Single zircon Pb-Pb and Sm-Nd whole rock ages for the Ebolowa greenstone belts: Evidence for pre-2.9 Ga terranes in the Ntem Complex (South Cameroon)

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ABSTRACT

The Ntem Complex of the northwest Congo craton represents the deeply eroded part of a granite-greenstone-gneiss terrane with a documented history starting from 2.9 Ga. Here we present results of recent field studies, single zircon Pb-Pb ages and Sm-Nd whole-rock isotopes for the Ebolowa greenstone belts (metasediments and garnet amphibolites) that extend this history back to ca 3.1 Ga. These greenstone belts are highly dismembered and were successively intruded by a charnockitic suite around 2.9 Ga, by a tonalite-trondhjemite-granodiorite suite (TTGs) between 2.83 and 2.82 Ga, by granites around 2.7 Ga, and by syenite plutons and doleritic veins dated at ca 2.05 Ga. Detrital zircon Pb-Pb ages from two metasediment samples range from 3.14 ± 3 Ga to 3.07 ± 3 Ga. Nd model ages calculated for the greenstone belts (felsic and mafic rocks) range between 3.41 and 3.01 Ga. These data provide important constraints on the timing and processes of early crust formation in the Congo craton.

Keywords. Archaean greenstone belts - single zircon Pb-Pb ages - Sm-Nd isotopes - Congo craton - South Cameroon

RÉSUMÉ

Le complexe du Ntem, bordure nord du craton du Congo est constitué d'un ensemble de roches vertes et de granito-gneiss très érodé. Les anciens travaux montrent que ce complexe a une histoire géologique qui commence à 2,9Ga. Dans cet article, les nouvelles observations de terrain, les âges Pb-Pb sur monozircon et les isotopes Sm-Nd sur roches totales des roches vertes (métasédiments et amphibolites à grenat) de la région d'Ebolowa montrent que l'histoire du complexe du Ntem commence plutôt à environ 3,1 Ga. Ces roches vertes sont très déstabilisées et sont successivement intrudées par la série charnockitique à environ 2,9 Ga, par la suite granodiorites – tonalites – trondhjémites (TTG) entre 2,83 et 2,82 Ga, par les granites à environ 2,7 Ga, par les plutons de syénites et les filons de dolérites datés à environ 2,05 Ga. Les analyses Pb-Pb sur les zircons détritiques de deux échantillons de métasédiments donnent les âges compris entre 3,14 ± 3 Ga et 3,07 ± 3 Ga. Les âges modèles T_{DM} de ces roches vertes (métasédiments et amphibolites) sont compris entre 3,41 et 3,01 Ga. Ces résultats sont une contribution importante sur le temps et sur les processus de formation des premières croûtes du craton du Congo.

Mots clés : Roches vertes archéennes - Ages Pb-Pb sur monozircon – Isotopes Sm-Nd – craton du Congo – Sud Cameroun.

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INTRODUCTION

Africa is the core of the supercontinent Gondwana. It includes three of the Earth's largest Archaean cratons : the Kaapvaal, the West African and the Congo cratons. Terranes older than 2.9 Ga are well known in the Kaapvaal craton, where various formations have been dated between 3.3 and 3.6 Ga (e.g. Hamilton et al. 1979; Jahn et al. 1982; Compston and Kröner 1988). In the West African craton, evidence for early Archaean (3.4-3.5 Ga) formations are provided from U-Pb zir-

