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New Constraints from Pb-Evaporation Zircon Ages of the Méiganga Amphibole-Biotite Gneiss, Central Cameroon, on Proterozoic Crustal Evolution

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Abstract

The amphibole biotite gneiss (ABGn) in the Méiganga area forms part of a meta volcano-sedimentary sequence of the Adamawa Yade domain (AYD), Central African Fold Belt (CAFB). This sequence shows affinity with immature sediments (greywackes, arkoses) with intercalation of mafic lavas or tuffs. New $^{207}Pb/^{206}Pb$ zircon evaporation ages for two ABGn samples range from 1887 - 2339 Ma and from 675 - 889 Ma, respectively. These ages and evidence from internal zircon structures indicate that igneous rocks of Archean to Paleoproterozoic and of early Neoproterozoic age contributed to the detritus of the sedimentary sequence. The deposition of detritus took place prior to 614 - 619 Ma which represent the syntectonic emplacement of the Méiganga metadiorite. Leucogranites north to the Méiganga area were generated by melting of crust identical to that which provided the source of the ABGn. The metasedimentary sequence investigated in this study is similar to that of the southern part of the AYD and in the Borborema Province, NE Brazil. The tectonic and geochronologic characteristics of the AYD in the Méiganga area support the idea that during the Proterozoic, Central Africa and NE Brazil were part of the same continental landmass.

Keywords: Metasediment, $^{207}Pb/^{206}Pb$ Ages, Crustal Evolution, Adamawa Yade Domain, Central African Fold Belt

1. Introduction and Geological Setting

The Adamawa – Yade Domain (AYD) is one of the three main lithostructural units of the Central African Fold Belt (CAFB), defined by [1] using petrographic, structural, and isotopic data in Cameroon and Central Africa Republic (**Figure 1**). These authors considered the AYD as a Paleoproterozoic basement unit that was dismembered during the Pan-African orogeny. In central Cameroon (Adamawa region), the AYD is characterized by Pan-African granitoids intruding Paleo- to Neoproterozoic gneisses which are intensively overprinted by regional-scale transcurrent shear zones [1-3]. The Bafia group to the north of Yaoundé, previously considered as a basement tectonic slice overthrusting the Yaoundé Group [4], is regarded as the southern extension of the AYD in Cameroon. This interpretation is strengthened by the presence of granulite facies assemblages retrogressed during the Pan-African nappe tectonics [5]. A limited number of studies are available about the petrography, deformation history, geochemistry and geochronology of the metasedimentary sequence in the southern part of AYD [5-10]. The AYD of the CAFB has several features in common with its equivalent in NE Brazil, the Brasiliano/Pan-African Borborema Province, including 1) a central position in relation to the sur- rounding cratons [11-13], 2) a network of transcurrent shear zones, and 3) the presence of metasedimentary sequences.

This study presents new zircon evaporation ages as well as geochemical data on amphibole-biotite gneiss (ABGn) from the AYD. The data are used to constrain the protolith age of the gneiss, and add knowledge to the tectonic and geochronological evolution of the AYD in

