

Mineral chemistry of intergrown rutile-garnet, and U-Pb dating of rutile from Medoumou-Ebol area, Central Cameroon: Provenance, age and Pan-African P-T metamorphic conditions of the protoliths

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Research Article

Keywords: Rutile-garnet intergrowth, metapelitic source, U-Pb age, P-T conditions, Pan-African Yaoundé group

Posted Date: September 9th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10951545/v1>

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Additional Declarations: The authors declare no competing interests.

1 **TITLE PAGE**

2 **Mineral chemistry of intergrown rutile-garnet, and U-Pb dating of rutile from Medoumou-Ebol area,**
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Mineral chemistry of intergrown rutile-garnet, and U-Pb dating of rutile from Medoumou-Ebol area, Central Cameroon: Provenance, age and Pan-african P-T metamorphic conditions of the protoliths.

ABSTRACT

This paper deals with electron probe microanalyses (EPMA) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) chemistry of intergrown rutile-garnet, and U-Pb LA-ICP-MS dating of rutile crystals from alluvial concentrates of the Medoumou-Ebol area in Cameroon, in view to assess P-T crystallisation conditions, age and provenance. The bedrock of the alluvia is a rutile bearing micaschist. U-Pb ages (601-525 Ma) of rutile comprise three growth episodes (588 ± 27 Ma, 549 ± 12 Ma, 518 ± 11 Ma). The last episode younger than that provided by zircon (ca 550 Ma) in previous works is attributable to the time interval between the closure temperatures of the zircon and rutile U-Pb systems ($> 900^\circ\text{C}$ and 600°C , respectively). Both EPMA and LA-ICP-MS data of rutile show high TiO_2 (97.5-100 and 97.1-98.5 wt.%, respectively) and Nb, Ta, Cr, V and Sn contents. Rutile Cr-Nb contents point to a metapelitic source which is consistent with the upstream micaschists and gneiss. The large range of Nb/Ta values (13.4-27.6) in rutile is typical of metamorphic origin. Garnet is a grossular and spessartine-rich almandine ($\text{Alm}_{60.3-68.5}\text{Gr}_{15-23}\text{Sp}_{7.8-8.2}\text{Py}_{4.5-10}\text{And}_{0.7-1.5}\text{Uv}_{0.18}$). Chlorite inclusion in rutile is Fe-rich chamosite. Microtextures have preserved stages of prograde (chlorite inclusion in rutile) and high-grade metamorphism (intergrown rutile-garnet) where the P-T conditions are 10.11-10.37 kbar, and 601-507°C, corresponding to the upper-amphibolite facies.

Key words: Rutile-garnet intergrowth, metapelitic source, U-Pb age, P-T conditions, Pan-African Yaoundé group

Introduction

During crystallisation, rutile incorporates several trace elements especially high-field strength elements (HFSE), such as U, Zr, Hf, Nb, W, Ta, which can be used in U-Pb dating, and also in the characterization of the provenance (Zack et al., 2004a, b). It also encloses other minerals such as apatite, ilmenite and zircon, the study of which helps to characterize rutile and gain insights into its origin. Rutile occurrences are common in low- to high-grade metamorphic rocks of the Pan-African Yaoundé Group (Bessoles and Trompette, 1980; Toteu et al., 2022; Knudsen et al., 2013; Nkoumbou et al., 2014; Tchakounté et al., 2017; Fuh et al., 2021a; Kundu et al.,