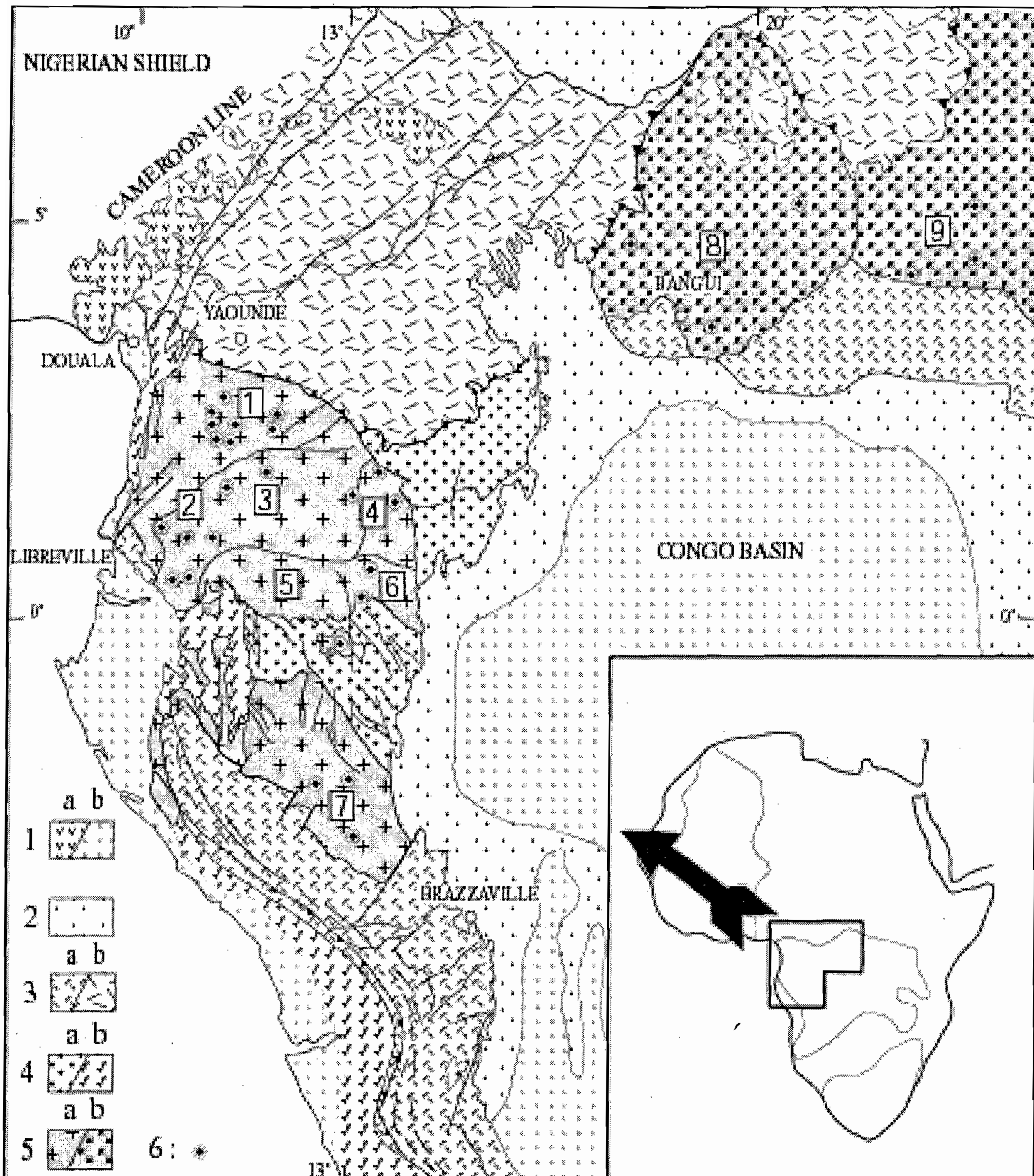


Figure 1. *Schematic map of the western part of Congo craton and its borders (modified after Feybesse et al., 1998). 1a : Cameroon Line volcanics; 1b: Recent sedimentary formations of the shore basins and of the Congo Basin; 2: Pharozoic cover; 3a: Meso to Neoproterozoic formations of the West Congo Belt and of Central Africa; 3b: Meso to Neoproterozoic formations of the Oubangui Belt; 4a: Palaeo to Mesoproterozoic cover of the Congo craton; 4b Palaeoproterozoic to Mesoproterozoic igneous and metamorphic formation of the Congo craton western margin; 5a: Archaean of Congo craton; 5b: Archaean to Palaeoproterozoic Bomu craton; 6: Location of early Archaean rocks in the Congo craton. Numbers refer to Table 1.*

con and Sm-Nd whole-rock ages by Potrel et al. (1996, 1998) in the Reguibat Rise, by Kouamelan et al. (1997), Thiéblemont et al. (2001) and Barth et al. (2002) in the Man Shield, and by Kröner et al. (2001) in the Nigeria Shield.

Table 1. *Main Archaean age data for the Congo craton. Numbers [1] to [9] refer to location in Fig. 1.*

Localities	Lithologies	Ages (Ma) and (Method)	State of the ages	Ref.
Ntem Compex [1]	Greenstone belts	3147 ± 3 (single zircon Pb/Pb) 3088 ± 2 (single zircon Pb/Pb) 3068 ± 3 (single zircon Pb/Pb)	Detrital zircon ages and metamorphic ages	1 and 2
	Charnockites	2900 ± 44 (Rb/Sr) 2880 ± 45 (Rb/Sr) 2896 ± 7 (U/Pb; zircon) 2912 ± 2 (single zircon Pb/Pb)	Emplacement and metamorphic ages	1, 3, 4 and 5
	TTG (trondhjemites, tonalites and granodiorites) suite	2833 ± 2 (single zircon Pb/Pb) 2860 ± 15 (single zircon Pb/Pb) 2860 ± 28 (Rb/Sr)	Emplacement ages	1, 6, 7 and 8
	K-rich granitoids	2600 ± 42 (Sm/Nd) 2628 ± 32 (Rb/Sr) 2666 ± 2 (single zircon Pb/Pb) 2687 ± 3 (single zircon Pb/Pb)	Emplacement ages	8
Monts de cristal zone [2]	Catazonal gneisses	3120 ± 67 (Rb/Sr) 3091 ± 53 (Rb/Sr)	Early metamorphic ages	9
	Granites Ultra basic and basic rocks Bissok and Efout granites	2802 ± 38 (Rb/Sr) 2783 ± 77 (Pb/Pb) 2676 ± 96 (Rb/Sr)	Emplacement ages	
Mitzic - Oyem area [3]	Mitzic gneisses Mitzic granodiorites	3186 ± 75 (Rb/Sr) 2838 ± 10 (U/Pb, zircon)	Early metamorphic age Emplacement age	9
	Oyem granitoids Ebel orthogneisses	2760 ± 70 (Rb/Sr) 2789 ± 25 (U/Pb ; zircon)	Emplacement ages	
Makokou zone [4]	Ferriferous belts	3091 ± 13 (Pb/Pb) 2970 ± 80 (Pb/Pb)	Early metamorphic ages	9, 10 and 11
	Dioritic gneisses	3040 ± 61 (Rb/Sr) 2861 ± 70 (Rb/Sr)	Early metamorphic ages	
The Massima series [5]	Greenstone belt (dacite) Biotite tonalite	2940 ± 06 (single zircon Pb/Pb) 2929 ± 05 (single zircon Pb/Pb)	Emplacement ages	12
Nounah - Ivindo and Afoumadzo areas [6]	Ferriferous belts	3091 ± 87 (Pb/Pb) 2970 ± 80 (Pb/Pb)	Early metamorphic ages	9
Chaillu Massif [7]	Tonalites Granodiorites and potassic granites	2875 ± 15 (single zircon Pb/Pb) 2863 ± 22 (single zircon Pb/Pb) 2752 ± 39 (single zircon Pb/Pb) 2732 ± 17 (single zircon Pb/Pb) 2710 ± 06 (single zircon Pb/Pb) 2637 ± 33 (Rb/Sr) 2603 ± 16 (single zircon Pb/Pb) 2544 ± 14 (single zircon Pb/Pb) 2510 ± 28 (single zircon Pb/Pb)	Emplacement ages	9 and 13
Mbomu Complex [8]	Greenstone belts	3005 ± 63 (Rb/Sr)	Early metamorphic age	10, 14 and 15
	Tonalites (TTG) Granites	2960 ± 68 (Rb/Sr) 2706 ± 71 (Rb/Sr)	Emplacement ages	
Upper Zaire granitoid massif [9]	TTG Granites	2836 ± 39 (Rb/Sr) 2894 ± 67 (Rb/Sr) 2725 ± 77 (Rb/Sr)	Emplacement ages	14