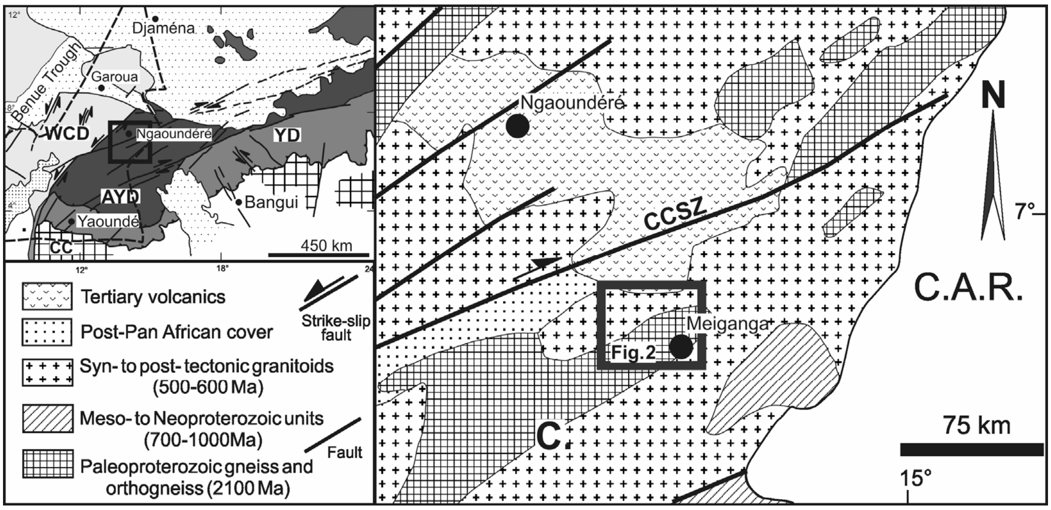

Figure 1. Geological sketch map of of the Méiganga area, East Adamawa. Inset map from [1]. Patterns are as follows: Grids, Congo Craton (CC); dark grey; Adamawa–Yadé Domain (AYD); medium grey, Yaoundé Domain (YD); light grey, West Cameroon Domain (WCD); heavy dots, Cameroon line; light dots, Mesozoic sediments. Square in inset map localizes the large figure. Cameroon (C.), Central Africa Republic (C.A.R.), Central Cameroonian Shear Zone (CCSZ).

central Cameroon during the Proterozoic and its relation to the Borborema Province.

2. Petrography of the ABGn

The ABGn (**Figure 2**) shows compositional banding marked by alternating amphibole-biotite-rich layers and quartzofeldspatic layers. It consists of green hornblende associated with brown-greenish biotite; plagioclase crystals show antiperthitic feldspar clusters, and epidote is formed at the expense of plagioclase. Accessory minerals are apatite, zircon, and titanite. The ABGn contains boudins or continuous bands (0.04 to 2 m thick) of amphibolites with nematoblatic to nematogranoblastic textures. The amphibolites are made up of green hornblende, biotite, plagioclase, quartz and opaque minerals. Accessory minerals are titanite, apatite and zircon, while secondary minerals are chlorite, epidote and calcite.

The ABGn has been affected by four deformational phases. Detailed studies on these phases can be seen in [3,14].

3. Analytical Techniques

Major and trace elements were analysed by X-ray fluorescence (XRF) at the University of Tübingen. Rare-earth elements were analysed by Inductively Coupled Plasma–Atomic Emission Spectrometry (ICP–AES) at the Centre de Recherches Pétrographiques et Géochimiques (CRPG), Vandoeuvre-lès-Nancy, France. Analytical uncertainties are estimated at ±1% for major elements and 5% - 10% for most trace elements.

Zircon grains were separated from 200–63-mm sieved rock fractions by standard separation techniques (milling, wet shaking table, magnetic and heavy liquid separation) and finally handpicked under a binocular microscope. Cathodoluminescence images were performed on an electronic microscope LEO Model 1450 VP (variable pressure) 4-Quadrant BSE-Detector working with an accelerating voltage of 10 kV. For single-zircon Pb evaporation, whole zircon grains were analysed using a double Re filament configuration [15,16]. Principles of the evaporation method are outlined in [10,17].

4. Geochemistry

Results of geochemical analyses on selected ABGn samples are shown in **Table 1**. In the MgO-K_2O-Na_2O diagram (**Figure 3**) of de la Roche [18], the ABGn samples deviate from the magmatic trend and their chemical composition shows affinity with immature detrital sediments like greywacke and arkose whereas the amphibolites have chemical composition similar to basalt. The studied samples show variable ($Na_2O + K_2O + FeO + MgO + TiO_2$) values ranging from 8 to 18 (**Figure 4(a)**, [19]) and molar $Al_2O_3/(MgO+FeO_{tot})$ values between 0.7 and 2.7 **Figure 4(b)**, [20]. These variations may imply the heterogeneity of the protolith of the ABGn, and are in accordance with the conclusion of [3] that the rocks of the ABGn belong to a metavolcanosedimentary sequence. The aluminium saturation index (A/CNK = $[Al_2O_3/(CaO + Na_2O + K_2O)$ mol%]) (**Table 1**) varies from 0.7 to 1.1 and the Mg-number [Mg# = $Mg/(Mg + Fe_{Total})$] from 0.43 to 0.50.

