deposition in an alluvial-fan and braided-river environment close to the source of the sediments.

The metasediments of the Ston Formation in northwestern Suriname have been correlated with the Rosebel Formation, but are more mature, consisting mainly of medium-grained meta-quartzarenites and oligomictic quartz-rich conglomerates with well-rounded pebbles (LOEMBAN TOBING, 1969). The Ston Formation shows broad, open folds, in contrast with the Rosebel Formation.

(4) *The diapiric intrusions* within the greenstone belt.

A. The biotite tonalites. The tonalite bodies consist mainly of biotite tonalite to trondhjemite, with subordinate biotite granodiorite to leucogranodiorite. They occur as intrusives in the mafic metavolcanics of the Paramaka Formation. Their margins against the steeply dipping country rock have a concordant, gneissic (and locally mylonitic) foliation and show amphibolite-facies metamorphism, characterized by abundant colourless mica and blastic epidote (VEENSTRA, 1978). The contact zone with the amphibolitic country rock consists often of a banded alternation of gneissose tonalite containing folded amphibolite xenoliths, and amphibolite with deformed and metamorphosed tonalite veins. Shape, contact relations, and orientation indicate diapiric ascent of the tonalite bodies (VEENSTRA, 1978). Their igneous character also appears from the common presence of HT-quartz pseudomorphs and euhedral plagioclase crystals with oscillatory zoning.

B. The bi-mica granites. The bi-mica granites are leucocratic rocks with a granite- to alkali feldspar granite composition and distinct magmatic textures, with muscovite occurring in euhedral booklets, and locally garnet. They are associated with pegmatites and other hydrothermal vein rocks. The bi-mica granites resemble the diapiric tonalite bodies in shape, size and contact relations. They display primary foliation and lenses of country rock along concordant contacts with amphibolite-facies plutono-metamorphic aureoles in the surrounding metagreywackes of the Armina Formation. The bi-mica granites may have originated from extensive anatexis of pelitic rocks (DE ROEVER & BOSMA, 1975).

## THE GRANITOID-VOLCANIC COMPLEX

### *Structural setting*

Granitoid and acid metavolcanic rocks of Lower Proterozoic age cover most of the central part of the country between the metamorphic belts. They form part of a much larger province of Trans-Amazonian acid magmatism (Fig. 3) that extends through southern Guyana, southern Venezuela, northern Brazil across the Amazon into the Brazilian Shield (SANTOS, 1980). In Suriname, apart from the diapiric intrusions in the greenstone belt, four different groups of igneous rocks can be discerned: (1) *deep-level granites*, often with migmatitic aspect and assimilation phenomena around enclaves of high-grade metamorphic rocks in central-eastern Suriname. Towards the greenstone belt in the northeastern part of the country gneisses predominate; (2) *shallow-level granites* in central-western Suriname, associated with and intruding into (3) acid and intermediate metavolcanic rocks of the *Dalbana Formation*; (4) small gabbroic to ultramafic bodies within both granitoid-volcanic terrains and within the metamorphic belts (*De Goeje Gabbro*).

### *Age*

The best-fitting isochron to the combined Rb-Sr isotopic age data of the diapiric intrusions, the deep-level granites, the shallow-level granites, and the Dalbana Formation metavolcanics gives an age of  $1874 \pm 40$  Ma (PRIEM ET AL., 1971; cf. Table 1). A separate study of some deep-level pyroxene granites from the Bakhuis Mountains gave a similar age of  $1923 \pm 55$  Ma. The De Goeje Gabbro intrusions yielded ages of  $1818 \pm 165$  Ma and  $1845 \pm 285$  Ma (PRIEM ET AL., unpublished data), in accordance with the ages of the similar Appinitic Intrusive Suite of southern Guyana (BERRANGÉ, 1977). The Tapuruquara gabbros in northern Brazil, which were correlated with the De Goeje Gabbro by SANTOS (1980) and SANTOS ET AL., (1981), gave according to these authors, apparent Archaean K-Ar mineral ages up to 3100 Ma. However, these high ages might be attributed to excess argon. Micas and hornblendes in the granitoid complex in eastern Suriname give Trans-Amazonian K-Ar and Rb-Sr ages, but in the western part of the country they show a resetting around 1250 Ma, attributed to the Nickerie Metamorphic Episode (PRIEM ET AL., 1971).