References (ref.) 1: Tchameni 1997; 2: this work; 3: Delhal and Ledent 1975;4: Lasserre and Soba 1976; 5: Toteu et al. 1994; 6: Shang et al., 2000; 7: Shang et al., 2001;8: Tchameni et al. 2000; 9: Caen-Vachette et al. 1988; 10: Lavreau and Ledent 1976; 11: Cahen et al. 1984; 12: Guerrot et al. 1994; 13: Maurin and Peucat 1998; 14: Lavreau 1980; 15: Poidevin 1991.

In contrast, only a few and poorly constrained geochronological studies indicate early Archaean ages in the Congo craton (Delhal and Ledent 1975; Lavreau and Ledent 1976; Lavreau 1982; Cahen et al. 1984; Caen-Vachette et al. 1988; Guérrot et al. 1994; Maurin and Peucat 1998; data in Table 1 and Figure 1). In the Ntem Complex (Ntem Unit precisely), which makes up the northwestern part of the Congo craton (Fig. 2), the oldest zircon age from the charnockite is close to 2.9 Ga (Toteu et al. 1994). In order to unravel the earliest history of the Ntem Unit, zircon and whole-rock samples were investigated by Pb-Pb single zircon and Sm-Nd isotope techniques respectively.

GEOLOGICAL SETTING AND PREVIOUS GEOCHRONOLOGICAL DATA FOR THE NTEM UNIT

The Ntem Complex constitutes the Archaean to Palaeoproterozoic basement of Southern Cameroon (Fig. 2). In the western part, it is divided in two main structural units: the Palaeoproterozoic Nyong Unit and the Archaean Ntem Unit. Both units were overthrusted by the Yaoundé group during the Pan-African time. The units are distinguished on the basis of different structural features and the recent geochrological studies (Maurizot et al., 1985; Toteu et al., 1994; Lerouge et al., 2004; Penaye et al., in press). The Ebolowa area is located in the Ntem Unit.

In the Ntem Unit, three distinct litho-tectonic units can be distinguished: (1) The remnants of greenstone belts that consist of the xenoliths of the metasediments and garnet amphibolites in the granitoids rocks (Vicat et al. 1998). (2) The charnockitic and granitoid plutons, mainly belonging to TTG-like suites, which are dated between 2.91 and 2.82 Ga, and by late K-rich granitoids dated at 2.66 Ga (Toteu et al., 1994; Tchameni and Nsifa 1998; Tchameni et al. 2000; Shang et al., 2001). (3) Late cross-cutting syenitic plutons and metadolerite dykes of Palaeoproterozoic (ca 2.05 Ga) age (Toteu et al. 1994; Vicat et al. 1996; Tchameni et al., 2001; Lerouge et al., 2004) which belong to the thermo-tectonic activity which affected the Ntem Complex at the time of the Eburnean orogeny. Before that, during the time of charnockite emplacement and high K-granite intrusions, the greenstone belts were affected by an amphibolite- to granulite-facies metamorphism. Mineral phase relationships and thermobarometric calculations indicate peak P-T conditions near 5 ± 1 kb and 750 ± 50°C for the high-grade metamorphism (Tchameni 1997). The Eburnean event caused retrograde metamorphism of the Archaean rocks in the amphibolite facies.

