

Copper and phosphate mineralization in the lower Proterozoic mobile belt of Bakhuis mountains, Upper Nickerie, Western Suriname, Guiana shield

E.H. Dahlberg

Department of Natural Resources, Minerals Division, Hibbing, P.O. Box 567, MN 55746, USA

Received 16 December 1986; accepted in revised form 5 April 1987

Abstract

Bornite and apatite mineralizations are found in a granulite facies section of the Trans-Amazonian Central Guiana mobile belt. The copper and phosphate mineralizations are associated with monzonitic to syenitic metavolcanic rocks, which in part occur interbanded with gabbro-norite gneiss. The country rocks include banded charnockitic granulites of the basement, granulites and gneisses of a Proterozoic supracrustal cover, and metamorphosed mafic to ultramafic intrusive rocks in basement and cover. Mineralization was located by a geochemical follow-up of coinciding aeromagnetic and electromagnetic anomalies, the latter with considerable in-phase components. The peculiar association of copper and phosphate mineralizations on the West flank of the Bakhuis granulite dome in the Central Guiana mobile belt shows aspects of volcano-sedimentary phosphorus and copper accumulations in an intracratonic rift basin. The supracrustal sequence of volcanics, clastic and chemical sediments in the basin was intruded by mafic magmas, which assimilated phosphorus- and copper-rich supracrustal rocks and on crystallization gave rise to copper- and phosphate mineralized mafic-ultramafic rocks. The subsequent mobile belt-style deformation and granulite to amphibolite facies metamorphism of the Central Guiana mobile belt have given rise to copper-mineralized monzonitic-syenitic and clinopyroxene-apatite rocks, representing a layered sequence of granulite facies metamorphosed cupriferous felsic volcanics and intercalated phosphatic siliceous carbonate sediments of the supracrustal sequence. The copper- and phosphate mineralizations of this volcano-sedimentary association occur associated with the similarly metamorphosed and deformed copper- and phosphate-mineralized rocks of the mafic plutonic association.

Introduction

In the mid-1960's the Geological and Mining Service of Suriname launched a base metal exploration program in the Lower Proterozoic high-grade metamorphic Bakhuis zone of western Suriname where previous airborne magnetic and electromagnetic investigations have established several anomalies.

Although no economic deposits have been found, copper-sulphide, phosphate, nickel-laterite, precious stones and graphite occurrences have been recorded that need to be fitted into a metal-

logenic scheme. This paper describes the geological setting and depositional characteristics of known mineralization in the Upper Nickerie area.

Tectonic division of the Precambrian of South America

General subdivision

Two major cratons can be distinguished on the South American continent (Cordani & Brito Neves, 1982): the Amazon craton and the São

Francisco craton, separated by the Tocantins mobile belt of the 500 Ma old Brazilian cycle. The latter mobile belt includes Archaean and Lower Proterozoic relics (Danni et al., 1982). The Archaean São Francisco craton (3400–3700 Ma) is dissected by mobile belts of younger Archaean (2800 Ma) and Trans-Amazonian (2000 Ma) ages (Mountinho-da-Costa & Mascarenhas, 1982). The Brazilian part of the Amazon craton, which straddles the Amazon river basin, includes the following main units (De Lima, 1984):

- Remnants of Archaean nuclei of granite-greenstone terrane (metamorphic ages around 2750 Ma).
- northwest-southeast-trending granulite-bearing mobile belts yielding metamorphic ages of 2450–2250 Ma, ± 2000 Ma, ± 1500 Ma, and younger late Proterozoic. Windows of Archaean rocks with ages of 2750 Ma have been recorded.
- The northeast-southwest-trending granulite-bearing Central Guiana mobile belt, which yields metamorphic ages of 1800–1900 Ma and is composed of intensively reworked basement; this belt is generally correlated with the similarly striking, Trans-Amazonian (± 2000 Ma) granulite-bearing mobile belts in adjoining Guyana and Suriname (see below).
- Extensive areas of plutono-volcanic rocks and associated platform cover sediments formed between 1850 and 1500 Ma.
- Graben-related mafic to ultramafic volcano-plutonic rocks emplaced between 1300 and 900 Ma.
- Cataclastic rocks formed between 1000 and 1200 Ma.
- Mesozoic plate tectonic-related mafic plutonics and graben-associated alkaline intrusives emplaced between 180 and 250 Ma.

In this paper attention will be focused on the Guiana Shield, i.e. the part of the Amazon craton north of the Amazon river (Fig. 1). Reference will also be made to the São Francisco craton and Tocantins mobile belt, which show similar mineralizations in a comparable geological setting as in the area described.

The Guiana Shield

Two Northeast-trending mobile belts of Trans-Amazonian (± 2000 Ma) metamorphic age are present on the Guiana Shield: the Imataca Complex or Imataca mobile belt in the Northwest (2 in Fig. 1) and the Central Guiana mobile belt in the central part of the Shield (3 in Fig. 1). These belts are bordered by Early to Middle Proterozoic Shield units composed of the following lithologic units (radiometric ages after Gibbs & Barron, 1983, and Gibbs & Wirth, 1985):

- Granitoids of migmatitic aspect (4 in Fig. 1) and high-grade metamorphic supracrustal rocks, granulites, and recrystallized mafic to ultramafic intrusions (6 in Fig. 1); ± 2250 Ma.
- Tightly folded epi- to mesozonal greenstones associated with predominantly tonalitic granulite domes; ± 2250 Ma (5 in Fig. 1).
- Flat-lying acid to intermediate metavolcanic rocks and subordinate metasedimentary rocks, thermally metamorphosed by associated hypabyssal granites; 1750–1950 Ma (7 in Fig. 1).
- Flat-lying cratonic, essentially non-metamorphic, slightly deformed quartzites or sandstones, arkoses and subordinate shales and tuffs; 1650–1730 Ma (7 in Fig. 1).
- Alkali-carbonatite complexes; 0.9–1.3 Ma (not indicated in Fig. 1).

In the mobile belts, a subdivision is possible between a lower basement supergroup of banded charnockitic granulites, mafic and ultramafic rocks and an infolded upper supracrustal supergroup of granulites, gneisses, and other rocks.

In the protolith of the Imataca Complex an Archaean age of 3700 Ma and resetting at 2000 Ma during Trans-Amazonian metamorphism have been established (Montgomery & Hurley, 1978).