### *Lithology*

(1) *The deep-level granites* and associated metamorphites – A greyish medium-grained biotite granite to granodiorite, locally with alkali feldspar megacrysts, dominates in central and southeastern Suriname, and was distinguished by IZERMAN (1931) as Gran Rio Granite. Its igneous character is demonstrated by the igneous crystallization sequence, the occurrence of HT-quartz pseudomorphs (MAJER, 1969a) and of small euhedral plagioclase crystals enclosed in microcline, the fairly constant chemical composition and the scattered

occurrence of endomorphosed xenolithic country-rock fragments. The Gran Río granite encloses enclaves and large tracts of high-grade quartzofeldspathic gneisses, and locally shows vague banding and schlieren. In places deviating granites occur, which seem to be related to specific adjoining country rocks:

A. The muscovite-biotite granite in central Suriname contains scattered xenocrysts of cordierite, andalusite, fibrolite, corundum, and garnet, and hornfelsic to migmatitic xenoliths with the same minerals (BOSMA & LOKHORST, 1975; BOSMA ET AL., 1977). This rock type probably originated from assimilation of pelitic rocks by the biotite granite.

B. The pyroxene-bearing granites, with numerous enclaves of high-grade gneisses and granulites and gabbroic-ultramafic rocks, occupy a large area of irregular outlines in the Pikien Río area in central Suriname amidst the biotite granite. They are also found in the Bakhuis Mountains, marginal to Falawatra Group charnockitic granulites. The occurrences coincide with areas of high magnetic contrast on the total-intensity magnetic contour maps. The most common variety has a distinct magmatic texture and contains dusty antiperthitic plagioclase, microcline megacrysts, reddish-brown biotite, clinopyroxene rimmed by hornblende, and locally orthopyroxene (i.e. true charnockites). In central Suriname gneissose and banded granite varieties of migmatitic aspect, in part with poikiloblastic pyroxenes, are intimately associated with homogeneous magmatic types. Microscopically they typically show the concurrence of magmatic and metamorphic textures in a single rock specimen. The intimate association of homogeneous and gneissose to migmatitic varieties, the irregular outline of the pyroxene granite bodies, and the presence of many enclaves of high-grade metamorphic rocks of varying size indicate that the pyroxene-bearing granites probably originated by widespread, catazonal assimilation of a granulitic basement (BOSMA ET AL., 1977).

(2) *The shallow-level granites* – A. The biotite granite which underlies about 40% of the western half of the country is of syenogranitic to monzogranitic composition, slightly variegated (when weathered) and contains usually microcline megacrysts. Contrary to the eastern Gran Río granite, the western granite is characterized by its great homogeneity. The granite surrounds areas of acid metavolcanics and hypabyssal granites, and has sharp intrusive contacts against the metavolcanics and other country rocks. The granite commonly contains xenoliths of acid metavolcanic rocks.

B. The hypabyssal granites occur in close association with Dalbana Formation acid metavolcanic rocks. They are pink to variegated alaskites to leucogranites with HT-quartz bipyramids, alkali feldspar and albitic plagioclase phenocrysts in a finer-grained groundmass, often with granophyric textures. Biotite and hornblende, locally rimming pseudomorphs of clinopyroxene, are the main mafic minerals. Porphyritic varieties alternate with non-porphyritic ones (VERHOFSTAD, 1970). The hypabyssal granites intruded the acid metavolcanics of which they contain rounded xenoliths. On account of the close regional association and the compositional similarity they are considered as comagmatic, hypabyssal equivalents of the acid metavolcanics.

(3) *The Dalbana Formation* – The Dalbana Formation consists of acid to intermediate metavolcanic rocks, in which rhyolitic-rhyodacitic rocks with a colour index < 5 predominate, and which represent a calc-alkalic differentiation series (BOSMA ET AL., in prep.). They are found throughout western Suriname in close association with hypabyssal granites and surrounded by biotite granites.

Acid metavolcanics that show little recrystallization can be recognized as ignimbrites. They consist mainly of collapsed pumice fragments and flattened glass shards (VERHOFSTAD, 1970). The less acid metavolcanics are mostly ash-fall tuffs with broken phenocrysts and other pyroclastic fragments. A substantial part of the andesites represent lavas with euhedral plagioclase, pyroxene and hornblende

phenocrysts in a microcrystalline pilotaxitic groundmass (MAAS & VAN DER LINGEN, 1975). Volcaniclastic metasediments, mostly current-rippled lithic meta-wackes of varying maturity and grain size, are intercalated locally.

Distinctly recrystallized metavolcanics (matrix grain size > 0.1 mm) form broad marginal zones along the granites. They are characterized by a hornfelsic groundmass and poikiloblastic outgrowth of feldspar, hornblende, muscovite, and epidote. Associated metasedimentary hornfelses contain cordierite, andalusite, and sillimanite. 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 (MAIJER, 1969b, DE ROEVER & BOSMA, 1975).