Structurally, the Ntem Unit is characterised by generally vertical foliation, lineation and isoclinal folds. Foliation trends E-W to NW-SE in the greenstone belts and in the magmatic granulitic suite and N-S to NNW-SSE in the TTGs and K-rich granitoids. These Archaean structures are attributed to the successive diapiric uprise of the granitoid plutons and to subsequent transcurrent deformation oriented NE-SW to ENE-WSW (Tchameni, 1997; Shang et al., 2001)

Previous Rb-Sr, U-Pb and Sm-Nd isotopic data on the Ntem Unit were used to establish the dominant Archaean emplacement of most of the granitoids and, a major late Eburnean tectono-metamophic event at ca 2.05 Ga. In detail, zircons of two Ebolowa charnockites defined regression lines which yield the same upper intercept age of 2896 ± 7 Ma. Metamorphic event of Eburnean age is identified from re-equilibration of Sm-Nd in gneiss and metadolerites of the Ntem Unit at ca. 2.05 Ga (Toteu et al., 1994). Lasserre and Soba (1976) obtained Rb-Sr age of 2880 ± 45 ~~Ga~~ with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7012 ± 0.0003 for seven gneisses of the Ntem Complex. This age is in good agreement with the zircon U-Pb age and is interpreted as representing the primary crystallization age of the Ntem Unit charnockites. Rb-Sr whole-rock data for both the Ntem Unit and Nyong Unit samples overlap within uncertainties, and Cahen et al. (1984) regressed the data of Lasserre and Soba (1976) together with those of Delhal and Ledent (1975) to obtain a composite age of 2900 ± 44 ~~Ga~~ with initial $^{87}Sr/^{86}Sr$ ratio of 0.7011 ± 0.0002, which they regarded as a good estimate for the age of charnockitization. Recent single zircon Pb-Pb evaporation ages indicate 2.91Ga for the charnockites (Tchameni, 1997) and 2.66 Ga for the K-rich granitoids (Tchameni et al., 2000) in the Ebolowa area. All previous geochronological data indicate a long thermal history for the Ntem Unit Cameroon that seems to have begun around 2.9 Ga.

FIELD RELATIONS AND PETROGRAPHY

Archaean greenstone belts are exposed in the Ebolowa area in the Ntem Unit. They are volumetrically of minor importance and generally define irregular shaped, elongate small bodies that are almost always in tectonic contact with granitoids (Fig. 3). In some areas, the greenstones are only preserved as trails of xenoliths in intrusions belonging to the TTG suite. All rocks were metamorphosed under amphibolite- to granulite-facies conditions. Thus, the metamorphic

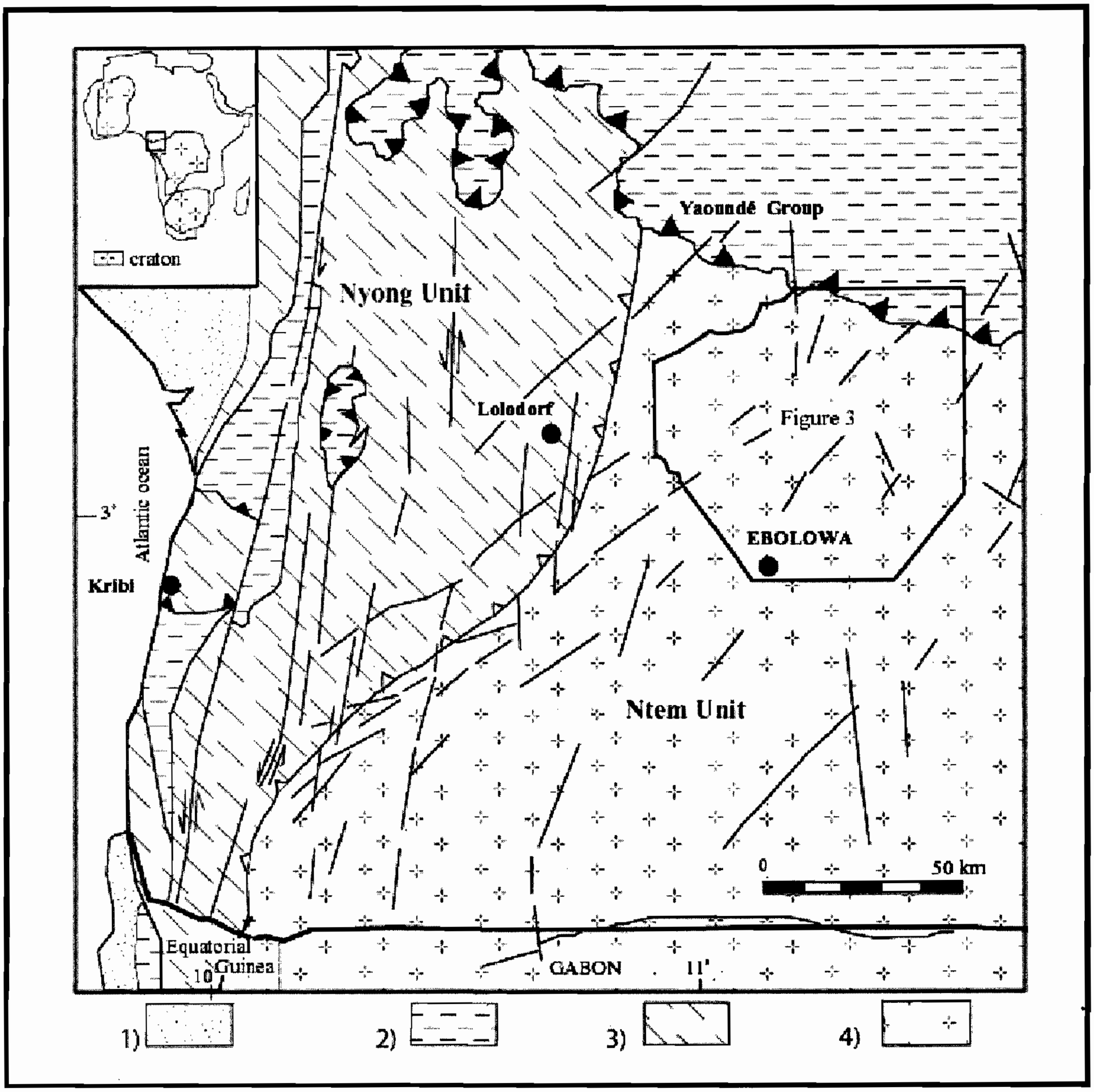


Figure 2. *Schematic map of the Ntem Complex showing the Ebolowa area. 1: Phanerozoic deposits; 2: Pan-African nappes (Yaoundé Group); 3: Palaeoproterozoic Nyong Unit; 4: Archaean Ntem Unit*

grade and occurrence of the greenstone belts as very narrow features associated with charnockitic bodies indicates that the Ntem Unit exposes a deeply eroded segment of Archaean crust.