2022) located north of the Congo craton. In these mica schists and gneiss, rutile is incidental (e.g. Nzenti et al., 1988 ; Mvondo et al., 2003 ; Yonta et al., 2009 ; Nkoumbou et al., 2006a, 2006b, 2014). The hardness (6-6.5), high density (4.2-5.6 g/cm³) and resistance to chemical alteration of rutile facilitate its concentration in unconsolidated lithified clastic sediments. Detrital rutile occurrences are abundant in the Pan-African Yaoundé group. Several authors have studied this alluvial rutile in order to understand its chemistry, geochronology, and geothermometry. Stendal et al., (2006) studied geochemistry, thermometry, fluid inclusions and Pb isotopes of alluvial and eluvial rutile, and concluded that alluvial and eluvial rutile derived from metapelites, metamafic rocks and pegmatites formed during the Pan-African metamorphism. Knudsen et al., (2013) analyzed the chemical compositions of detrital rutile of the Yaoundé group and calculated the crystallisation temperatures that range from 400 to 900° C. They noticed that the temperatures of detrital rutile correlate well with the grades of the local metamorphic rocks. Morphological and geochemical data on both *in-rock* and detrital rutile provided evidences on the provenance and the crystallisation temperatures (Ngo Bidjeck et al., 2020) while U-Pb ages evidenced five main rutile growth events at 719 ± 32 Ma, 661 ± 21 Ma, 630 ± 6 Ma, $613-590 \pm 9$ Ma, and 561 ± 8 Ma in the Yaounde Group (Binely Betsi et al., 2020). All research works carried out so far on rutile in alluvium west and east of Yaoundé mainly focussed on mineral chemistry and U-Pb dating of the ore (e.g. Stendal et al., 2006; Knudsen et al., 2013; Tonje et al., 2014; Ngo Bidjeck et al., 2020 ; Bineli et al., 2020). Consequently, the question of the primary deposits or source rocks of alluvial rutile arises. While primary rutile deposits in Cameroon is yet to be discovered, this paper deals with mineral chemistry of interpenetrated rutile and garnet, and U-Pb dating of rutile crystals from placer concentrates and stream beds of the Medoumou-Ebol area located west of Akonolinga in Cameroon (figure 1a). They are studied using petrography, electron probe microanalyser (EPMA), LA-ICP-MS and U-Pb LA-ICP-MS in view to assess crystallisation P-T conditions, the provenance and the age. New findings reported here are the metamorphic events registered in each single rutile crystal with inferences on the geodynamic evolution of the Pan-African Yaoundé group.

1. Geological setting

Rutile occurrences in Cameroon are located in the formations of the Pan-African Yaoundé group (PYG) also known as Southern Pan-African domain (Fig. 1a). The current state of knowledge on the group is presented here based on the results of chronostratigraphic research works (e.g. Nkoumbou et al., 2014, 2017; Fuh et al., 2021a, b; Tchakounté et al., 2021; Kundu et al., 2022). It has been demonstrated from boreholes' results that carbonatic and pelitic formations known as the Mintom Formation rest unconformably on the Archean

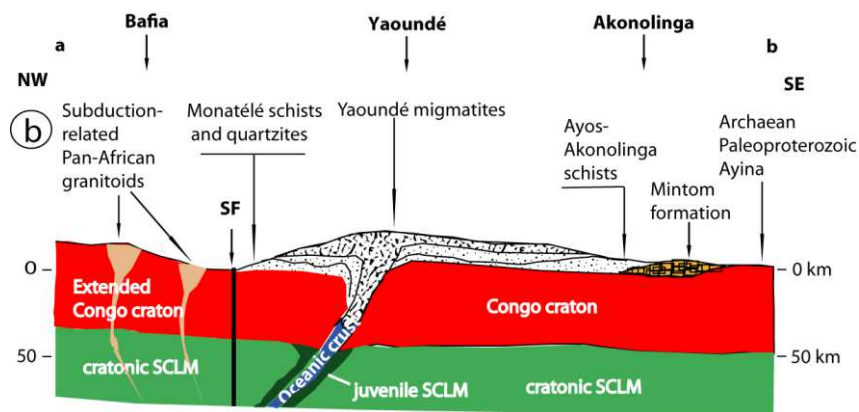
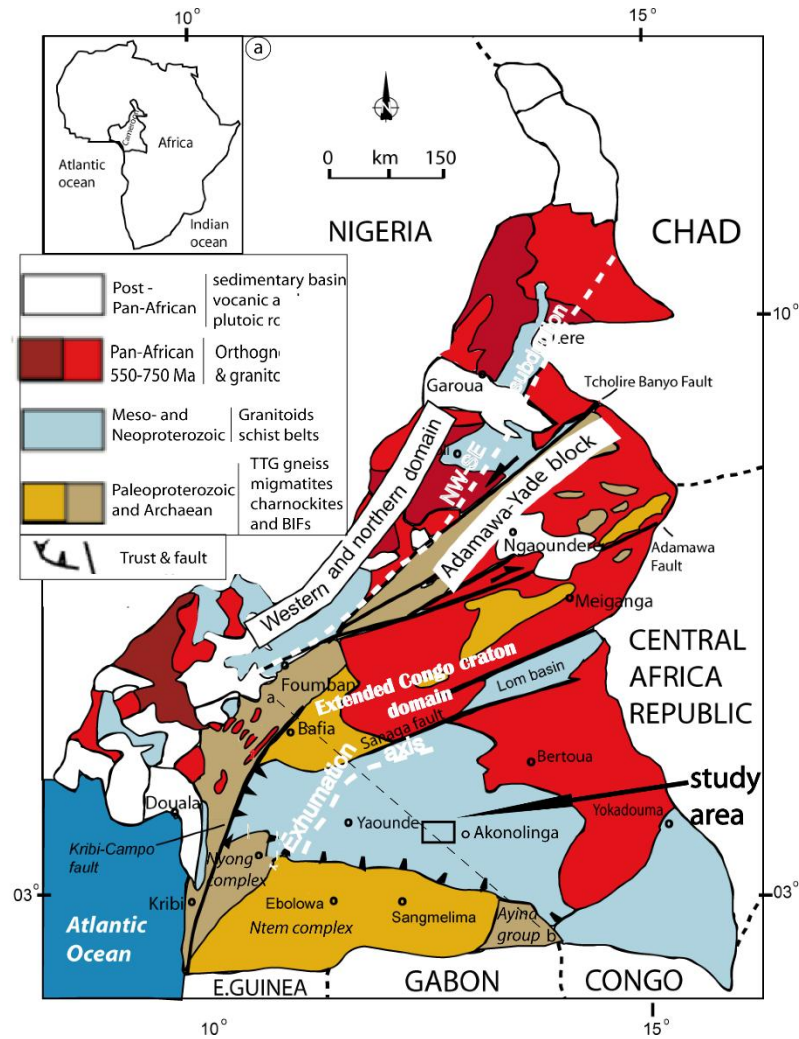