Priem et al. (1978) assumed a Trans-Amazonian metamorphic age of 2000 Ma and a possible pre-metamorphic age of up to 2400 Ma for the granulites of the Suriname part of the Central Guiana mobile belt, whereas Gaudette et al. (1978) assumed ages of up to 2600–2800 Ma. More recent works (De Vletter, 1984; De Vletter & Kroonenberg, 1984; Kroonenberg & De Vletter, in prep.) maintain that in the Central Guiana mobile belt

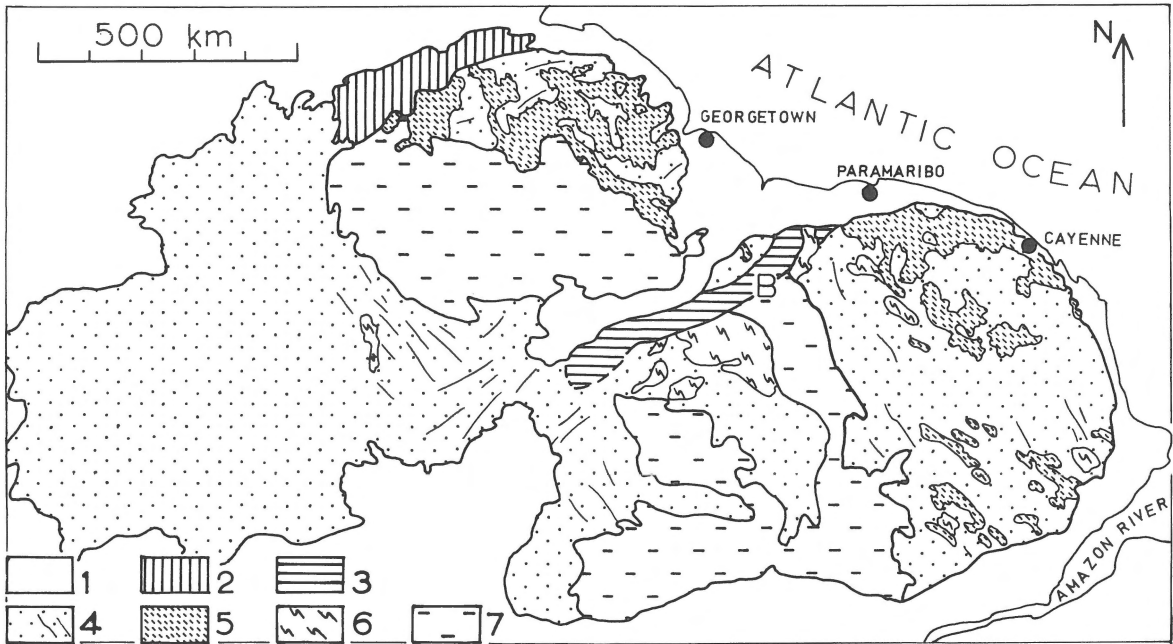


Fig. 1. Geological sketch map of the Guiana Shield, mainly after Gibbs & Barron (1983), Commission of the Geological Map of the World (1978) and De Lima (pers. comm.). 1. Phanerozoic cover. 2. Imataca mobile belt. 3. Central Guiana mobile belt. 4–7 Guiana Shield craton: 4. Migmatitic granitoids and gneisses; 5. granite-greenstone terranes; 6. metavolcanic and metasedimentary gneisses and associated granitic rocks; 7. essentially post-orogenic acid to intermediate volcanic rocks and associate hypabyssal granites and platform cover sediments. B. Bakhuis granulite dome with K/3 prospect.

rocks older than 2400 Ma have not been indicated.

The Central Guiana mobile belt

The Central Guiana mobile belt (De Lima et al., 1982) was originally defined by Kroonenberg (1976) as the Central Guiana granulite belt. This belt extends from Brazil through Guyana and Suriname to the Atlantic coast over a distance of about 1000 km. The major part of the belt is formed by northeast-trending granulites and catazonal gneisses of the Bakhuis and Kanuku Mountain ranges of Suriname and Guyana and parts of Estado do Amazonas and Territorio Federal de Roraima of Brazil (De Lima, 1984).

Along the Suriname and Guyana parts of the belt, three domal structures with granulite facies mineral parageneses were recognized (Dahlberg, 1975a); the Central Bakhuis granulite dome, the Corantyn granulite dome along the boundary with

Guyana, and the Darukuban-Kudiditau granulite dome in Guyana, all three surrounded by blastomylonitic gneisses.

Pseudotachylites are found along transcurrent northeast-trending border faults.

The charnockitic granulites, younger infolded high-grade supracrustal gneisses, and intrusive pyroxene granites of the Bakhuis granulite dome have been referred to as the Falawatra group by Bosma et al. (1983).

The Bakhuis and Corantyn granulite domes

Dahlberg (1975a and b) and De Roever (1975) have divided the rocks of the Bakhuis and Corantyn granulite domes into the following units (Fig. 2):

1. A basement of banded charnockitic granulites s.l. (1 in Figs. 2 and 3) of enderbitic, noritic and pyroxene-amphibolitic compositions. De Roever (1975) mentioned intercalations of met-