Petrographically, the Ebolowa greenstone belts display varying proportions of felsic and mafic rocks. Felsic rocks consist of metasediments including arkoses, greywackes, shales, quartzites and banded iron formations. The pelitic units now occur as biotite-sillimanite-bearing gneisses and leptynites composed of quartz + K-feldspar + plagioclase ± garnet ± sillimanite ± biotite ± magnetite. Accessory minerals include zircon, graphite, allanite and monazite. Mafic rocks correspond to a former volcanic sequence and consist of garnet-pyroxene-bearing amphibolites which are composed of plagioclase + hornblende + garnet ± orthopyroxene ± clinopyroxene ± biotite and accessory minerals (magnetite, ilmenite, titanite and quartz). Replacement of high grade minerals by lower grade minerals such as actinolite, biotite, albite and quartz is widespread, particularly to the north near the Pan-African thrust terranes (Yaoundé Group) and to the west in the Nyong Unit, where thermal metamorphism was dated at ca. 2.05 Ga (Toteu et al. 1994; Lerouge et al., 2004).

The greenstone belts and TTG's are characterized by vertical tectonics (foliation, lineation and isoclinal folding) which makes it difficult to reconstruct the original stratigraphical relationships. However, in the field, coarse banding of gneisses, quartzites and garnet amphibolites and their structural features suggest that all greenstone belt rocks may belong to the same sedimentary and volcanic sequence. As already shown, dome- and basin-structures are a fundamental characteristic of many TTG-greenstone terrains (Choukroune et al. 1997). Their structural interpretation is the subject of debate between authors who favour models similar to those in present plate tectonic regimes (lateral accretion, thrusts and tangential tectonics) and those who consider that diapirism and vertical accretion may have been the main crust-formation process in the Archaean. In the Ntem Unit, field data indicate that diapirism played an important part in the evolution of the crust and that significant proportions of the crust may have formed during vertical accretion by magmatic underplating, melting of the lower crust, and the development of gravitational instabilities (Tchameni 1997).

ANALYTICAL TECHNIQUES

Zircons were separated using standard mineral separation techniques. They were split into different size fractions and into fractions of different magnetic susceptibility. Before analysis, zircons were selected under a binocular microscope. Pb-Pb ages were obtained by the single grain evaporation method described by Kober (1986, 1987). The details of the technique are described in Kröner and Hegner (1998). For Sm and Nd analyses, ca 50 to 100 mg of whole-rock powders were spiked with a ^{149}Sm-^{150}Nd tracer prior to dissolution. The samples were digested in Krogh-style Teflon PFA^{R} bombs at 210°C for up to one week. Subsequent to drying down, the samples were treated again with $HClO_4$ to break down fluorides. After complete dissolution was achieved, the samples were dried and redissolved for cation exchange column chemistry. Details of the chemical procedure are described in White and Patchett (1984). Sm and Nd were loaded separately on Re- double filaments and run as metals. All analyses were performed on a Finingan MAT261 mass spectrometer at the Max-Planck-Institut für Chemie in Mainz. Nd isotope ratios were normalized to ^{146}Nd/^{144}Nd = 0.7219. During the course of this work, mean values of ^{143}Nd/^{144}Nd ratios obtained from four analyses of La Jolla standard were 0.511841 ± 16 (2σ). Model ages were calculated using values of present depleted mantle defined by Goldstein et al. (1984): ^{143}Nd/^{144}Nd = 0.5315 and ^{147}Sm/^{144}Nd = 0.217.

RESULTS AND DISCUSSION

In the Ebolowa area (Fig 3), the relationship between charnockites and greenstone belts is quite evident. The greenstone belt rocks, garnet-bearing amphibolites, paragneisses and quartzites, occur as xenoliths, bands, linear bodies of variable thickness, and irregular lenses in the charnockites. The discordance between the charnockite foliation and the strike of the greenstone belt rocks indicates that the deformation, which generated the dominant structures within the greenstone belts, predates the emplacement of the charnockites (Nsifa et al., 1993; Tchameni and Nsifa, 1998). To determine the age of the greenstone belt protholith, two samples of gneiss were dated by the single grain evaporation zircon method of Kober (1986, 1987). Their sources were characterized using Sm-Nd isotopes. The sample location is shown in Figure 3.

Single zircon Pb-Pb ages

Zircons from two samples of garnet- sillimanite-bearing gneiss (S30 Y and TR9237) were analysed. (Table 2 and Fig. 4).