(4) *The De Goeje Gabbro* – Numerous metamorphosed gabbroic to ultramafic bodies up to 20 km in diameter occur scattered throughout the Precambrian basement. They have an equidimensional to sill-like shape and a wide compositional range, from dunite to pyroxene granodiorite. Drilling and mapping often reveal both vertical and concentric zoning, usually with ultramafic rocks in the lower and inner parts, and gabbro-norites or granodiorites in the upper and outer parts of the bodies. Cumulate textures are common, particularly in ultramafic rocks. Typical cumulus minerals are olivine, orthopyroxene and magnetite, while hornblende biotite and calcic clinopyroxene are the main intercumulus minerals. The zonation and cumulate textures suggest that the compositional variation resulted from differentiation of a gabbroic magma, which is corroborated by geochemical data (BOSMA & LOKHORST, 1975; VEENSTRA, 1978; BOSMA ET AL., in prep.). The bodies show up as prominent anomalies on aeromagnetic total-intensity maps.

The (meta)gabbro-norite and (meta)ultramafite bodies are intrusive into the metamorphic complexes. In the granitoid complex they display hybrid dioritic border zones, granite veins, and other effects of assimilation by the surrounding granites, so that they are considered to be slightly older than the main phase of granitoid magmatism (BOSMA & LOKHORST, 1975; DE ROEVER, 1975b).

## THE RORAIMA FORMATION

Subhorizontal sequences up to 700 m in thickness of Middle Proterozoic, unmetamorphosed quartz-arenites and conglomerates with thin acid pyroclastic intercalations unconformably overlie the crystalline basement at the Tafelberg plateau and at some other locations. These rocks form an outlier of the Roraima Formation (IJZERMAN, 1931; BISSCHOPS, 1969), which covers extensive areas in Venezuela, Guyana, and Brazil. No detailed stratigraphical or sedimentological studies of these rocks have been made so far in Suriname, therefore correlation with published sections from Venezuela (REID, 1974) and Guyana (KEATS, 1976) is not possible. PRIEM ET AL., (1973) obtained a Rb-Sr isochron age of  $1655 \pm 18$  Ma for the intercalated acid pyroclastic rocks. A dolerite dyke that intrudes the Roraima Formation yielded a K-Ar age of  $1544 \pm 50$  Ma. The acid pyroclastic rocks in the Roraima Formation at the Tafelberg Mountain are considerably younger than the acid metavolcanics of the Dalbana Formation. Possibly the extrusion of the Roraima volcanics may be correlated with the extensive acid magmatism between 1750 and 1400 Ma at the southwestern border of the Guiana Shield in northwestern Brazil and adjacent parts of Venezuela and Colombia (TASSINARI, 1981).

## THE DOLERITE DYKES

### *The Avanavero Dolerites*

Dykes, sills and irregular bodies of hypersthene-pigeonite dolerite up to 150 km long and up to 1 km in thickness intersect the crystalline basement as well as the Roraima sandstones. They usually display NE-SW strikes. A typical constituent is inverted pigeonite (lamellar hypersthene-clinopyroxene intergrowths). Low grade metamorphism is common. A Rb-Sr isochron age of  $1659 \pm 27$  Ma was obtained from the Avanavero Dolerite at the type locality (HEBEDA ET AL., 1973). K-Ar ages show a considerable spread due to excess argon.

### *The Käyser Dolerites*

Olivine dolerites form a 300 km long NW-SE striking dyke swarm in southwestern Suriname. The individual dykes do not exceed 50 m in width. On account of the absence of metamorphic effects they resemble the Apatoe Dolerite, but K-Ar dating of one specimen from the Westrivier gave an 'age' of 5000 Ma, indicating a considerable argon excess. Since excess argon in the Avanavero Dolerite is thought to have been acquired during the Nickerie Metamorphic Episode around 1250 Ma, this would represent a minimum age for the olivine dolerite.

### *The Apatoe Dolerites*

Swarms of narrow N-S striking pigeonite dolerite dykes of Permo-Triassic age intersect all other rock units throughout the Precambrian basement, and can be followed for distances over 300 km in eastern Suriname. Pigeonite is never inverted in these dolerites. K-Ar dating of 11 whole-rock specimens from all over the country gives an average age of  $230 \pm 10$  Ma (PRIEM ET AL., 1968, 1970).