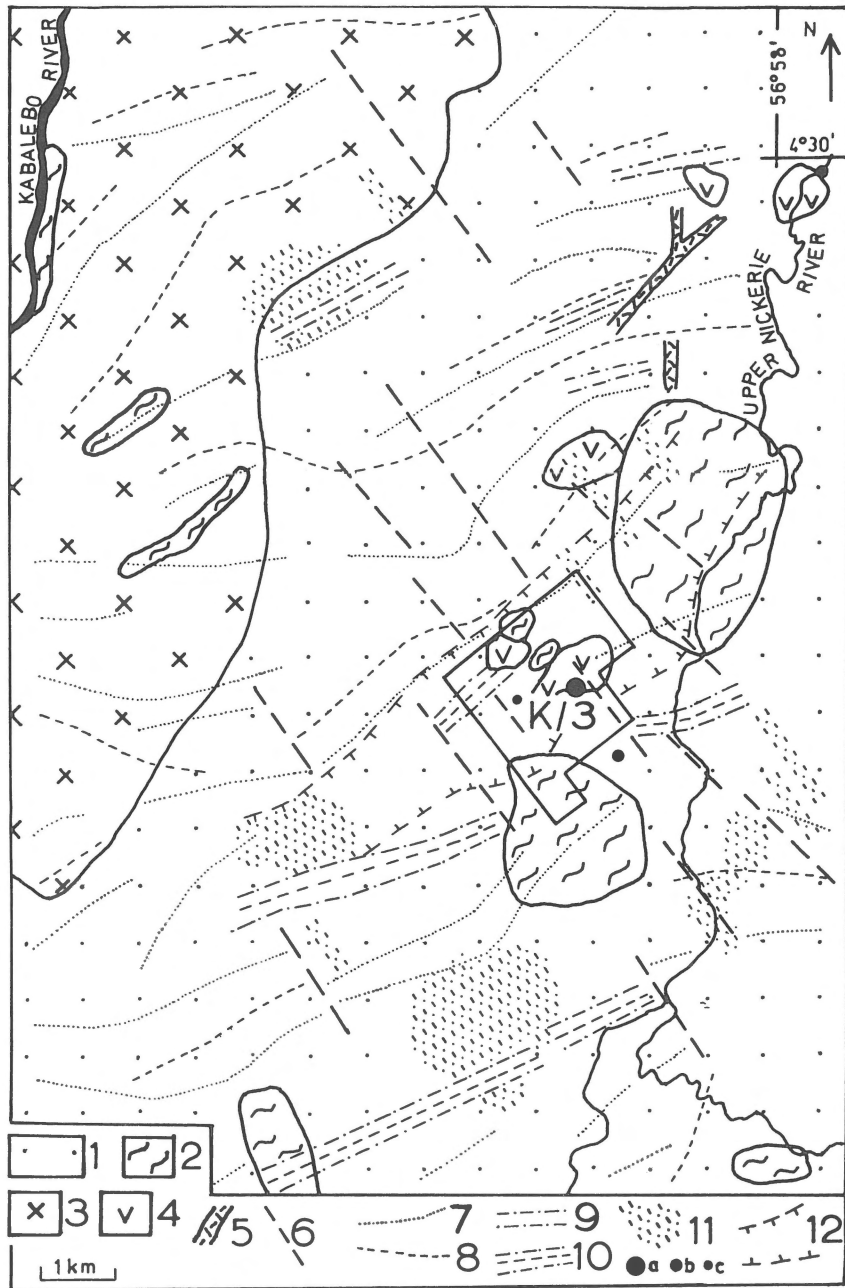


Fig. 2. Geological sketch map of the upper Nickerie area, Bakhuis Mountains, Suriname; magnetic, electromagnetic and geochemical anomalies are indicated. 1. Banded charnockitic granulites of the basement. 2. Banded metasedimentary granulites and gneisses of the infolded supracrustal sequence. 3. Clinopyroxene granite. 4. Mafic and ultramafic intrusives. 5. Metadolerites. 6. Faults, inferred from magnetic lineations and topography. 7. Positive magnetic axes. 8. Negative magnetic axes. 9. Zone of magnetic contrast. 10. Zone of magnetic contrast coinciding with negative magnetic axis. 11. Out-of-phase electromagnetic anomaly; locality with in-phase/out-of-phase ratio >3 (a), 0.75–1.5 (b), and 0.0–0.75 (c). 12. Zone of anomalous Ce-Th stream sediments. K/3. Location of K/3 prospect.

asedimentary granulites of quartzitic and calcsilicate composition and graphite-bearing rocks.

2. Banded mesoperthite-bearing granulite to amphibolite facies pelitic and calcsilicate granulites, gneisses, gondites and quartzites (2 in Fig. 2; 2–4 in Fig. 3). These banded metasedimentary granulites and gneisses are found along the borders of the Bakhuis granulite dome; they represent part of a supracrustal sequence folded in the basement of charnockitic granulites (Bosma et al., 1983). Metavolcanic rocks of syenitic to monzonitic composition occur intercalated in the metasedimentary granulites of the Bakhuis granulite dome (3 in Fig. 3).
3. Clinopyroxene granites (3 in Fig. 2) and mafic to ultramafic intrusives (4 in Fig. 2; 5 and 6 in Fig. 3) in the charnockitic and metasedimentary granulites; the rocks display a migmatitic aspect and are partly recrystallized under amphibolite facies conditions. These rocks are found on the western flank of the Bakhuis granulite dome and in the core of the Corantyn granulite dome.
4. Crosscutting metadolerites (5 in Fig. 2), statically recrystallized under pyroxene granulite facies conditions (De Roever, 1975). These rocks are not observed in the metasedimentary granulites.

The mafic to ultramafic rocks of unit (3) show the characteristic geometrical, aeromagnetic and electromagnetic properties of the suite of mafic rocks to which the so-called De Goeje Gabbro belongs (Bosma & Lokhorst, 1975; Bosma et al., 1983).

Metamorphic history of the Bakhuis granulite dome

According to De Roever (1975) and Bosma et al. (1983), prograde dehydration metamorphism has resulted in the granulite facies assemblages hypersthene + clinopyroxene + (partly brown) hornblende + plagioclase + quartz + perthite in felsic and mafic granulites of units (1) and (2). Inclusions of biotite and olive green hornblende are occasionally observed in hypersthene and clinopyroxene.

Replacement of cordierite by garnet in pelitic rocks, growth of Ca-rich garnet at the expense of

anorthite in calcsilicate rocks, and garnet blastesis consuming hypersthene and the anorthite component of plagioclase in the charnockitic granulites, are indicative of a change to higher pressure conditions during static metamorphism. Retrogressive dynamometamorphism is shown by hydration reactions at the expense of hypersthene and cordierite, giving rise to a foliation of newly formed biotite in amphibolite facies rocks and to the formation of lower amphibolite to greenschist facies blastomylonites.

Mineralization in the mobile belts

Banded iron ore is mined in the Imataca mobile belt. Banded iron formation and graphite occur in the Guyanan part of the Central Guiana mobile belt (Walrond, 1980), whereas copper, phosphate, nickel laterite and graphite are present in the Bakhuis granulite dome in the Surinamean part of the latter mobile belt. In the São Francisco Craton and Tocantins mobile belt copper, chromite, Fe-Ti-V, and nickel laterite are mined from mafic to ultramafic rocks, whereas apatite and manganese protores are reported to occur in the supracrustal rocks (Danni et al., 1982; Moutinho-da-Costa & Mascarenhas, 1982).

The Upper Nickerie copper-phosphate prospect

The prospect is situated on the southwest flank of the Bakhuis granulite dome of charnockitic and metasedimentary granulites (Fig. 2).

The prospect, referred to as the K/3 area, was located by combined magnetic and electromagnetic airborne surveys (Rattew, 1964) and ground follow-up by soil sampling, geophysical surveys, and diamond drilling (Dahlberg 1982a and b).

Mineralization is reflected by a north-trending copper soil anomaly, found in a 50 × 100 m gridded area, and by mineralized float assaying up to 3.5% copper. The anomaly is paired with a combined Ni and Cr anomaly in the area to the southeast, which is underlain by pyroxenite and peridotite. Combined magnetic-induced polarization-resistivity

surveys (Lokhorst & Haarman, 1977), confirmed the presence of copper sulphide anomalies and indicated coincidence of a chargeability-resistivity-high with quartzitic metasediments. Magnetic highs were found to coincide with mafic to ultramafic rocks and copper sulphide mineralization. On the surface wavelite float is found. Anomalous P, Ce, Th, Zr and Sr soils in a roughly north-trending zone underlain by monzonite and norite correspond to buried apatite-rich lenses observed in drill cores. This zone is part of a larger open northeast-trending Ce-Th anomaly, found by stream sediment sampling, with a length of 9 km and a width of about 1.5 km (Fig. 2). The elevated values of P and REE are probably caused by enrichment of monazite, allanite and zircon in the top soil and in the drainage system. Reddish-yellow zircon of gemstone quality ('hyacinth' assaying 0.5 qt) has been reported by Perez (1984) from heavy mineral concentrates with spinel, topaz and corundum.

It was concluded (Dahlberg, 1982a) that at present the copper mineralization in the upper 50 m investigated by shallow drilling is of no economic interest. Occurrence of better grades at depth is not excluded, however, as 11 out of 63 core holes show an increase of copper content with depth.

The regional geochemical survey started by the Geological and Mining Service (Pollack, 1981) was completed by the United Nations Revolving Fund for Natural Resources Exploration (UNRFNRE). The results indicate that the mineralization is confined to the Upper Nickerie Area (UNRFNRE, oral comm.).

With regard to the phosphate potential of the Bakhuis Mountains an evaluation was made by Sheldon (1982) with recommendations for follow-up exploration.