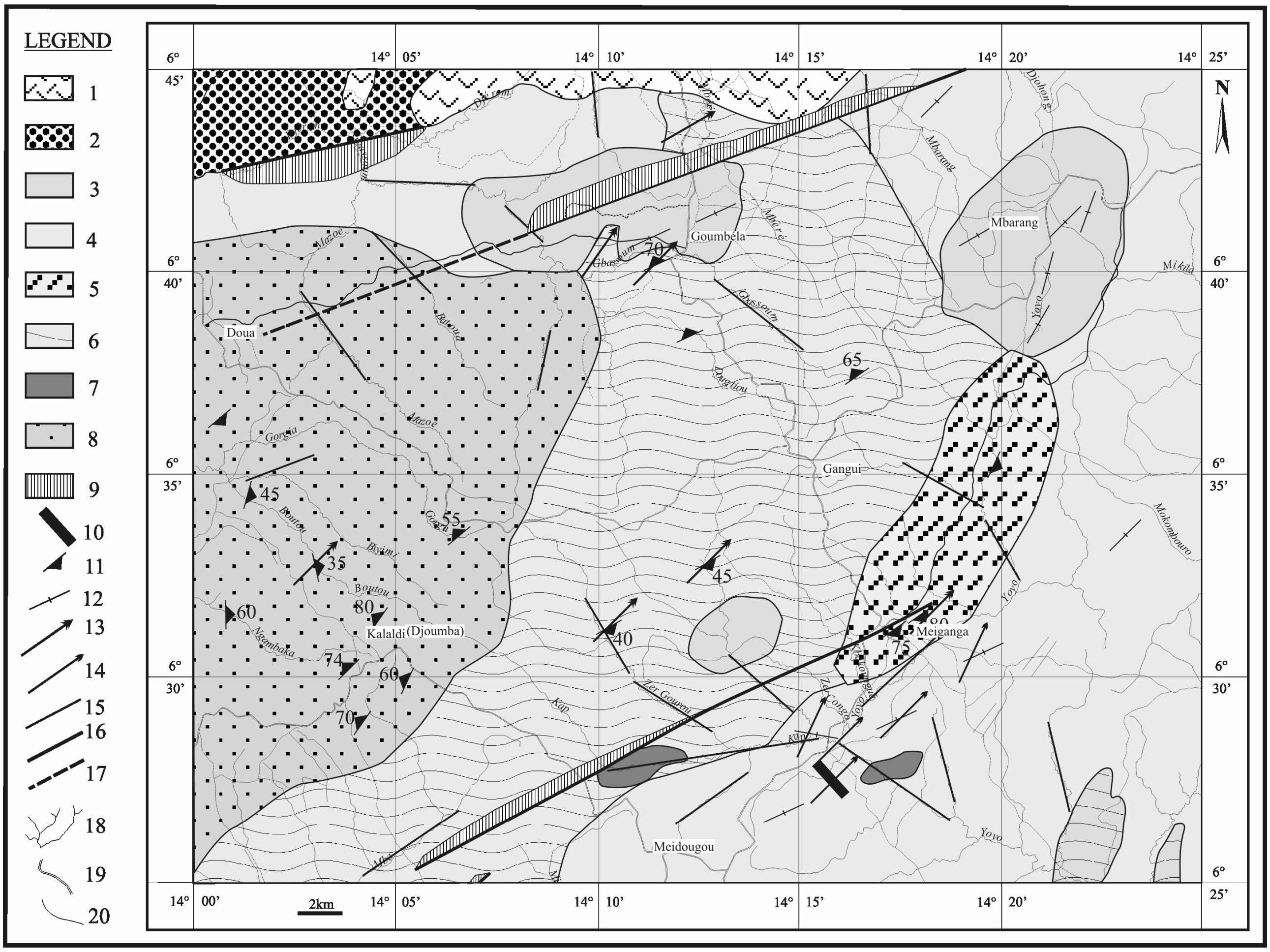

Figure 2. Geological map of Méiganga area showing the distribution of the ABGn. Legend: (1) basalt, (2) conglomerate, (3) biotite–muscovite granite, (4) pyroxene–amphibole–biotite granite, (5) banded amphibolite, (6) amphibole–biotite gneiss (ABGn), (7) amphibolite, (8) pyroxene–amphibole gneiss, (9) mylonite, (10) dolerite, (11, 12) schistosity, (13, 14) lineation, (15) fracture, (16) fault, (17) supposed fault, (18) river, (19) road, (20) path.