## DISCUSSION

Three orogenic events have been recognized in the Precambrian basement of Suriname: (1) an *Archaean* event, not confirmed geochronologically, but geologically evidenced in the charnockitic granulites of the Falawatra Group; (2) the *Trans-Amazonian Orogenic Cycle* in the Lower Proterozoic, during which deposition of the Marowijne and Coeroeni Groups and of part of the Falawatra Group occurred, followed by deformation and metamorphism in both high-grade and low-grade metamorphic belts around 2000 Ma and by acid magmatism around 1870 Ma (Table 1); (3) The *Nickerie Metamorphic Episode*, around 1250 Ma, evidenced by low-grade metamorphism, mica resetting and mylonitization in western Suriname.

Regarding the geotectonic environment and the development of the main orogenic event, the Trans-Amazonian Orogenic Cycle, the following questions arise: (1) Was there an Archaean basement underlying the whole or parts of the Trans-Amazonian orogenic belt? (2) What are the depositional environments of the Marowijne Group metavolcanics, the Coeroeni Group protoliths and their equivalent in the Falawatra Group? (3) What is the relationship between low-grade metamorphism in the Marowijne Group and contemporaneous granulite-to amphibolite-facies metamorphism in the Coeroeni and Falawatra Groups? (4) To what type of magmatism belong the granitoid-volcanic rocks in central and southern Suriname?

### *An Archaean basement in the Trans-Amazonian orogenic belt?*

Within the Suriname part of the greenstone belt, the Marowijne Group, no outcrops of older sialic basement have been found. The Trans-Amazonian U-Pb zircon ages found by GIBBS (1980) and GIBBS & OLSZEWSKI (1982) in gneisses surrounding the greenstone belt in Guyana (see Fig. 3) do not favour an older basement origin for these rocks. As to the granitoid-volcanic complex and the high-grade metamorphic belts, possible pre-Trans-Amazonian basement is only evidenced in the Falawatra Group charnockitic granulites, by the presence of cross-cutting granulite facies metadolerite dykes. Similar pre-Trans-Amazonian basement might be present in the Pikien-Rio area within the granitoid-volcanic complex of central eastern Suriname, where pyroxene-bearing granites are considered to originate from remobilized granulitic basement<sup>6</sup> (BOSMA ET AL., 1977), as suggested by their close association with high-grade partly pyroxene-bearing rocks, by their petrographic and aeromagnetic characteristics, and by their irregular outcrop pattern on the map and LANDSAT photographs. Extending this conclusion to the whole granitoid-volcanic complex, it is tentatively assumed that an older Archaean continent already existed at the start of the Trans-Amazonian Orogenic Cycle.

Granulite facies metamorphism took place around 2000 Ma, according to U-Pb zircon age data for the Falawatra Group. This metamorphism is probably the reason why no conclusive geochronological proof for an Archaean age of the Falawatra Group has been found, since such metamorphism is known to be a particularly effective mechanism to obscure an older history. The presence of kinked amphibole and biotite inclusions is hypersthene from Falawatra Group granulites (DE ROEVER, 1975a) implies a lower-grade history before the Trans-Amazonian granulite facies metamorphism. Since these rocks are assumed to be of Archaean age, the lower-

<sup>6</sup>An interesting detail is that granites originated from such remobilized granulitic terrains probably would not have a high initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio, as commonly expected for granites from old crustal material, but a low one, in view of the Rb depletion commonly found in granulitic rocks (cf. Falawatra Group rocks, PRIEM ET AL., 1978).

Table 1.

General stratigraphy and geochronology of the basement of Suriname. All cited Rb-Sr ages have been recalculated for  $\lambda = 1.42 \cdot 10^{-11} \cdot a^{-1}$ . Authors of geochronological data are referred to in the text. \*Denote hitherto unpublished data.