Faults

Morphology, geology and aeromagnetic trends reflect discontinuities, for example, along the watershed of the Kabalebo and upper Nickerie River drainage basins (Fig. 2). These discontinuities are indicative for a northwest-southeast trending sys-

tem of sinistral and dextral faults with offsets of 1.5–2.5 km. The fault directions coincide with regional lineations in the Guiana Shield (De Lima, 1984). The K/3 area occurs in a fault zone, which offsets a zone of magnetic contrast to the northwest. A cluster of relatively strong aero-electromagnetic point-source anomalies with in-phase to out-of-phase ratios of 0.75 to over 3.00 coincides with the above mentioned fault system.

Geology of the mineralized K/3 area

Detailed 1:5 000 geological traverses were made along 100 m spaced northwest running lines, resulting in a provisional geological map with boundaries partly inferred from bedrock float (Fig. 3). Additional data from soil geochemistry were used to project boundaries of ultramafic (Ni, Cr) and monzonitic rocks (P_2O_5 , Ce). The following rock units are distinguished (Fig. 3):

Banded charnockitic granulites (1 in Fig. 3).

These rocks are well-layered granulites of enderbite, charnockite and norite-anorthosite composition; they show a fine- to medium-grained granoblastic texture with some orientation due to a foliation, lineation or thin layering.

Quartzitic varieties occur mainly in the southern part of the area associated with pelitic metasediments and basic volcanic or calcsilicate rocks.

Banded metasedimentary gneisses and granulites (2 in Fig. 3).

These rocks are composed of thin layers with garnet, sillimanite, fibrolite, cordierite, and biotite, alternating with leucosomes of mesoperthite-bearing monzonite, mangerite, granite and quartzite. Locally observed mineral parageneses include: orthopyroxene-cordierite, spinel-corundum, and andalusite-kyanite. Blastomylonitic textures are rather common in rocks containing up to several percent of interstitial pyrrhotite, pyrite and chalcopyrite. In the southern part of the area fine-grained granoblastic parageneses of basic plagioclase-clinopyroxene-hypersthene apparently represent metamorphosed carbonate-bearing

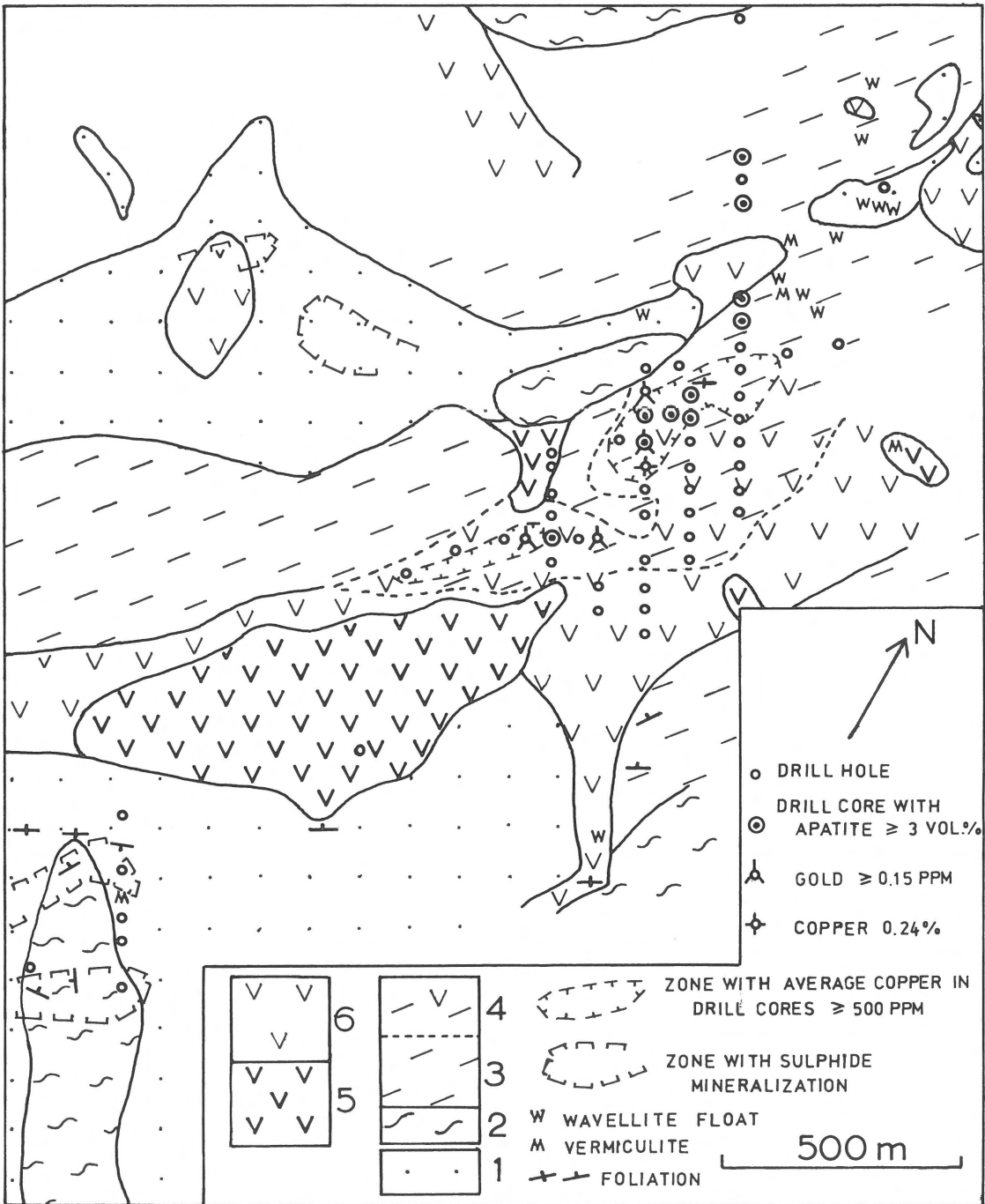


Fig. 3. Geological sketch map of the K/3 prospect. 1. Banded charnockitic granulites of the basement. 2-4. Banded metasedimentary granulites and gneisses of the infolded supracrustal sequence: 2. banded metasedimentary granulites and gneisses, 3. banded meta-volcanic monzonitic and syenitic rocks, 4. monzonitic and syenitic rocks mixed with gneissic gabbro-norites. 5. Ultramafic, and 6. mafic, gabbro-noritic rocks.

pelitic sediments or basic volcanic rocks. In the western part of the area north-northeast to east trending, 50 m wide zones with disseminated pyrite, chalcopyrite and pyrrhotite occur in quartzitic metasedimentary granulites.

Monzonitic and syenitic rocks (3 in Fig. 3).

These pink to grey fine- to medium-grained rocks have a granoblastic texture and compositions that vary from syenite through mangerite to monzonite and monzodiorite. The main constituent minerals are: perthite, mesoperthite, albite-oligoclase, and biotite. The monzonitic and related rocks constitute a banded rock unit of concordant layers of granulite facies metamorphosed felsic to intermediate rocks. The layered nature of the rocks and alternations with layered metasedimentary rocks suggest that the monzonitic and related rocks represent granulite facies recrystallized felsic to intermediate metavolcanics.