5. ^{207}Pb/^{206}Pb Geochronology

Representative zircon grains were studied in two samples (Me5, NY1) of the ABGn (**Figure 5**). Zircon grains of sample Me5 are short and oval in shape with smooth crystal faces. Grain b1 shows a high luminescence rim with truncated oscillatory zoning, surrounding a dark grey core domain. The other grains are dominated by less luminescence domains. Zircon grains from sample NY1 vary in shape. Grains b4 and b5 show dark cores surrounded by homogeneous rims with faint oscillatory zoning. This behaviour is attributed to the differential absorption of contaminants during crystallization [21] or to the effects of deformation during subsequent recrystallization [22]. Grain b3 is made up of a high luminescence rim, free of zonation, and a composite core fragment. This core is similar to the core of grain b1. Zircon grains portraying truncation of oscillatory zoning or regions with fading oscillatory zoning are typical of magmatic zircons modified by high-grade metamorphism [23]. **Table 2** shows the analytical data obtained from evaporation of representative zircon grains of samples Me5 and NY1. In the first sample, U/Th ratios (1.2 - 2.9) decrease with increasing evaporation temperatures. The ^{207}Pb/^{206}Pb ages are Neoproterozoic, and increase with increasing evaporation temperature from 675 ± 7 Ma to 889 ± 2 Ma. Sample NY1 portrays U/Th ratios of 2.0 to 5.8, decreasing with increasing evaporation temperature. The ^{207}Pb/^{206}Pb ages of NY1 vary from 1888 ± 2 Ma to 2339 ± 3 Ma. High U/Th ratios of the two ABGn samples indicate that the zircons were derived by erosion of an igneous protoliths [24]. The ABGn was affected by the same metamorphic event as the metadiorite of the Méignanga area which was dated at 614 - 619 Ma [3]. It is likely that the deposition age is therefore older than 619 Ma. The youngest age (675 Ma) of sample Me5

Table 1. Geochemical composition of the amphibole-biotite gneiss from the Méiganga area. (b.d.l. = below detection limit).

Samples	NY2	Me5	Me7	PNg2	Moo	ZBo-1
SiO_2	58.25	61.66	59.41	74.88	67.88	63.12
TiO_2	0.75	0.48	0.92	0.294	0.50	0.63
Al_2O_3	15.23	20.07	16.12	12.90	15.45	15.44
Fe_2O_3	8.54	3.18	7.23	2.16	4.24	6.36
MnO	0.12	0.04	0.12	0.03	0.07	0.1
MgO	3.80	1.20	3.59	0.76	1.68	2.81
CaO	7.33	2.76	5.69	2.77	3.59	5.33
Na_2O	3.72	4.21	3.35	3.91	4.59	4.18
K_2O	1.75	6.33	2.59	1.12	1.80	1.32
P_2O_5	0.28	0.22	0.26	0.06	0.12	0.18
LOI	0.73	0.75	0.92	0.38	0.64	0.67
Sum	100.75	101.47	100.48	99.43	100.81	100.32
$Na_2O + K_2O$	6.71	10.54	5.94	5.02	6.39	5.50
Na_2O/K_2O	4.25	0.66	1.29	3.50	2.54	3.17
A/CNK	0.7	1.1	0.9	1.0	1.0	0.9
Mg#	0.47	0.43	0.50	0.41	0.44	0.47
Ba	907.4	3362	984.3	730.4	1190.5	616.5
Co	49.99	31.6	41.5	58.1	13	20.6
Cr	92.46	106.6	164	93.4	90.6	51.7
Ni	44.82	53	70.5	27.9	50.9	40.2
Rb	41.6	114.7	78.9	18.8	45.7	24.9
Sr	546.5	853.7	558.6	549.4	524.3	591.3
V	143.7	40.98	146.5	25.5	63.5	123.7
Y	34.44	5.93	26.8	b.d.l.	12.3	15.2
Zn	72.41	56.84	77.6	b.d.l.	48.5	58.4
Zr	229.2	534.6	187.3	184.4	227.5	148.4
K	14543	52970	21500	9264	14967	10957
La	109.2	54.29	42.7	30	63.2	53.9
Ce	203.7	100.7	74.5	b.d.l.	102.1	59.5
Pr	22.06	11.13				