ERA	OROGENY	ROCK UNITS	SEQUENCE OF EVENTS	AGE	METHOD		
PERMO-TRIASSIC		APATOE DOLERITE	Tensional faulting, intrusion	230 ± 10 Ma	K-Ar whole rock 11 specimens		
UPPER PROTEROZOIC	NICKERIE METAM. EPISODE	Mylonites	Shearing, low-grade metamorphism, mica updating	1200 ± 100 Ma	K-Ar and Rb-Sr, micas and hornblendes		
MIDDLE PROTEROZOIC		KÄYSER DOLERITE AVANAVERO DOLERITE	Tensional faulting, intrusion	1659 ± 27 Ma	Rb-Sr whole rock isochron Avana-vero		
		RORAIMA FORMATION	Continental sedimentation, acid pyroclastic volcanism	1655 ± 18 Ma	Rb-Sr whole-rock isochron pyroclastics		
LOWER PROTEROZOIC	TRANS - AMAZONIAN OROGENIC CYCLE		Erosion - Uplift				
			De Goeje Gabbro		1818 ± 165 Ma	Rb-Sr whole rock* De Goeje Gabbro Kabalebo	
			Dalbana Formation	Intrusion and acid Volcanism		1845 ± 285 Ma	Rb-Sr whole rock* De Goeje Gabbro Maskita
		GRANITOID-VOLCANIC COMPLEX	Shallow-level granites			1874 ± 40 Ma	Rb-Sr whole rock isochron, 32 samples
			Deep-level granites			1923 ± 55 Ma	Rb-Sr whole rock,* pyroxene granite
			Tonalite diapirs	Metamorphism			
		MAROWIJNE GROUP	Rosebel Formation	Shallow marine - continental sedimentation			
			Armina Formation	Deep marine sedimentation		1950 ± 150 Ma	Rb-Sr whole rock isochron
			Paramaka Formation	Basic to intermediate volcanism		2000 ± 40 Ma	K-Ar whole rock* amphibolitic metadolerite
		COEROENI GROUP		Shallow-marine - continental sedimentation		2020 ± 100 Ma	K-Ar magnesioriebeckite Tapajé*
FALAWATRA GROUP	gneisses	Shallow marine - continental deposition		2001 ± 97 Ma	Rb-Sr whole rock isochron		
				2026 ± 20 Ma	U-Pb zircon, charn. granulite		
ARCH (?)		FALAWATRA GROUP charnockitic granulites	Amphibolite-facies metamorphism? Sedimentation? Volcanism?				

-grade history probably implies that the pre-Trans-Amazonian basement was not granulitic, but lower-grade. In another granulite belt in the Guiana Shield, the Imataca complex in northern Venezuela, a similar 2000 Ma granulite-facies event was demonstrated to overprint lower-grade Archaean rocks (MONTGOMERY & HURLEY, 1978; MONTGOMERY, 1979). In that case, a protolith age of 3.4 to 3.7 Ga could be established by special sampling techniques. The similarity in metamorphic history between the Imataca Complex and the Falawatra Group also favours an Archaean age for the latter.

Summarizing, both granulite facies metamorphism around 2000 Ma and extensive remobilization around 1870 Ma contributed to the disappearance of pre-Trans-Amazonian basement.

*The depositional environment of Trans-Amazonian volcanic and sedimentary rocks*

Trans-Amazonian supracrustal rocks were deposited at least in two different environments, one characterized by abundant basic volcanism (Marowijne Group), and one by the predominance of pelitic and quartzofeldspathic rocks (Coeroeni Group and part of the superstructure of the Falawatra Group).

The Lower Proterozoic Paramaka metavolcanics in the Marowijne Group constitute the first evidence for important basic volcanism in the Surinam part of the Guiana Shield. Contrary to many other shields, where Archaean high-grade gneisses are associated with Archaean greenstone belts with abundant (ultra)mafic volcanics, there is no evidence for important basic volcanism in the Guiana Shield older than Early Proterozoic (CHOUDHURI, 1980; TARLING, 1981). The northern Guiana greenstone belt, therefore, might be transitional between the basic volcanism of Archaean times, with its peculiar geochemical characteristics, and modern basic volcanism in different tectonic settings.

Various geochemical parameters have been used to compare the Surinam greenstones both with Archaean and with modern basic volcanics (VEENSTRA 1978; BOSMA ET AL., in prep.), just as in Guyana (GIBBS, 1980). Most Surinam metabasalts and metagabbros resemble modern ocean floor tholeiites in their minor and trace element contents, and in REE pattern. This would imply either a mid-oceanic ridge or a backarc marginal basin environment. Most metaquartz-andesites and metadacites resemble modern island-arc volcanics of the calc-alkaline type (BOSMA ET AL., in prep.). GIBBS (1980) noted similar minor and trace element contents in the Guyana part of the greenstone belt. However, there are significant differences with modern basic rocks as well: just as the Guyanese and Archaean tholeiites, the Surinam tholeiites contain less Ti and Zr than modern ocean floor tholeiites (BOSMA ET AL., in prep.). Cr contents in Surinam meta-andesites are anomalously high in comparison with modern circum-pacific andesites (VEENSTRA, 1978), and compare better to Guyanese and Archaean calc-alkaline rocks (cf. GIBBS,

1980). Also the REE pattern of the metabasalts shows more affinity to Archaean basalts than to modern ocean floor basalts (VEENSTRA, 1978). Komatiites have not been found as yet in Suriname, but magnesian schists similar to those of Guyana which show a komatiite-like geochemistry (GIBBS, 1980), occur locally. Komatiites also have been found in French Guyana (MAROT & CAPDEVILA, 1980). These results indicate that the Surinam greenstone belt volcanics cannot be compared simply to modern volcanic environments.