Fig. 1: a) Geological map of Cameroon (modified from Donkeng et al., 2025) showing the Medoumou-Ebol area. Insert: location of Cameroon in Africa, b) Sketch cross section showing the Pan-African nappes of the Yaoundé group piling on the Congo craton. Oceanization and subsequent subduction are evidenced by numerous ophiolite occurrences (Nkoumbou et al., 2006a, b, 2008a, b, 2009, 2014; Kundu et al., 2022). The NW-deeping subduction plane is consistent with the subduction-related granitoids around Bafia (see Tchakounté et al., 2021). Migmatite exhumation is evidenced by many research works (Mvondo et al., 2003; Fuh et al., 2021b; Kundu et al., 2022). SF: Sanaga fault; Bafia, Yaoundé and Akonolinga are displayed by orthogonal projection on the cross section line. The section is not at the scale

formations of the Ntem complex (Caron et al., 2010, 2011) before being overthrust in turn by the Mbalmayo-Ayos-Bengbis schists (Nédélec et al., 2006). West of the Mbalmayo-Ayos-Bengbis schists, the Yaoundé series correspond to the core of the PYG. This series is made up of high-grade migmatitic gneisses comprising metasedimentary and meta-igneous units (P-T conditions up to 750-800 °C, 10-12 kbar, Nzenti et al., 1988; Owona et al., 2011). The tectonic evolution can be summarized as the superposition of two main deformation events (Mvondo et al., 2003): a first phase (D1) that consisted of E-W to NW-SE shortening accompanied of crustal thickening by nappe stacking; it was overprinted by a second phase (D2) that led to a generalized N-S and E-W extension with the exhumation of the Yaoundé migmatitic gneisses and orogenic collapse. Exhumation led to the thrusting of these migmatite nappes on the Mbalmayo-Ayos-Bengbis schists at east and on the Boumnyebel series at West (Fig. 1b). The latter consists of metasedimentary (mica schists, minor calc-silicate rocks and marbles) and meta-igneous rocks (hornblende gneiss, amphibolites, metagabbros, pyroxenites, serpentinites, chlorite schists and talc schists). The peak metamorphism (~650 °C/9.5 kbar; ca 620 Ma) postdated the nappe emplacement (Yonta et al., 2009). The question concerning the northern limit of the Yaoundé group merits a clarification here. Former reviews of the geology of Cameroon included the Adamawa plateau in the Pan-African domains (e.g. Toteu et al., 2004 ; Ngako and Njonfang, 2011). Recent studies highlight that the Adamawa plateau is made up of Archean granulitic TTG (Nkoumbou et al., 2014, 2017; Tchakounté et al., 2017) intruded by Neoproterozoic granitoids (e.g. Ngamy et al., 2019 ; Tchakounté et al., 2021) and covered by discordant Pan-African meta-sedimentary silica-rich micaschists and quartzites displaying flat-lying schistosity (Nkoumbou et al., 2017). Many other geochronological results (e.g. Ganwa et al., 2008; Tchakounté et al., 2017; Assomo Ngono et al., 2021) show that the Adamawa-Yade is an Archean-Paleoproterozoic block. The new geological map of Cameroon on 1 :500.000 scale (Vic et al., 2025) shows that the Congo craton extends northwards up to Ngoro-Belabo shear zone, under the Pan-African Yaoundé group. The geological setting is summarized in figure 1b. Most rutile occurrences known are located in the PYG (see figure 4 in Knudsen et al., 2013 and figure 4 in Vic et al., 2025). The Medoumou-Ebol area belongs to the eastern rutile district of the PYG. Muscovite-biotite-garnet micaschists of Ayos-Akonolinga are the country rocks of detrital rutile there.