Nd	78.16	39.92	38.7	9.7	34.2	28.8
Sm	12.17	5.65	3.7	b.d.l.	6.3	5.1
Eu	2.62	1.37	1.5	1.2	1.6	1.7
Gd	8.70	3.11				
Tb	1.21	0.34				
Dy	6.53	1.41				
Ho	1.12	0.22				
Er	3.34	0.57				
Tm	0.47	0.08				
Yb	3.02	0.55	2.3	0.2	0.7	1.2
Lu	0.45	0.10				
Hf	5.28	10.04				
Ta	0.56	0.32				
W	248.2	202.3				
Pb	13.79	38.98				
Th	13.38	9.34	8.4	3	14	1.1
U	0.71	0.26	b.d.l.	6.4	4.9	1.7
Nb	28.56	2.93	b.d.l.	b.d.l.	b.d.l.	b.d.l.
Be	2.70	1.37				
Cs	0.36	1.17				
Cu	8.04	79.72				
Ga	21.45	22.02				
Ge	1.51	0.96				
Mo	1.51	1.24				
Sn	1.86	1.02				
∑REE	487.27	225.38				
K/Rb	373.25	458.33	272.49	492.76	327.50	440.05
Rb/Sr	0.04	0.13	0.14	0.03	0.09	0.04
Th/U	21.50	35.39		0.47	2.86	0.65
Sr/Y	15.87	143.87	20.84		42.63	38.90
La_N/Yb_N	24.55	67.30	24.55			
Eu/Eu*	0.75	0.96	0.75			

Table 2. Zircon evaporation data including radiogenic $^{207}Pb/^{206}Pb$ ratios and corresponding $^{207}Pb/^{206}Pb$ ages for samples Me5 and NY1.

Sample and zircon number (a,b,c,d,e = Temp. Step)	Evap. Temp ˚C	No. of ratios	U/Th ratio	$^{206}Pb/^{208}Pb$ ratio	$^{204}Pb/^{206}Pb$ ratio	$^{207}Pb/^{206}Pb$ isotope ratio	$^{207}Pb/^{206}Pb$ age (Ma) 2σ error
Me5-1a	1380	114	2.60	8.64	0.000102	0.064825 ± 127	768.7 ± 4.1
Me5-1b	1400	114	1.53	5.00	0.000050	0.068293 ± 106	877.5 ± 3.3
Me5-1c	1420	114	1.49	4.87	0.000041	0.068362 ± 097	879.6 ± 2.9
Me5-3a	1400	113	1.57	5.22	0.000202	0.063386 ± 099	721.3 ± 3.3
Me5-3b	1420	112	1.30	4.27	0.000105	0.066173 ± 096	811.9 ± 3.0
Me5-3c	1440	112	1.20	3.94	0.000101	0.067232 ± 108	845.0 ± 3.4
Me5-4a	1400	110	2.32	8.00	0.000249	0.063961 ±195	740.4 ± 6.5
Me5-4b	1420	111	1.27	4.19	0.000139	0.067693 ± 130	859.2 ± 4.0
Me5-4c	1440	108	1.14	3.72	0.000088	0.068612 ± 217	887.1 ± 6.6
Me5-5a	1400	114	1.92	6.26	0.000060	0.064358 ± 132	753.5 ± 4.3
Me5-5b	1420	107	1.59	5.21	0.000060	0.066254 ± 195	814.4 ± 6.2
Me5-5c	1440	114	1.35	4.41	0.000048	0.068689 ± 075	889.4 ± 2.3
Me5-6a	1420	98	2.94	9.87	0.000131	0.062028 ± 201	675.1 ± 7.0
Me5-6b	1440	109	1.44	4.72	0.000106	0.066721 ± 196	829.1 ± 6.2
NY1-1a	1410	113	3.36	11.52	0.000042	0.124573 ± 147	2022.8 ± 2.1
NY1-1b	1440	114	3.28	11.15	0.000013	0.130093 ± 066	2099.3 ± 0.9
NY1-1c	1470	114	2.04	6.97	0.000013	0.149428 ± 229	2339.4 ± 2.6
NY1-2a	1430	103	5.77	19.85	0.000028	0.121856 ± 116	1983.7 ± 1.7
NY1-2b	1460	81	5.08	17.44	0.000028	0.122150 ± 127	1988.0 ± 1.9
NY1-2b	1460	30	5.08	17.44	0.000028	0.123358 ± 125	2005.5 ± 1.8
NY1-4a	1430	114	2.02	6.87	0.000028	0.134196 ± 109	2153.7 ± 1.4
NY1-4b	1460	109	1.88	6.43	0.000028	0.143420 ± 210	2269.0 ± 2.5
NY1-4c	1490	114	1.82	6.24	0.000028	0.147719 ±147	2319.7 ± 1.7
NY1-5a	1430	107	4.28	15.76	0.000174	0.115491 ± 133	1887.6 ± 2.1
NY1-5b	1460	105	3.74	12.78	0.000030	0.119954 ± 177	1955.6 ± 2.6
NY1-5c	1490	107	4.29	15.82	0.000174	0.120504 ± 171	1963.8 ± 2.5