- Sample S30Y: The zircons are transparent, elongate, sub-circular and euhedral grains. Four euhedral grains were wrapped together into the evaporation filament and 72 isotopic ratios (^{207}Pb*/^{206}Pb*) were used to calculate the average age of 3144 ± 3 Ma (Fig. 4a).
- Sample TR9237: The zircons are round to ovoid and euhedral to subhedral grains, a few showing overgrowth structure suggesting partial dissolution that accompanies recrystallization. Two groups of three grains each were evaporated separately. They yield an age of 3088 ± 2 Ma and 3068 ± 3 Ma respectively (Fig. 4b).

It is known that many metamorphic rocks contain zircons that formed during an earlier event and recrystallized during a thermal overprint in a regional metamorphic context or as a result of a magmatic process (e.g. Mezger and Krogstad, 1997). The difference between the ages of the two samples, ca. 79 Ma, indicates different tectono-thermal events prior to the major phase of charnockite formation, that took place around 2.9 Ga. Then, a previous tectono-thermal event may have occurred at ca. 3.1 Ga demonstrated that there are some older source regions in the Ebolowa area.

Rocks with similar ages have been found in the north-

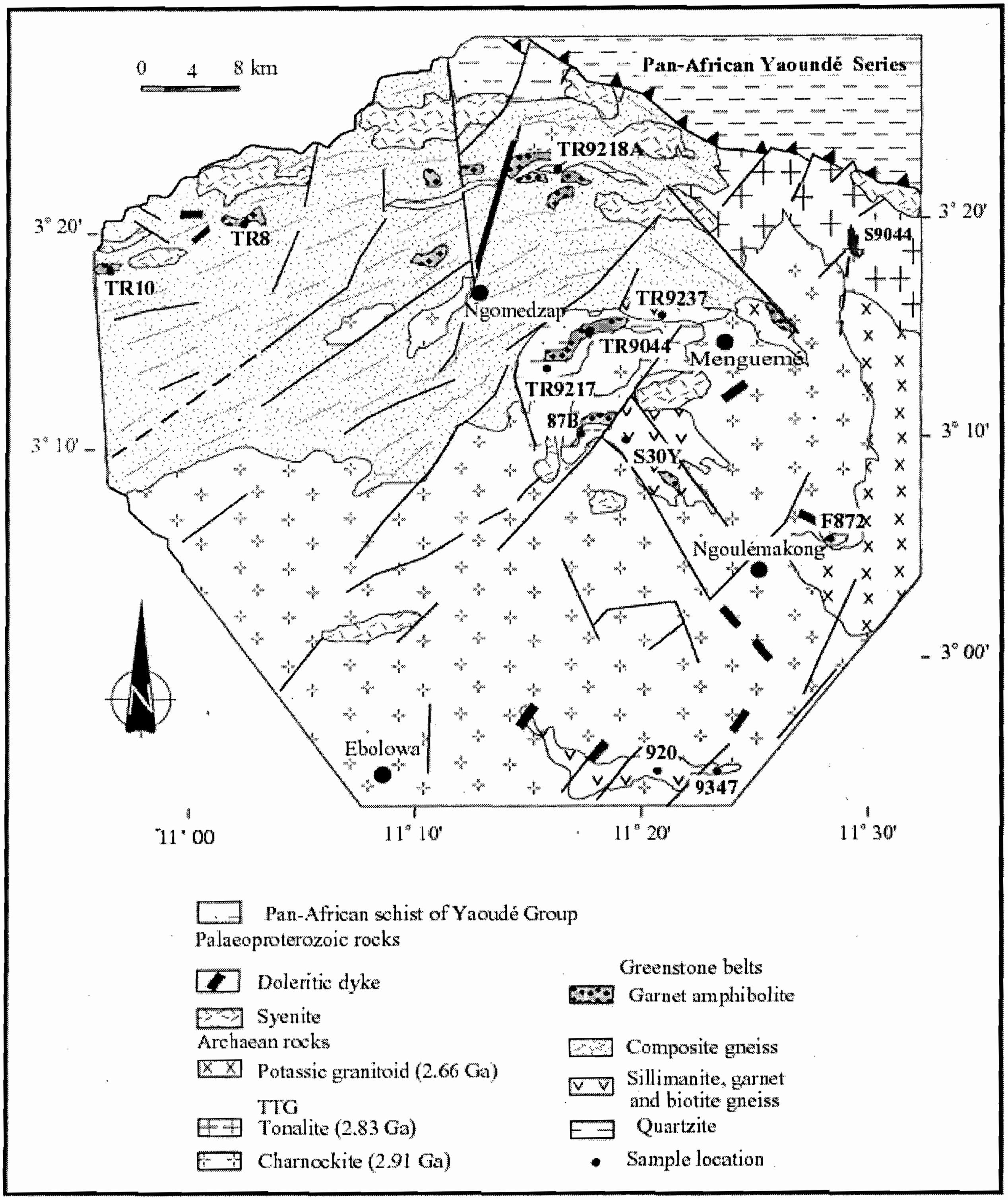


Figure 3. ***Geological map of the Ebolowa area showing location of analysed greenstone belt samples. The ages given for the individual geologic units are taken from the summary in Tchameni (1997).***

western Congo craton (Fig. 1). For example, Rb/Sr ages of 3120 ± 67 and 3091 ± 53 Ma are reported from gneisses and charnockites of Monts de Cristal and an age of 3186 ± 75 Ma is reported from a gneiss of Mitzic in Gabon (Rb-Sr, Caen-Vachette et al. 1988) ; these are interpreted as reflecting a metamorphic event pre-dating the emplacement of the granitoids. However, these data, based only on Rb/Sr isochrons, remain somewhat problematic due to the general problem involved with the interpretation of whole rock isochrons. Mafic material of the Makokou greenstone belts, east of Gabon, was dated at 3091 ± 13 and 2970

Table 2. Zircon Pb-Pb evaporation data for samples S30Y and TR92337.