However, in spite of the geochemical differences, both Archaean greenstone belts and the Lower Proterozoic Guiana greenstone belt have an important characteristic in common with Phanerozoic island arcs: a volcanic pile with a tholeiitic base and with increasing calc-alkaline depositions towards the top. Hence, the differences in geochemistry might rather suggest a trend in the geochemical evolution of island arcs and back-arc marginal basins, than a different tectonic setting. Therefore, we tentatively assume a primitive island arc-back arc marginal basin as depositional environment for the Paramaka volcanics.

The depositional environments of the Armina and Rosebel Formations are insufficiently known. The volcanoclastic greywackes of the Armina Formation are flysch-type sediments, deposited by turbidity currents. On account of their position at the northern (outer) side of the main volcanic arc (Fig. 2), they might correspond to arc-trench sediments. The close spatial relation between the Paramaka and Rosebel Formations suggests that the coarse clastic Rosebel rocks were derived directly from the Paramaka volcanic edifices, and hence represent proximal equivalents of the Armina Formation. On the other hand, the presence of phyllite pebbles in the Rosebel conglomerates suggests an intervening period of uplift and lowgrade metamorphism. In this case these rocks would correspond to postorogenic molasse deposits.

The Coeroeni Group pelitic and quartzofeldspathic supracrustal rocks lack important basic volcanism. Because they are surrounded on all sides by Trans-Amazonian granitoid-volcanic rocks (interpreted as remobilized older basement), it is unlikely that they have been deposited in a continental margin environment. An intracratonic basin such as the present Amazon basin would be a much more likely tectonic setting. The same holds for the Trans-Amazonian pelitic gneisses mantling the granulite core of the Falawatra Group. The symmetry of lithologies (both greenstones and granitoid-volcanic rocks) on both sides of the Bakhuis Mountains Horst are more compatible with an intracratonic basin than with an asymmetric – continental margin.

*The metamorphism in the high-grade belts and the greenstone belt*

The geochronological data suggest that granulite facies metamorphism in the high-grade belts and greenschist facies metamorphism in the greenstone belt are essentially Trans-Amazonian. In both the high-grade belts and the greenstone

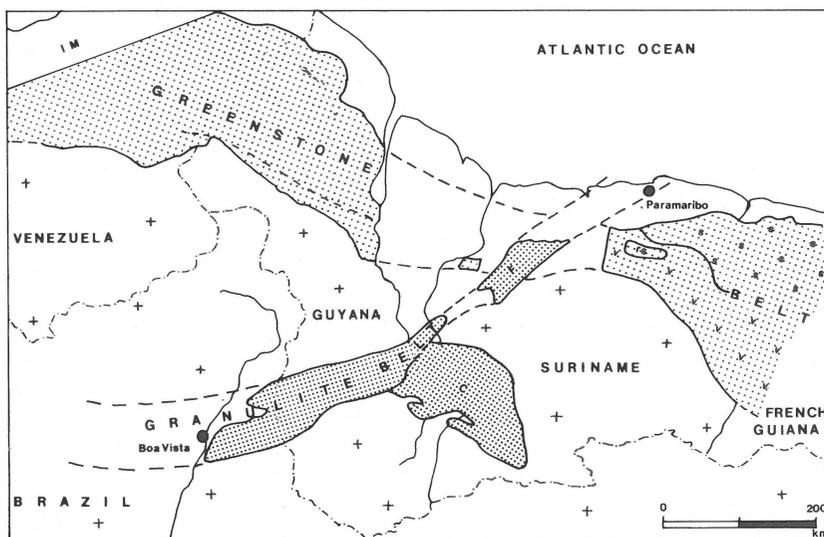


Fig. 4

Intersection of Trans-Amazonian metamorphic belts in Suriname. s: metagreywackes; v: metavolcanics; rs: coarse metasediments.

belt metamorphism is synkinematic with the folding. However, in spite of the contemporaneity of the metamorphism and the folding in both belts, their structural trends are grossly discordant. This is particularly clear in northwestern Suriname, where the NE-trending granulite belt (Falawatra Group) intersects the E-W trending greenstone belt (Fig. 4). This anomalous situation is partially explained if one takes into account that the discordances are tectonic contacts, the border faults of the Bakhuis Mountains Horst. These faults were active during the Trans-Amazonian orogenic cycle and were reactivated during the Nickerie Metamorphic Episode, thereby juxtaposing different levels of the earth's crust.