could be a post-depositional metamorphic age or a mixing age between pre-depositional and post-depositional zircon domains. It seems most likely to us, that this age post-dates the deposition of the sediments.

6. Discussion

6.1. Age and Provenance of the Protolith

Geochemical characteristics of the studied samples show that the ABGn comes from a sedimentary sequence whereas the protolith of the intercalated amphibolites was igneous, probably representing mafic lava, or tuff. Thus, it is likely that the whole complex represents an ancient volcano-sedimentary sequence. The ABGn shows affinity with detrital immature sediments (**Figure 3**), indicating that the detritus was transported only over a short distance. These sedimentary deposits were probably formed during alternate phases of volcanic activity. The zircon crystals of the ABGn show relics of magmatic structures (truncated and faint oscillatory zoning) and their U/Th content also militates for a magmatic ori-

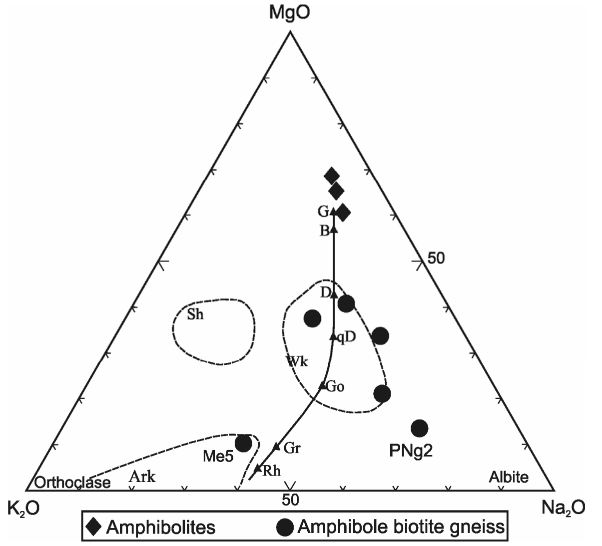

Figure 3. Geochemical characteristics of the samples from the ABGn (this study) and amphibolites [3] in the MgO-K_2O-Na_2O diagram [18]. Solid line shows the compositional trend of plutonic rocks with rhyolite (Rh), granite (Gr), granodiorite (Go), quartz diorite (qD), diorite (D) basalt (B), gabbro (G). Dashed contours delimit the field of shales (Sh), greywackes (WK), and arkoses (Ark).

gin. The $^{207}Pb/^{206}Pb$ zircon evaporation ages obtained for ABGn sample NY1 (1887 - 2339 Ma) fit in the range of those reported by Ganwa *et al.* [17] for the neighbouring pyroxene amphibole gneiss (1685-2602 Ma). The oldest age (2339 Ma) of sample NY1 could be interpreted as a mixing age of Paleoproterozoic and Archean zircon domains; this is strengthened by the presence of dark cores in some zircon crystals (**Figure 5**). It seems possible that erosion of the pyroxene amphibole gneiss provided detritus for the sedimentary sequence of the ABGn. Zircon ages obtained from sample Me5 (675 - 889 Ma) indicate that early Neoproterozoic plutonic rocks also contributed to the detritus of the sedimentary sequence. The metasedimentary sequence of the southern AYD was derived by erosion of Mesoproterozoic (1617 Ma) to Paleoproterozoic (2289 - 2351 Ma) plutonic rocks [9,10]. Zircon grains of samples Me5 and NY1 yield ages in the same range as those of a two mica granite (sample Man and Mi, **Figure 6**) north of the study area [3,14]. It is likely that this Neoproterozoic leucogranite was formed by melting of the crustal material similar to the inferred protolith of the ABGn. Leucogranites generated by melting of Paleoproterozoic crustal rocks have been also described in the Serrinha–Pedro Velho Complex (Borborema Pro-