2. Materials and analytical methods

2.1. Sampling methods

Based on preliminary pre-selection of points on a map of the area and field criteria, eighteen sediment samples were collected from the active stream channels (0-20 cm depth) and from pits dug at the meanders of rivers and on placers (Fig. 2).

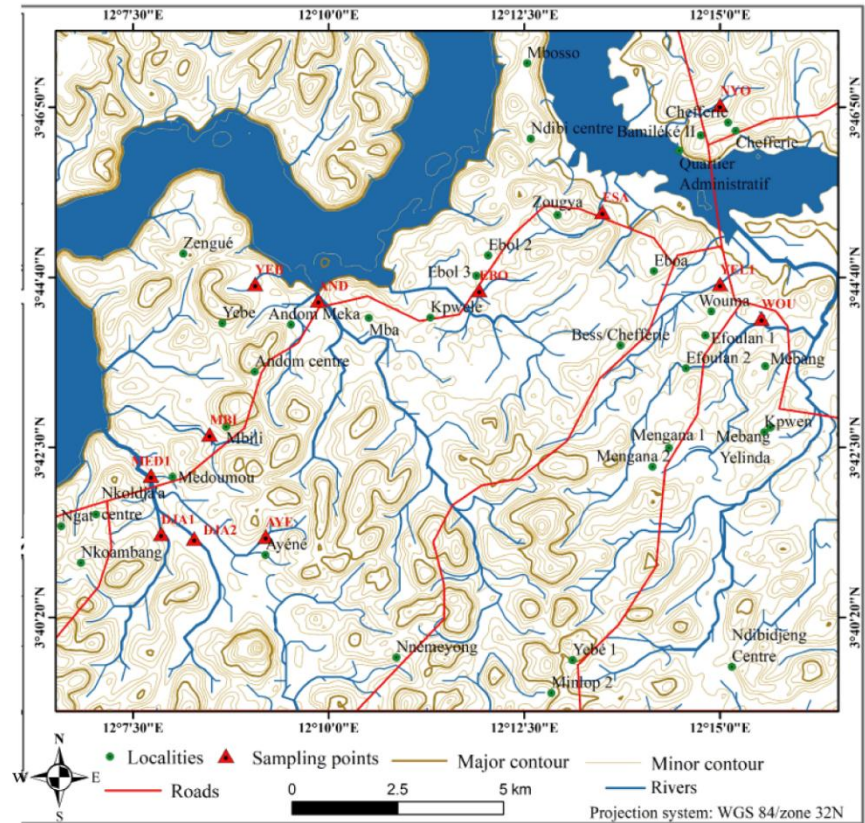


Fig. 2: Sampling map of the Medoumou-Ebol area. The river Nyong (in blue) with numerous meanders that favours rutile concentration in the alluvia

2.2. Analytical methods

2.2.1. Sample preparation and analysis criteria

The powders of heavy mineral concentrates from 12 samples were carefully prepared and sent for chemical analysis to ALS Geochemistry laboratory (South Africa). There, chemical analyses of the major elements were performed using Inductively Coupled Plasma Atomic Spectrometry (ICP-AES) ; the concentrations of rare earths and other trace elements were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Rutile and garnet grains were selected for mineral chemistry analyses by EPMA (oxides) and laser ablation (LA ICP-MS) for trace elements and U-Pb dating at Beijing GeoAnalysis Technology Co., Ltd, Beijing, China. The selections of crystals and analyses spots were based on criteria such as the shape, size and structure of the crystals observed under the microscope. Slightly blunt crystals with straight edges and sharp angles were chosen to

represent crystals from proximal source. The blunt crystals with fairly curved angles, attributable to distal sources, were chosen. In addition, crystals with rutile appearing as veinlet or as patches in the garnet were chosen because they could provide information on the petrogenetic conditions. Spots were made on apparently healthy crystals without defects, with the aim to follow possible core-rim variations of the chemical compositions.