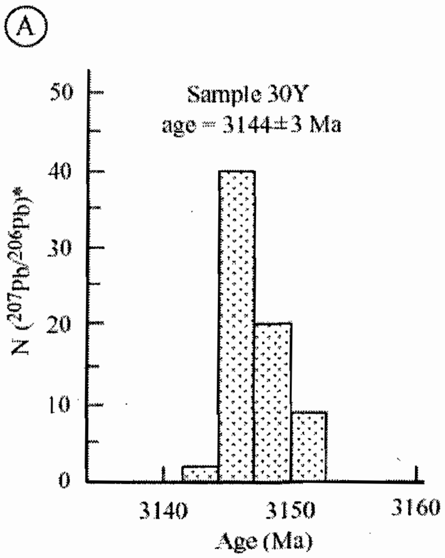
Samples	Zircon morphologies	Number of grains in the filament	Number of scans	T°C	$^{207}Pb/^{206}Pb$ (2σ)	age $^{207}Pb/^{206}Pb$ (2σ)
S30Y	transparent, elongate and euhedral grains	4	72	1597	0.24364 ± 44	3144 ± 3 Ma
TR9237	round to ovoid, subhedral grains	3	72	1598	0.23524 ± 33	3088 ± 2 Ma
	irregular contour and presence of overgrowth structures	3	40	1589	0.23235 ± 49	3068 ± 3 Ma

± 80 Ma (Pb-Pb whole-rock, Caen-Vachette et al. 1988). Granites intruding these belts were dated at 3040 ± 61 Ma (Rb-Sr, Caen-Vachette et al. 1988). However, more precise data have been obtained by the single zircon method from the Massima (south Gabon) greenstone belt granitic rocks namely: 2940 ± 6, 2929 ± 5 and 2928 ± 6 Ma (Guérrot et al. 1994), and from the Chaillu massif granites namely: 2881 ± 19 and 2875 ± 15 Ma (Maurin and Peucat 1998). For the Nzangi gneiss of the Mbomu Complex (NE Congo craton), the age 3005 ± 64 Ma (Lavreau and Ledent 1976; Cahen et al. 1984) is interpreted as an ancient tectono-metamorphic event that led to deformation of the mafic to intermediate gneiss. Younger ages of 2.8 to 2.6 Ga are related to successive granite production and metamorphic imprints.

Sm-Nd whole-rock isotope data

Neodymium isotope results are represented in Table 3. To constraint the source material, we have to date the protolith of the amphibolites, but this age is actually unknown. However in the field, the structural features of the greenstone belt suggest that all the rocks (amphibolites and paragneisses) belong to the same sedimentary and volcanic sequence. Then we use the age of 3.1Ga (the old Pb-Pb age) to calculate the ?Nd values.

It is generally thought that continental crust was differentiated from depleted mantle sources (e.g., DePaolo 1981; McCulloch and Compston 1981; Zhao et al. 1992). T_{DM} reflects the time when continental crust was separated and fractionated from the depleted mantle. The provenance (formation) age of a sediment (T_p) is the time since its source material was originally fractionated in the mantle. If the sediment reaching its depositional site has the same Sm/Nd and epsilon Nd value as its source region, i.e., no REE fractionation has occurred, then $T_p = T_{DM}$. Also, numerous studies (Allègre and Rousseau 1984; Goldstein et al. 1984; McLennan and Taylor 1984; Miller and O'Nions 1984; Dia et al. 1990) have demonstrated



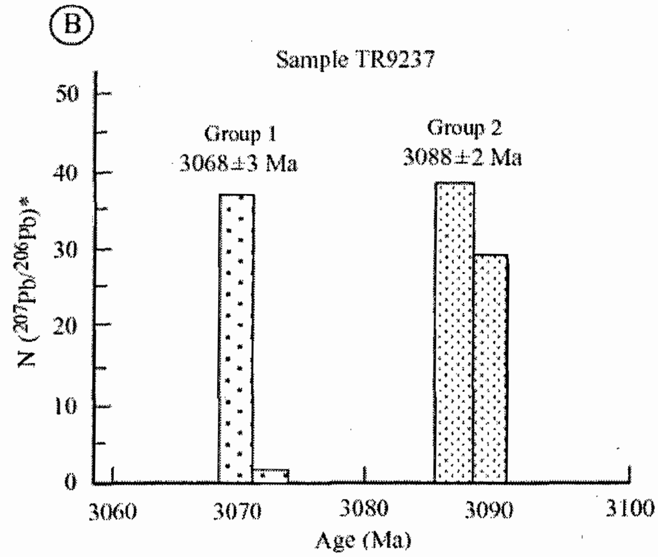


Figure 4. *Histograms showing $^{207}Pb/^{206}Pb$ ratios obtained on single zircons from the metasedimentary rocks (samples S30Y and TR9237)*

Table 3. Sm-Nd isotopic data for Ebolowa whole-rock samples of the greenstone belts. The values of present depleted mantle are from Goldstein et al. (1984)