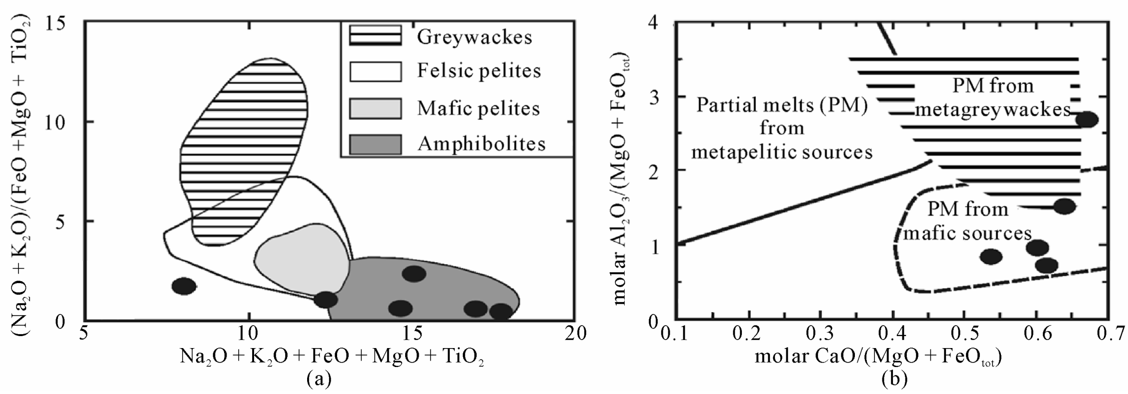

Figure 4. Geochemical characteristic of the ABGn in (a) the ($Na_2O + K_2O + FeO + MgO + TiO_2$) vs (($Na_2O + K_2O$)/(FeO + MgO + TiO_2)) [18] and (b) molar CaO/(MgO+FeO_{tot}) vs molar Al_2O_3/(MgO + FeO_{tot}) [19] diagrams. One sample has a molar CaO/(MgO + FeOtot) of 1.0 and is not shown in the diagram.

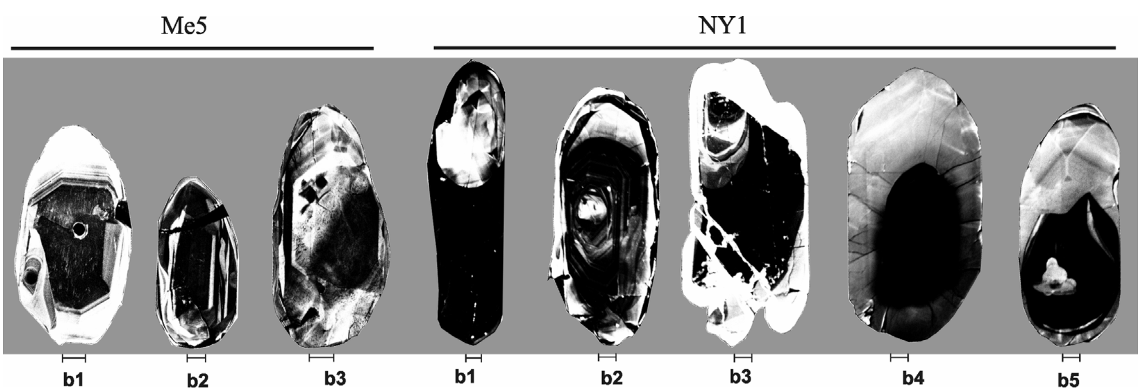

Figure 5. Cathodoluminescence images of representative zircon crystals from the ABGn.