Apatite-clinopyroxene rocks

Coarse-crystalline lensoid aggregates of green clinopyroxene, apatite, and minor anhydrite and carbonate, occur interlayered with the monzonitic and related rocks. The apatite-clinopyroxene lenses have an average thickness of up to 2 m; they are frequently encountered in drill cores, but are not indicated as a separate lithologic unit in Fig. 3. The apatite-clinopyroxene rocks are interpreted as granulite facies metamorphosed, originally phosphatic and siliceous carbonatic sedimentary or exhalative-sedimentary intercalations in a sequence of predominantly acid to intermediate volcanic rocks.

Ultramafic rocks (5 in Fig. 3)

These are dark-green fine-grained rocks of the following compositions: pyroxenite grading into hornblendite and locally amphibolite, pyroxenite (websterite) grading into peridotite and alternating with fine-grained gabbro and leucogabbro. The main minerals are orthopyroxene, clinopyroxene, olivine (forsterite), green hornblende, and magnetite. Sharp contacts of pyroxenite and gabbro were observed in drill cores.

Gabbro (6 in Fig. 3)

In this rock unit massive gabbros, leucogabbros and gneissic gabbros are distinguished. The rocks are medium – to coarse – grained and have a rather inhomogeneous texture of coarser remnants of pyroxene or plagioclase embedded in a granular matrix.

The leucogabbros, which are observed only in drill cores, presumably occur as several tens of metres thick intrusions in an interlayering of gneissic gabbros with monzonitic and syenitic rocks (Fig. 3). Pigeonite schists of mafic to ultramafic composition were apparently formed by strong deformation of these interlayered rocks.

Metadolerites and microgabbros

These rocks are not shown in Fig. 3. The rock bodies have a flat sill-like form as inferred from drill cores. These sills are found in the gabbros and monzonites, but have not been recorded in the metasedimentary granulites and gneisses.

The metadolerites are massive rocks with relict igneous (e.g. ophitic) textures and characteristic hypersthene phenocrysts with exsolved fine opaque needles. Locally the rock is recrystallized into fine-grained granoblastic aggregates of olive-green hornblende and plagioclase with interstitial opaque minerals.

The microgabbros have hypidiomorphic granular to granoblastic textures. Occasionally sphene and rutile exceed 1%.

Quartz veins, quartzites and pegmatites

White veins of quartz are found in the north of the area crosscutting the banded monzonites. A massive body of a blue-grey quartz rock crosscuts the metasediments in the south. These quartz rocks and veins often contain typical lensoid plagioclase aggregates; sometimes opaque minerals occur concentrated along the lensoid aggregates.

In places coarse-grained euxenite- and tourmaline-bearing pink syenite and granite pegmatites with biotite booklets and quartz veins were observed crosscutting the country rocks.

Hydrothermal alteration

Montmorillonite occurs in subconcordant veins in monzonite and in veinlets in ultramafic rocks. Accompanying minerals in the veins in monzonite are: calcite, monazite, apatite, magnetite, microcline, albite, biotite, muscovite, quartz, zircon, ilmenite, goethite, tremolite, epidote and hematite. Associated minerals in veinlets in ultramafic rocks are: enstatite, albite, tremolite, dolomite and chlorite.

Montmorillonite occurs down to a depth of 50 m along the full length of two adjoining drill cores in the central part of the area. The average Cu-content of these cores exceeds 0.1%.

Local occurrence of wavellite, vermiculite and hydrobiotite in the north, is probably also related to hydrothermal activity.

Structural relations

The general strike of the rocks in the K/3 area is northeast to north-northeast and the layering is either subvertical or steeply dipping to the northwest (Fig. 3).

A system of cross faults is indicated by abrupt changes of directions of layering and by displacements of rock units. Furthermore strike-slip faulting is inferred from coincidence of a resistivity low (Lokhorst & Haarman, 1977) with cataclastic ultramafic rocks that occur in the southeast of the centre of the area, and that are in strike with pigeonite schists and blastomylonites in the interlayering of gneissic gabbro-norite and monzonite rocks.

Additional indications for faulting in the middle and northern part of the area are given by the presence of quartz veins, pegmatite and vermiculite schists.

The faults are probably related to the northwest composite fault zone described in the section on the geology of the Upper Nickerie area.

Hostrock of copper and phosphate mineralization

Copper

A projection on the geological map of the 500 ppm average copper contents of the diamond drill cores

reveals that copper mineralization is confined to the monzonitic and syenitic rocks and interlayered gabbro-noritic and other gneisses in the central part of the K/3 area (Fig. 3). Closer inspection of the drill core sections also shows copper enrichments of lower grades in massive gabbro-norite intercalated in blastomylonitic gabbro-norite, in leucogabbro with oxide-rich pyroxenite lenses, and in garnetiferous hypidiomorphic to granular norite to anorthosite.

The drill core with the strongest copper-mineralized rocks (averaging 0.33% Cu, Fig. 3) shows the following subvertically dipping sequence from top to bottom:

- 22 m of interlayered gabbro-norite gneiss and monzonitic rocks, assaying 0.25% Cu;
- 5 m metadolerite, assaying 500 ppm Cu;
- 2 m gabbro-norite, assaying 600 ppm Cu;
- about 10 m, predominantly of monzonitic rock, assaying 0.69% Cu.

The richest mineralization is observed in pink to grey monzonitic rock in random veins and micro-joints, in blastomylonite streaks, and along the contacts with pyroxene schist and microgabbro-norite intercalations.

Low-grade disseminated mineralization is usually present in massive monzonitic rocks.

The ore minerals are bornite, occasionally with telluride inclusions, and chalcopyrite, accompanied by some pyrite, pyrrotite, pentlandite, sphalerite, gold, magnetite, titanomagnetite, magnetite-hematite, rutile and chromite. Secondary sulphides are chalcocite, covellite and digenite. Gangue minerals are carbonate, anhydrite, apatite, scapolite and vermiculite.

Phosphate

The phosphate mineralization is observed in diamond drill cores. Lenses of clinopyroxene – apatite rock with thickness as much as 2 m are found in the monzonitic rocks. The length of these lenses can not be inferred from the available data, as the diamond drill cores can not be correlated. In the southern part of the area an intercalation of ca. 3.5 m of a phosphate-rich monzonitic rock was found in sillimanite gneisses and granulites. To the

north apatite occurs in apatite-rich hypidiomorphic to granular norites and in some hypersthene-bearing granitoids. Drill cores with an estimated content of more than 3 vol % of apatite were analysed over stretches of two metres; the analyses give P_2O_5 values up to 14.4%. A compilation of the analytical data given by Sheldon (1982) is shown in Table 1.

The apatite occurrences coincide partly with copper mineralization; out of 8 apatite-rich lenses, 3 assayed copper contents of 600 to 1200 ppm, but the highest P_2O_5 contents were found outside the zone with copper mineralization.