Samples	Sm (ppm)	Nd (ppm)	$^{143}Nd/^{144}Nd$	2σ	$^{147}Sm/^{144}Nd$	$(^{143}Nd/^{144}Nd)_{3.1}$	εNd_0	$\varepsilon Nd_{3.1Ga}$	T_{DM} (Ga)	$f_{Sm/Nd}$
Metasediments										
TR9218A	2.925	23.56	0.51039	15	0.0750	0.50885	-43.9	4.8	3.03	-0.62
F872	3.160	24.47	0.51040	13	0.0780	0.50880	-43.7	3.8	3.08	-0.60
AN88	2.422	20.08	0.51036	15	0.0729	0.50886	-44.5	5.0	3.02	-0.63
TR9237	8.102	60.73	0.51045	11	0.0806	0.50879	-42.8	3.6	3.09	-0.59
920	6.721	44.96	0.51067	9	0.0903	0.50882	-38.3	4.2	3.05	-0.54
9347	3.002	23.52	0.51038	13	0.0771	0.50880	-44.1	3.7	3.09	-0.61
S30Y	5.614	28.89	0.50945	8	0.0605	0.50821	-62.2	-7.9	3.66	-0.69
TR9217	13.609	76.02	0.51065	67	0.1082	0.50844	-38.7	-3.4	3.60	-0.45
Garnet amphibolites										
S9044	2.959	13.99	0.51137	9	0.1278	0.50875	-24.7	2.8	3.16	-0.35
TR8	5.716	24.43	0.51158	11	0.1414	0.50868	-20.7	1.4	3.32	-0.28
TR10	6.088	25.63	0.51158	13	0.1436	0.50864	-20.7	0.5	3.42	-0.27
87B	4.789	25.37	0.51103	14	0.1141	0.50869	-31.5	1.5	3.25	-0.42
TR9044	5.890	25.49	0.51157	14	0.1397	0.50871	-20.9	1.9	3.26	-0.29

$$\varepsilon Nd_T = (((^{143}Nd/^{144}Nd)_{initial\ sample}/(^{143}Nd/^{144}Nd)_{initial\ CHUR}))-1)x10^4$$

$$T_{DM} = 1/\lambda \ln(((^{143}Nd/^{144}Nd)_{sample} - (^{143}Nd/^{144}Nd)_{DM}) / ((^{147}Sm/^{144}Nd)_{sample} - (^{147}Sm/^{144}Nd)_{DM}) + 1)$$

that sediment Nd-model ages in the Archaean are typically close to their stratigraphic ages.

The metasediments, except for sample TR9217, show an extreme fractionation in their $^{147}Sm/^{144}Nd$ ratios with values as low as 0.06 (Table 2). The average $^{147}Sm/^{144}Nd$ ratio of all the metasediments is 0.08 and thus significantly lower than the average crustal $^{147}Sm/^{144}Nd$ ratio of 0.12 (Taylor and McLennan, 1985) that is also common for most Archaean tonalites and trondhjemites (Henry et al., 2000). Except for samples TR9217 and S30Y, the $\varepsilon Nd_{3.1Ga}$ range from +3.6 to +5.0 and the T_{DM} model ages range between 3.02 Ga and 3.09 Ga. The samples TR9217 and S30Y show an early Archaean T_{DM} age of 3.66 Ga and 3.59 respectively and negative $\varepsilon Nd_{3.1Ga}$ values of –3.4 and –7.9 respectively.

Sample TR9217 has a $^{147}Sm/^{144}Nd$ ratio of 0.11, that is significantly higher than the ratios of the other metasediments (Table 3). This rock has a Nd model age of 3.66 Ga and a negative $\varepsilon Nd_{3.1Ga}$ value of –3.4. This value implies that this paragneiss contains recycled early Archaean material.

The garnet amphibolite samples display high $^{147}Sm/^{144}Nd$ ratios (0.11 - 0.14) and T_{DM} between 3.16 Ga and 3.42 Ga. ε $Nd_{3.1Ga}$ values range from +0.5 to +2.8 with an average value of +1.7. The near chondritic initial Nd isotope composition and the Sm/Nd ratios higher than chondritic values are strong evidence for a crustal pre-history of the amphibolites. Thus, these mafic rocks could have been modified by contamination with older continental material or are themselves reworked material. These chemical and isotopic features provide arguments for the involvement of early to mid-Archaean material in the greenstone belt formation.

Given the Pb-Pb zircon evaporation ages of the metasediments and their field relationships with garnet amphibolites and charnockites, the Sm-Nd system could have been affected by the major Archaean tectono-thermal event at 2.9 Ga and by the post-emplacement events of the K-rich granitoids at ca. 2.7 Ga.

CONCLUSION

All previous geochronological data indicate a long thermal history for the Ntem Unit Cameroon that seems to have begun around 2.9 Ga. No clear evidence of the protolith age of the Archaean greenstone was established from the Ntem Complex; however Pb-Pb zircon ages combined with Nd-isotope systematics on greenstone belt lithologies from the Ebolowa area provide evidence for the existence of Archaean crust at least as old as 3.14 Ga. This early crust was affected by a thermal event and intruded by a charnockitic suite at 2.9 Ga. The following succession of Archaean events is proposed: (i) > 3.1 Ga, early crust providing source rocks for the supracrust, (ii) 3.14 to 3.08 Ga, deposition of the Ntem Unit supracrustals and tectonothermal event, (iii) 2.9 to 2.8 Ga, major accretion with intrusion of suites of syn-tectonic (charnockites) and late-tectonic (tonalite) TTGs, (iv) 2.7 Ga, intracrustal melting and intrusion of calc-alkaline K-rich granitoids.

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