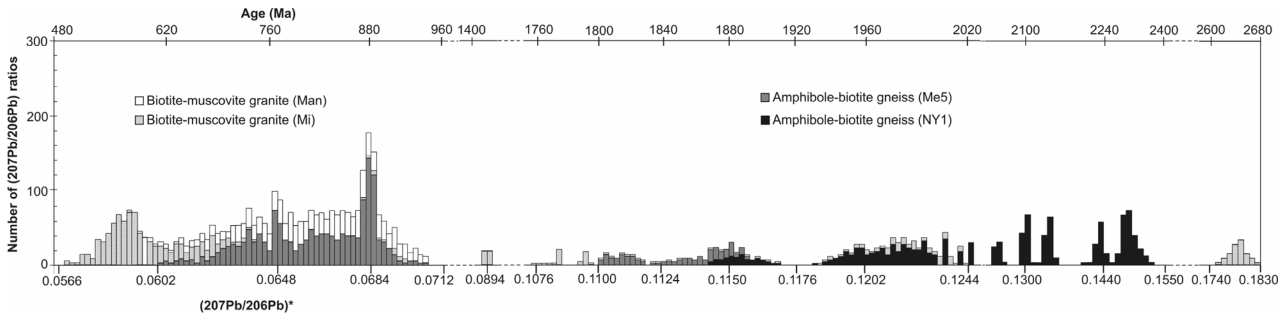

Figure 6. Histogram showing the distribution of radiogenic $^{207}Pb/^{206}Pb$ ratios obtained from evaporation of zircons from ABGn (samples Me5, NY1).

vince, NE Brazil; [25]).

6.2. Deposition Age and Evolution of the ABGn

The ABGn shows the same solid state deformation as syntectonic diorite plutons for which emplacement ages between 614 and 619 Ma were obtained [3]. It appears that the age of metamorphism in the Méiganga area is Neoproterozoic. Therefore, sedimentation must have started prior to 619 Ma with episodes of volcanic activity. After this period, the basin and the whole region was subjected to a regional solid state transformation with four deformational phases [3]. The D1 deformational phase is present only in the ABGn whilst the D2 deformational phase, which is the major deformational phase in the AYD, is present both in the ABGn and the metadiorite.

6.3. Comparison with the Borborema Province, NE Brazil

A common feature between the CAFB and the Brasiliano/Pan-African Borborema province is the occurrence of metasediments outcropping in their central domain. In the Borborema province, metasediments are found in the Cachoeirinha, Alto Pajeú, Alto Moxotó and East Pernambuco belts. They consist of metapelites, metagreywackes and associated bimodal volcanic rocks, which were metamorphosed under variable conditions [26,27]. As for the CAFB, Neoproterozoic depositional ages (660 - 620 Ma) were determined for the metasediments in the Borborema province [26,27]. Like in the AYD, the detritus of the metasedimentary sequences in the Borborema province was derived from Archean to Neoproterozoic sources. Zircon ages up to 3275 Ma have been reported for a quartzite sample from the Cachoeirinha belt [28]. Similarly, a metasedimentary complex in the AltoMoxotó belt yielded Sm-Nd ages varying from 2.0 to 3.0 Ga [29]. In the East Pernambuco belt, U-Pb data for detrital zircons from paragneiss exhibit ages ranging from 3320 to 665 Ma [30].

7. Conclusions

Based on the present findings and relevant previous studies [3,14,16], the tectonic and geochronologic evolution of the AYD in the Méiganga area can be summarized as follows: 1) 2.1 - 1.8 Ga – formation of Paleoproterozoic juvenile crust, 2) 889 - 675 Ma – generation and emplacement of early Neoproterozoic granitic melts, 3) > 619 Ma – erosion, transportation and deposition of the detritus of the former magmatic rocks accompanied by episodes of volcanism, 4) 619 - 614 Ma – syntectonic magmatism and metamorphism of the sedimentary sequence, 5) 601 - 558 Ma – intrusion of late to post-tectonic granites.

The evolution summarized above is closely linked to that of the Borborema province, NE Brazil [29]. Furthermore, the existence of Archean zircon inheritances in both Central Cameroon and NE Brazil [17,29,31-35] suggests that these two regions share a similar geological history since the Paleoproterozoic.

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