Additional minerals in the phosphate rock include: greenish clinopyroxene, plagioclase, anhydrite, scapolite, monazite, allanite, dolomite, Fe-dolomite (ankerite), magnetite and goethite. Monazite occurs intergranularly and probably also as inclusions in apatite. The apatite is a Sr-bearing fluor-rich variety (indicated by X-ray fluorescence), assaying 42.5% P_2O_5 and 4700 ppm Ce with traces of lanthanum, molybdenum, yttrium, manganese and iron.

Surface expression of phosphate-rich zones

Float of altered apatite (= wavellite, $Al_3(OH)_3(PO_4)_5 \cdot 5H_2O$) and turquoise are found in the northern part of the area underlain by monzonites. In this part of the area the maximum value of float assaying of 19.37% P_2O_5 is located in an open phosphate soil anomaly. Wavellite occurs in 'laterized syenite' and weathered syenitic gneiss and schist. Vermiculitization and silicification are widespread in these rocks.

Association of wavellite with Ba-rich adularia was found by Prof. R.D. Schuiling of the University of Utrecht (pers. comm.). Additional analyses of Ba, Sr and Ce in apatite-rich rocks have revealed extremely high values of these elements (Table 1), whereas U, Nb, Th and Zr are low with maximum values of 15 ppm (detection limit), 85 ppm, 45 ppm and 520 ppm, respectively.

Summary of geological events related to copper and phosphate mineralization in the K/3 area

Geological mapping has revealed the following field relationships and petrological characteristics of the mineralized rocks and their surroundings:

- A lower succession of hypersthene-bearing, charnockitic granulites is overlain by an infolded upper succession of predominantly meta-sedimentary granulites and gneisses (Dahlberg, 1975a).
- Granulite and amphibolite facies mafic to ultramafic meta-igneous rocks characterize the lower succession of charnockitic granulites, whereas amphibolite facies mafic to ultramafic meta-igneous rocks occur in the upper succession of meta-sedimentary granulites (Dahlberg, 1975a; De Roever, 1975).
- A blastomylonitic border zone of migmatitic amphibolite facies gabbros and granitoids separates granulite gneiss domes from the surroundings (Dahlberg, 1975a).
- Copper and phosphate mineralizations are associated with monzonitic, gabbronoritic, and plagioclase-clinopyroxene rocks, which occur in-

Table 1. Frequencies of average P_2O_5 , Ba, Ce and Sr contents in 2 m drill core segments in the K/3 area

P_2O_5	ns	Ba	ns	Ce	ns	Sr	ns
12-14	1	>0.4	3	0.2-0.3	2	>0.5	1
10-12	0	0.3-0.4	4	0.1-0.2	6	0.4-0.5	1
8-10	3	0.2-0.3	11	<0.1	69	0.3-0.4	5
6-8	9	0.1-0.2	23			0.2-0.3	20
4-6	5	<0.1	33			0.1-0.2	34
2-4	26					<0.1	18
0-2	58						

(Analyses in weight percent; ns frequency or number of analyzed 2 m core segments)

terlayered with pelitic metasediments in the metasedimentary succession and show retrogradation from granulite to amphibolite facies (Dahlberg, 1982a and b).

- Undeformed syenitic and granitic pegmatites and quartz veins crosscut the silicified and sheared country rocks (Dahlberg, 1982a).
- Subconformable montmorillonite-calcite-vermiculite veins with REE-bearing minerals occur in monzonitic and clinopyroxene-plagioclase rocks (Dahlberg, 1982a).

The regional occurrence of oval structures with granulite facies rocks in the core and amphibolite to granulite facies rocks in the outer parts defines a granulite-gneiss dome belt (Dahlberg, 1975a). Granulite-gneiss domes aligned on a continental scale and coinciding with anomalous aeromagnetic zones bounded by transcurrent faults, are also described from other mobile belts, e.g., those in Southern Africa (Anhaeusser et al., 1969; Kröner, 1977).

For the described section of the Central Guiana mobile belt the following succession of geological events is deduced:

- Proterozoic transgression over older basement. Deposition in shallow seas connected with the ocean of mature sandstones, shales, phosphatic and siliceous carbonates, and evaporites. Extrusion of copper-bearing felsic to intermediate and basic volcanic rocks. According to Sheldon (1982) copper is also provided by submarine-exhalative processes, while phosphorus is precipitated from seawater enriched by upwelling waters from the deep ocean.
- Intrusion of mafic magmas. Assimilation of supracrustal phosphorus and copper by mafic magmas and crystallization of copper- and phosphate-mineralized mafic and ultramafic rocks.
- Granulite facies metamorphism and deformation of basement and supracrustal rocks. This resulted in charnockitized basement covered by metasedimentary granulites. The recrystallization of supracrustal cupriferous trachite and dacite and associated phosphatic siliceous carbonate sediments resulted in copper-bearing syenitic and monzonitic rocks associated with clinopyroxene-apatite lenses. Peridotites,

pyroxenites and norites were forced into semi-conformable setting with basement and supracrustals.

- Formation of dome structures under amphibolite facies conditions. Retrogressive metamorphism of granulite facies rocks occurred during the Trans-Amazonian tectono-thermal event about 2000 Ma ago (Bosma et al., 1983). Layered mixing of monzonites and mafic to ultramafic rocks.
- Upheaval and formation of lower amphibolite facies blastomylonites. Copper remobilization and mineralization along shear zones in and along monzonitic, mafic and ultramafic rocks. Intrusion of granite and syenite pegmatite. This stage is characterized by a spread of mineral ages between 2000 and 1200 Ma (Tassinari et al., in prep.; Priem et al., 1973).
- Finally, alkaline magmatism about 240 Ma ago (Tassinari et al., in prep.) and deposition of REE-bearing hydrothermal veins.

Survey of literature on copper and phosphate mineralization

A literature survey shows that in amphibolite to granulite facies terranes in gneissic belts, the following two types of mineralization are often found: (1) copper mineralizations in phosphatic mafic to ultramafic plutonic rocks, and (2) Pb-Zn-(Cu) mineralization in volcano-sedimentary sequences associated with Fe- and Mn-oxide deposits, and sometimes also with apatite deposits.

Copper mineralization associated with apatite concentrations have been reported from the Okiep District, Namaqualand, South Africa (Stumpfl et al., 1976; McIver et al., 1983; Lombaard, 1986) and the Caraiba District, State of Bahia, Brazil (Townend et al., 1980; Hasui et al., 1982). The mineralization occurs as subvertical bodies in granulite facies supracrustal rocks, including chemical metasediments of Late Archaean to Middle Proterozoic age. Similar mineralized rock associations have been described from the Middle Proterozoic of Rogaland, Southwestern Norway (Brons, 1973; Hermans et al., 1975; Verwey, 1981).