Notwithstanding this, the main NE-trending foliation of the Falawatra Group is discordant to the E-W to NW-SE foliation trend of the Marowijne Group. The Falawatra foliation is roughly parallel to its boundaries with the granitoid-volcanic complex, not only in northwestern Suriname, but over the entire expanse of the Central Guiana Granulite Belt. If, as postulated above, this belt corresponds with a Trans-Amazonian intracratonic basin, the structural discordance with the greenstone belt is explained. The triple junction pattern thus formed in northwestern Suriname, consisting of two branches of a continental margin-type metamorphic belt and one coeval intracratonic belt, resembles modern triple junctions with one unopened arm (aulacogen). However, the metamorphism and folding in an intracratonic belt are difficult to explain although several mechanisms have been proposed by KRÖNER (1977). Another triple-junction pattern is displayed by the prolongations of the Falawatra and Coeroeni Groups into southern Guyana; the junction near the Rewa River seems to correspond with a break in metamorphic grade (second hypersthene isograd of BERRANGÉ, 1973, 1977; KROONENBERG, 1975), but the structural relations are unclear.

The high-grade belts do not only differ from the greenstone belt in lithology, metamorphic grade, and structural trend, but also in the pressure regime during metamorphism. DE ROEVER & BOSMA (1975) recognized the paired character of the metamorphism in Suriname; the Marowijne Group being mainly of high-pressure type; the Falawatra and Coeroeni Groups mainly of the low-pressure type. The high-pressure type of metamorphism is thought to be related to low geothermal gradients at continental margins, the low-pressure metamorphism might correspond to high heat-flow values in intracratonic belts. The second, static high-pressure metamorphic overprint evidenced in the high-grade belts, which earlier was thought to indicate a separate metamorphic event, is now considered to represent an essentially retrogressive phase of the same Trans-Amazonian metamorphic event, possibly related to the emplacement of the domal structures in the belt (KROONENBERG, 1976).

#### *The acid to intermediate magmatism and the De Goeje Gabbro*

The asymmetry displayed by the greenstone belt in the northeastern part of the country continues in the compositional and depth zonation exhibited by the granitoid-volcanic complex (Fig. 2). There is a clear increase in acidity moving from the greenstone belt diapiric tonalites to the shallow-level intrusions in the central-western part of the country. Deviating granite types such as the bi-mica granites which do not fit into this pattern largely are the result of anatexis of specific parent rocks. Major element analyses (BOSMA ET AL., in prep.) show a calc-alkaline differentiation trend from tonalite to shallow-level granite. Within the Dalbana metavolcanics a calc-alkaline trend can be discerned also. Field relations in the deep-level granites of eastern

Suriname (see above) suggest that granitic magma mainly formed from widespread anatexis of older continental crust and minor amounts of Trans-Amazonian sediments.

Petrological and geochemical research on the De Goeje Gabbro suggests formation by fractionated crystallization from a hydrous gabbroic magma with high-alumina basalt affinities. The mafic to intermediate rocks of the De Goeje Gabbro follow a calc-alkaline differentiation trend (BOSMA & LOKHORST, 1975; DE ROEVER, 1975a; KROONENBERG, 1976; VEENSTRA 1978; BOSMA ET AL., in prep.). In view of these data the acid to intermediate plutonic and metavolcanic rocks are considered to be comagmatic; the De Goeje Gabbro is probably cogenetic in view of age, occurrence, and calc-alkaline nature, but probably not comagmatic. They resemble the zoned ultramafic complexes in Alaska and the Urals (TAYLOR, 1967), western Colombia (BARRERO, 1979) and the basic plutons in southern California (WALAWENDER & SMITH, 1980).

The parallelism between the zonation in the greenstone belt and in the granitoid-volcanic complex suggests that both have formed as a result of the same orogenic event. However, the radiometric ages indicate a gap of at least 100-125 Ma (Table 1), or even 300 Ma, if GIBBS & OLSZEWSKI'S (1982) 2250 Ma age for the greenstone belt is accepted. In northern Brazil, the acid magmatism around 1800-1850 Ma is not included into the Trans-Amazonian Orogenic Cycle, but is considered to represent a separate event of anorogenic magmatism reactivating the basement (SANTOS, 1980). However, in view of the compositional zonation described above, and of the correspondence of the Rb-Sr isochron ages of the tonalitic diapirs within the greenstone belt, with those of the main granitoid volcanic complex, we prefer to include the acid magmatism in Suriname within the Trans-Amazonian Orogenic Cycle. Therefore, we consider the Trans-Amazonian Orogeny to have taken place in two main stages, a deformational and metamorphic one around 2000 Ma and an essentially magmatic one around 1870 Ma.