2.2.2. Rutile EPMA method description

Twenty-four analyses of in-situ major elements of rutile and four garnet analyses were completed by using an electron probe microanalyzer (JXA-8230 of JEOL) at Beijing GeoAnalysis Technology Co., Ltd, Beijing, China. The voltage and current used were 25 kV and 20 nA, respectively. The peak analysis time of all elements was 30 seconds, and the background analysis time was 15 seconds. The calibration standard samples for the contents of major elements used 53 kinds of mineral standard samples, 44 kinds of elemental standard samples, and 15 kinds of rare earth element standard samples provided by SPI Company. The data correction method adopts the ZAF correction method of JEOL.

2.2.3. Rutile U-Pb dating and trace element analyses of rutile by LA-ICP-MS

U-Pb dating of twelve grains and trace element analyses of twenty-two trace element analyses of rutile and one related chlorite were simultaneously conducted by LA-ICP-MS at Beijing GeoAnalysis Technology Co., Ltd, Beijing, China. Detailed operating conditions for the laser ablation system and the ICP-MS instrument and data reduction follow the description by Zang et al., (2019). Laser sampling was performed using a GeolasPro laser ablation system that consists of a COMPexPro 102 ArFexcimer laser (wavelength of 193 nm and maximum energy of 200mJ) and a MicroLas optical system. An Agilent 7900 ICP-MS instrument was used to acquire ion-signal intensities. Helium was applied as carrier gas. Argon was used as the make-up gas and mixed with the carrier gas via a T-connector before entering the ICP. A ‘wire’ signal smoothing device is included in this laser ablation system (Hu et al.,, 2015). The spot size and frequency of the laser were used as external standards for U-Pb dating calibration. Each analysis incorporated a background acquisition of approximately 20-30 s followed by 50 s of data acquisition for the sample. The software Iolite 4.0 (Paton et al.,, 2011) was used to perform off-line selection and integration of background and analyzed signals, time-drift correction and U-Pb dating. The Terra-wasserburg diagram of rutile samples and ^{207}Pb corrected age weighted average were calculated using Isoplot/Ex_Ver3 (Ludwig, 2003) completed.

3. Results

3.1. Petrography of garnet mica schist

Muscovite-biotite-garnet micaschists of Ayos-Akonolinga are the country rocks of detrital rutile of Medoumou-Ebol area (Nkoumbou et al., 2014; Vic et al., 2025). Under the microscope, the mica schist exhibits a heterogranular granolepidoblastic texture (Fig. 3) made up of garnet, biotite, muscovite, plagioclase, chlorite, quartz, sphene and accessory opaque minerals, zircon and rutile. Subautomorphic to xenomorphic quartz crystals (0.1-3 mm, 30 vol.%) is found in the interstices between biotite, muscovite, and garnet, or as inclusions in garnet (Fig. 3a, b) and alkali feldspar. Quartz also occurs as monocrystalline or polycrystalline ribbons with an average size of 0.6 x 0.1 mm. Biotite crystals (30 vol.%) often occur in bundles of lamellae (0.2-1.2 mm) that mould garnet porphyroblasts. Small crystals of rutile are found as inclusions in garnet and plagioclase crystals. Some biotite crystals contain zircon inclusions. Occasionally, they are associated to chlorite and opaque minerals. Muscovite (15 to 20 vol.%) appears as stretched lamellae wreathing garnet and quartz porphyroblasts (Fig. 3c, d). The lamellae (< 100 µm to 1 mm) are oriented parallel to the rock's schistosity. Garnet crystals (0.7-2.5 mm, 15vol.%) are either globular, lenticular or xenomorphic. The garnet porphyroblasts are wreathed by biotite and muscovite flakes. They contain inclusions of quartz and biotite. Occasional retrogression into biotite and opaque minerals are observed. Sizes of subautomorphic to xenomorphic plagioclase crystals (10 vol.%) range from a few microns to 1 mm in long axis. Some crystals contain biotite and quartz inclusions. Prismatic, subauomorphic to xenomorphic alkali feldspar crystals (0.2 to 1.5 mm in long axis) occupy 6 vol.%. Opaque minerals (0.2-1 mm) occupy less than 2 vol.%. Some crystals may result from the alteration of biotite and garnet. Accessory minerals (< 2 vol.%) are sphene, zircon and rutile. Sphene crystals usually occur as clusters or isolated minute crystals in the matrix. Zircon often occurs as inclusion in biotite and garnet or as disseminated crystals throughout the rock (Fig. 3e, f). Rutile is associated to muscovite and biotite. Sericite is a secondary mineral (< 1 vol.%) derived from the alteration of biotite and plagioclase.