The massive sulphide deposits of Zn-Cu in the Pyhasalmi-Pielavesie District, Finland (Kahma, 1973; Huhtala, 1979), Pb-Zn-Ag in the Broken Hill district, Australia (Stanton, 1979; Rutland & Both, 1979), Cu-Pb-Zn-Ag in the Aggeneys district, South Africa (Ryan, 1982), Pb-Zn in the Gamsberg district, South Africa (Stumpfl, 1977), and Zn-Cu in the Prieska district, Bushmanland, South Africa (Wagener, 1982), are found in high-amphibolite to granulite facies gneissic belts. The metamorphic age of these deposits is Middle to Upper Proterozoic. A gneissic or granulitic Archaean basement can often be indicated. An uraniferous phosphate horizon hosted by dolomite marble and skarn (average 3–5% P₂O₅) is found in Finland associated with the Vihanti Zn-Fe sulphide deposits and interlayered felsic volcanics (Rehtijärvi et al., 1979). The latter phosphate deposit shows similarities with those found in the K/3 in Suriname.

Conclusions

According to Sawkins (1984), metal deposits related to the early stages of continental rifting include the copper and nickel sulphide deposits in mafic rocks in for example the Precambrian Thompson Belt in Canada and Limpopo Belt in southern Africa. These mafic rocks occur as intrusions in a supracrustal sequence, which also includes copper-rich volcanics, phosphorites, and sulphur-rich evaporites. Deformation and metamorphism of the Proterozoic supracrustal sequence with the mafic intrusions, together with remobilization of the Archaean basement, resulted in the formation of high-grade metamorphic linear orogenic belts. Sawkins' (1982) model for the rift-related origin of intracratonic mobile belts may also be applied to the Precambrian Namaqualand, Caraiba, and Central Guiana mobile belts. The intrusive mafic magmas in the supracrustal sequence of clastic sediments, cupriferous volcanics, chemical sediments as phosphorites, sulfates, and carbonates, may assimilate Cu, S, and P from the supracrustal rocks and so acquire a potential to segregate copper sulphides and apatite on crystallization. The subsequent deformation and high-

grade metamorphism of mobile belt-style resulted in dismembering of the copper- and phosphate-mineralized and other mafic to ultramafic intrusives, resulting in the characteristic occurrence of disrupted and metamorphosed, layered mafic rock bodies in granulite-gneiss belts (Windley et al., 1981). Copper- and phosphate-mineralized syenitic and monzonitic rocks and lenses of clinopyroxene-apatite rocks represent metamorphosed cupriferous felsic to intermediate volcanics and phosphatic siliceous carbonate sediments of the supracrustal succession, respectively. Thus, metamorphosed copper- and phosphate-mineralizations of the mafic to ultramafic plutonic association tend to occur besides metamorphosed copper- and phosphate-mineralizations of the volcano-sedimentary association in the same mobile belt. In the Central Guiana mobile Belt the copper- and phosphate-mineralization of the volcano-sedimentary association seems to predominate among indicated occurrences.

Acknowledgements

I wish to thank the Netherlands Organization for the Advancement of Pure Research (ZWO) for a visitor's fellowship grant, Prof. Dr. Oen Ing Soen is thanked for his guidance and critical remarks leading to major revision of the manuscript, Prof. Dr. A.C. Tobi, Prof. Dr. J. Touret, and Prof. Dr. Matt Walton for the many fruitful discussions and Dr. A. Senior and Dr. John Spletstoesser for the critical reading of the manuscript.

The hospitality of colleagues at the Geological Institutes of the Universities of Amsterdam and Utrecht and at the Minnesota Geological Survey, St. Paul has been greatly appreciated.

References

- Anhaeusser, C.R., R. Mason, M.J. Viljoen & R.P. Viljoen 1969 Reappraisal of some aspects of Precambrian Shield Geology – Geol. Soc. America Bull. 80: 2175–2200
- Bosma, W. & A. Lokhorst 1975 Geophysical, geological and geochemical characteristics of some De Goeje-type gabbroic bodies – Geol. Mijnb. Dienst Suriname, Meded. 23: 176–193