#### THE MAIN STAGES OF THE TRANS-AMAZONIAN OROGENIC CYCLE

The asymmetric structure of the greenstone belt and the adjacent granitoid-volcanic complex strongly suggest an origin along an active continental margin (Fig. 2). The orogenic stage started with the extrusion of mafic, tholeiitic volcanics, followed by intermediate, calc-alkaline volcanic rocks, probably in a backarc marginal basin-island arc environment at the border of an older, pre-Trans-Amazonian continent. Subsequently, turbidity currents deposited the greywackes of the Armina Formation, probably in an arc-trench clastic wedge. The Rosebel Formation coarse clastic sediments were deposited on top of the Paramaka Formation metavolcanics, possibly after an initial deformational and metamorphic event. Around this time, clastic sediments

accumulated in the Falawatra and Coeroeni intracratonic basins, which formed a triple junction within the pre-Trans-Amazonian basement.

Intense tectonism, deformation and metamorphism, around 2000 Ma ago, greatly affected the continental margin and the intracratonic belts, caused the uplift of deeper portions of the Archaean basement in the Bakhuis Mountains Horst, and added the greenstone belt to the continent. The marked difference in metamorphic character between the high-pressure low-temperature Marowijne Group and the low-pressure high-temperature Falawatra and Coeroeni Groups might indicate the presence of a southerly dipping (Fig. 2) subduction zone, but the triple junction of the Falawatra and Marowijne Groups in northwestern Suriname interrupts the parallel pattern.

Orogenic activity did not end with the folding and metamorphism around 2000 Ma. Southward subduction of a plate north of the continent continued until around 1870 Ma and gave rise to calc-alkaline ignimbrite volcanism on the continental margin, closely followed by extensive calc-alkaline plutonism, including gabbroic intrusions. The position of this volcanism at the edge of the continent in comparison with the older island-arc calc-alkaline volcanism can be related to a greater depth of the volcanic source corresponding with higher potassium contents (see e.g., VERHOFSTAD, 1970). It may, however, indicate repositioning of the subduction zone as a result of intensive deformation and narrowing of the Marowijne Group greenstone belt.

The response to this stage of subduction, unlike the strong deformation and crustal shortening of around 2000 Ma, was rather extensive anatexis, almost completely reworking the pre-Trans-Amazonian basement. The accompanying deformation was only weak as is shown by open folds in the acid to intermediate metavolcanics, and the metamorphism in these rocks is generally low-grade with high-temperature-low pressure aureoles around granitic plutons. In the greenstone belt diapiric tonalite and granite intruded, with amphibolite-facies plutonometamorphism in the greenstones. Gneiss and granulite domes in the high-grade metamorphic belts, resembling the domal structures in the greenstone belt, probably formed at this time, too. The doming probably was accompanied by high-grade metamorphism overprinting the main (2000 Ma) metamorphism of these rocks.

#### THE POSTOROGENIC EVENTS

The time gap of at least 200 Ma between the acid magmatism of the granitoid-volcanic complex, and the deposition of the Roraima Formation, makes the interpretation of these rocks as a molasse deposit of the Trans-Amazonian Orogenic Cycle improbable (PRIEM ET AL., 1973). The intrusion of the Avanavero and Käyser Dolerites along up to 300 km long tensional fractures shortly after the deposition of the Roraima Formation also indicates that the shield was already cratonized in the Middle Proterozoic.

The Nickerie Metamorphic Episode around 1250 Ma appears to represent an independent event, which did not only result in low-grade metamorphism and the resetting of mica ages in the entire western part of the Guiana Shield up to central Suriname, but also in widespread mylonitization along ENE-trending shear zones. Its effects have been attributed to an important orogenic event, possibly of a continental collision type, along the westernmost margin of the Guiana Shield, as evidenced by a granulite belt in the Colombian Andes (KROONENBERG, 1982).

The intrusion of the Permo-Triassic Apatoe Dolerites around 230 Ma is widely held to mark the beginning of rifting between South America and Africa (e.g., MAY, 1971). Faulting and reactivation of faults since Cretaceous time is reflected, e.g., in the Bakhuis Mountains by different levels of Tertiary bauxite-laterite (ALEVA, 1970) and in the coastal plain by small abrupt changes in depth to the basement and a northward bulge in the Cretaceous-Eocene surface contours in line with the Bakhuis Mountains Horst (BOSMA & DE ROEVER, 1975).

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