- Bosma, W., S.B. Kroonenberg & E.W.F. De Roever 1983 Igneous and metamorphic complexes of the Guiana Shield in Suriname – *Geol. Mijnbouw*, 62: 241–254
- Brons, J.H. 1973 Verslag van een geologisch-petrografisch veldwerk in het gebied begrensd door Lysefjorden-Hogsfjorden-Espedalen, Kommune Forsand, Rogaland, Zuidwest Noorwegen – *Inst. Aardwetensch. Univ. of Utrecht: unpubl. report*
- Commission of the Geological Map of the World 1978 The tectonic map of South America, scale 1:500,000
- Cordani, U.G. & B.B. de Brito Neves 1982 The geological evolution of South America during the Archaean and Early Proterozoic – *Rev. Brasileira de Geociencias* 12: 78–88
- Dahlberg, E.H. 1975a Lithostratigraphical correlation of granulite facies rocks of the Guiana Shield – *Geol. Mijnb. Dienst Suriname, Meded.* 23: 26–33
- Dahlberg, E.H. 1975b Basemetal exploration in a basic granulite terrain in the Bakhuis Mountains, Western Suriname – *Geol. Mijnb. Dienst Suriname, Meded.* 23: 194–205
- Dahlberg, E.H. 1982a Copper, Phosphate and REE explorations in the K/3 area, Bakhuis Mts, Western Suriname – *Geol. Mijnb. Dienst Suriname: unpubl. report*
- Dahlberg, E.H. 1982b Geochemical investigation of magnetic and electromagnetic anomalies in the upper Nickerie copper-rare earth mineralization area, Suriname – In: Laming, D.J.C. & A.K. Gibbs (eds): *Mineral exploration techniques in tropical rain forest – AGID Report 7: 95–109*
- Danni, J.C.M., R.A. Fuck & O.H. Leonardos 1982 Archaean and Lower Proterozoic units in Central Brazil – *Geol. Rundsch.* 71: 291–317
- De Lima, M.I.C. 1984 Provincias Geologicas do Craton Amazonico em Territorio Brasileiro – *Anais II Amazon Symposium, Dep. Nac. Prod. Mineral, Manaus: 9–23*
- De Lima, M.I.C., E.P. De Oliveira & C.C.G. Tassinari 1982 Cinturoes granuliticos da porcao setentrion do Craton Amazonico – *Anais I Symposium Amazonia, Dep. Nac. Prod. Mineral, Manaus: 147–162*
- De Roever, E.W.F. 1975 Geology of the central part of the Bakhuis Mountains (W. Suriname) – *Geol. Mijnb. Dienst Suriname, Meded.* 23: 65–101
- De Vletter, D.R. 1984 Synthesis of the Precambrian of Suriname – *Geol. Mijnb. Dienst Suriname, Meded.* 27: 11–30
- De Vletter, D.R. & S.B. Kroonenberg 1984 Review of some outstanding problems in the Precambrian geology of Suriname – *Anais II Symposium Amazonico, Dep. Nac. Prod. Mineral, Manaus: 163–168*
- Gaudette, H.E., P.M. Hurley, H.W. Fairbairn, A. Espejo & E.H. Dahlberg 1978 Older Guiana basement south of the Imataca Complex in Venezuela and Suriname – *Geol. Soc. America Bull.* 89: 1290–1294
- Gibbs, A.K. & C.N. Barron 1983 The Precambrian geology of the Guiana Shield – *Episodes* 2: 7–14
- Gibbs, A.K. & K.R. Wirth 1985 Origin and evolution of the Amazonian Craton – *Workshop on early crustal evolution, Lunar Planet. Sci. Inst.: unpublished*
- Hasui, Y., L.J. Homem del'Rey, F.J. Lima e Silva, P. Mandetta, J.A. Canário de Moraes, J.G. Genario de Oliveira & W. Miola 1982 Geology and copper mineralization of Curacao River Valley, Bahia – *Rev. Brasileira Geosciencias* 12: 463–474
- Hermans, G.A.E.M., A.C. Tobi, R.P.E. Poorter & C. Maijer 1975 The high-grade metamorphic Precambrian of the Sirdal-Orsdal area, Rogaland/Vest-Agder, S.W. Norway – *Norsk Geol. Unders. Bull.* 318: 51–74
- Huhtala, T. 1979 The geology and zinc-copper deposits of the Pyhasalmi-Pielavesie district, Finland – *Econ. Geol.* 74: 1069–1083
- Kahma, A. 1973 The main metallogenic features of Finland – *Bull. Geol. Surv. Finland* 265: 30 pp
- Kröner, A. 1977 Precambrian mobile belts of southern and eastern Africa-ancient sutures or sites of ensialic mobility? A case of crustal evolution towards plate tectonics – *Tectonophysics* 40: 101–135
- Kroonenberg, S.B. 1976 Amphibolite facies and granulite facies metamorphism in the Coeroeni-Lucie area, South-western Suriname – *Thesis Univ. of Amsterdam, Geol. Mijnb. Dienst Suriname, Meded.* 25: 109–289
- Lokhorst, A. & A.H.M. Haarman 1977 Progress report of basement exploration Part III. Geophysical investigations in the Kabalebo-Upper Nickerie Region, Area XVI – *Geol. Mijnb. Dienst Suriname: unpubl. report*
- Lombaard, A.F. & the Exploration Department Staff of the O'okiep Copper Company Ltd 1986 The copper deposits of the Okiep District, Namaqualand. In: Anhaeusser, C.R. & S. Maske (eds): *Mineral deposits of Southern Africa II – Geol. Soc. S. Africa: 1421–1445*
- McIver, J.R., T.S. McArthur & B. de V. Packham 1983 The copper-bearing basic rocks of Namaqualand – *Mineral. Deposita* 18: 135–160
- Montgomery, C. & P.M. Hurley 1978 Total-rock U-Pb and Rb-Sr systematics in the Imataca Series, Guiana Shield, Venezuela – *Earth Planet. Sc. Lett.* 39: 281–290
- Moutinho-da-Costa, L.A. & J.F. Mascarenhas 1982 The high-grade metamorphic terrains in the interval Mutuípe-Jequié: Archaean and Lower Proterozoic of East-Central Bahia – *Abstracts excursions Intern. Symp. Archaean and Early Proteroeic evolution and metallogenesis-ISAP/82: 19–36*
- Perez, H.G. 1984 Estudio gemologico de minerales pesados provenientes del area de Kabalebo Suriname – *Anais II Symposium Amazonico, Dep. Nac. Prod. Mineral, Manaus: 301–312*
- Pollack, H.R. 1981 Regional geochemical stream sediment survey in the Upper Nickerie-Threefalls Creek area, Bakhuis Mountains, Western Suriname – *Geol. Mijnb. Dienst Suriname: unpubl. report*
- Priem, H.N.A. 1973 Provisional isotope geochronological framework for some major events in the geologic column of Suriname – *Geol. Mijnb. Dienst Suriname, Meded.* 22: 9–16
- Priem, H.N.A., N.A.I.M. Boelrijk, E.H. Hebeda, R.P. Kuijper, E.W.F. de Roever, E.A.Th. Verdurmen, R.H. Verschure & J.B. Wielens 1978 How old are the supposedly Archaean charnockitic granulites in the Guiana Shield base-

- ment of western Suriname? – Short papers 4th Int. Congr. Geochron. Cosmochron. Isotope Geol., U.S. Geol. Survey, Open File Rept. 78-101: 341-343
- Rattew, A.R. 1964 Combined airborne in-phase EM and magnetometer survey part III for the Geological and Mining Service, Government of Suriname, by International Aero Service Corporation – Geol. Mijnb. Dienst Suriname: unpubl. report
- Rehtijärvi, P., O. Aikäs & M. Mäkelä 1979 A Middle Precambrian uranium- and apatite-bearing horizon associated with the Vihanti zinc ore deposit, Western Finland – Econ. Geol. 74: 1102-1117
- Rutland, R.W.R. & R.A. Both 1979 Major stratiform basemetal deposits of the Australian Proterozoic. In: The Development potential of Precambrian mineral deposits. Publ. of U.N. Dept of Technical Cooperation for Development: 307-344
- Ryan, P.J. 1982 The geology of the Broken Hill ore deposit, Aggeneys, South Africa – Proc. 12th CMMI Congr., S. Afr. Inst. Min. Metall. and Geol. Soc. of S. Africa: 181-192
- Sawkins, F.J. 1982 Metallogenesis in relation to rifting. In: Palmeson, G. (ed): Continental and oceanic rifts – Geodynamic Ser. 8: 259-269
- Sawkins, F.J. 1984 Metal deposits in relation to plate tectonics Springer (Berlin): 323 pp
- Sheldon, R.P. 1982 Analyses of preliminary studies of the Bakhuis Mountains apatite deposit, Suriname – Geol. Mijnb. Dienst Suriname: unpubl. report
- Stanton, R.L. 1979 A preliminary account of chemical relationships between sulfide lode and 'Banded Iron Formation' at Broken Hill, New South Wales – Econ. Geol. 67: 1128-1145
- Stumpfl, E.F. 1977 Mineralogical aspects of ores, sediments, ores and metamorphism – Phil. Trans. Roy. Soc. Lond. A.286: 507-525
- Stumpfl, E.F., T.N. Clifford, A.J. Burger & D. van Zyl 1976 The copper deposits of the O'Okiep district, South Africa: New data and concepts – Mineral. Deposita 11: 46-70
- Townend, R., P.M. Ferreira & N.D. Franke 1980 Caraiba, A new copper deposit in Brazil – Trans. Instn Min. Metall. 89: B159-B164
- Verwey, R. 1981 Onderzoek aan de vererfing van een mafische intrusie nabij Oltesvik, Rogaland, S.W. Noorwegen – Inst. Aardwetensch. Univ. of Utrecht: unpubl. report
- Wagener, J. 1982 The Geology and exploitation of the Prieska zinc deposit, northern Cape Province – Proc. 12th CMMI Congr. S. Afr. Inst. Min. Metall. and Geol. S. Africa: 193-202
- Walrond, G.W. 1980 A metallogenic scheme for the Guiana Shield – IUGS Symposium Metallogenesis in Latin America, Mexico City: unpublished
- Windley, B.F.J., F.C. Bishop & J.V. Smith 1981 Metamorphosed layered igneous complexes in Archaean granulite-gneiss belts – Ann. Rev. Earth Planet. Sci. 9: 175-198