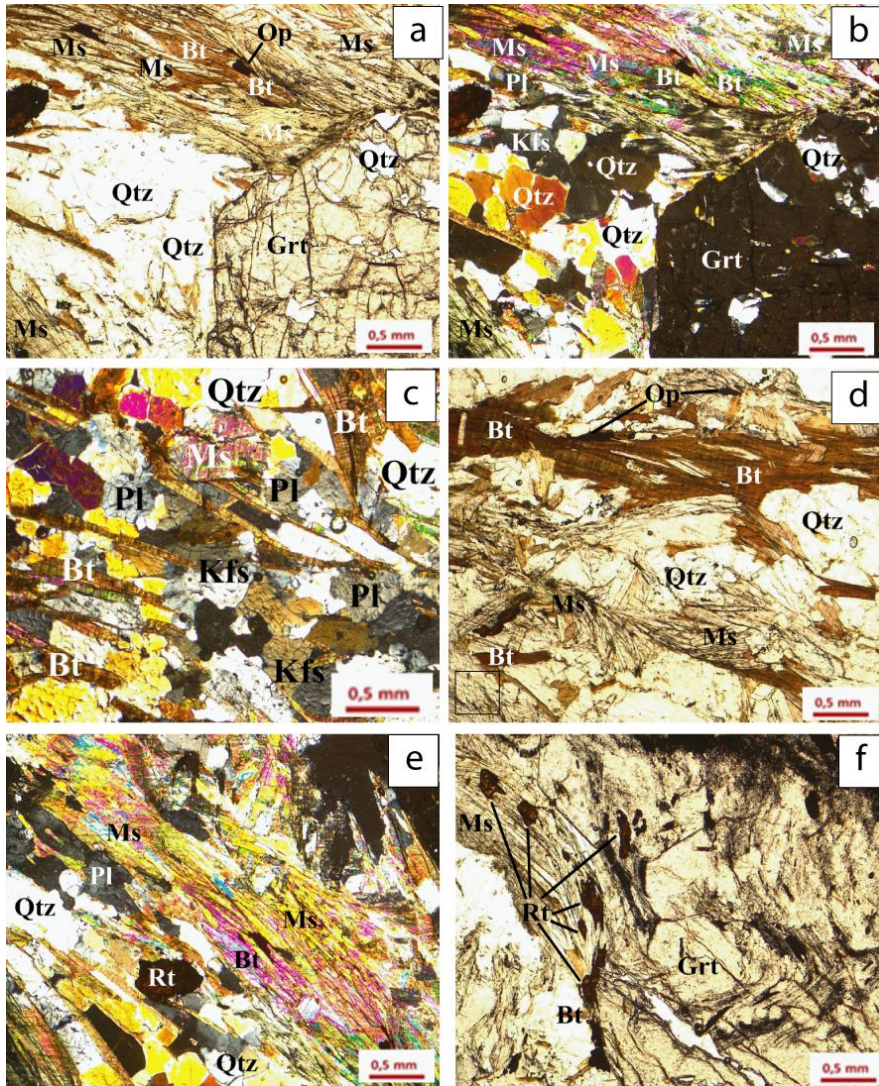


Fig. 3: Photomicrographs of garnet-mica schist. a & b) Heterogranular granolepidoblastic texture of the mica schist; c) Mineral assemblage comprising quartz, biotite, alkali feldspar and muscovite; d) biotite and muscovite lamellae lying in the schistosity; e & f) rutile crystals along biotite and muscovite. Bt: biotite, Grt: garnet, Ms: muscovite, Kfs: K-feldspar, Qtz: quartz, Rt: rutile, Op: opaque minerals.

3.2. Heavy minerals

The heavy minerals from 12 samples were mounted on thin slides and identified using a microscope. Approximately 80 heavy grains were identified and described on the slides of each samples. Their abundances are listed in Table 1 and a selection is displayed in Fig. 4. The chemical compositions of the heavy mineral concentrates of the Medoumou-Ebol area are listed in Table 2. TiO_2 and SiO_2 display the highest contents (44-86 wt.% and 39-59 wt.%, respectively). Al_2O_3 and Fe_2O_3 contents are low (2.0-8.8 wt.% and 0.67-7.1 wt.%, respectively).

Exceptionally, one sample has a Fe_2O_3 content as high as 22.3 wt.%. Those of CaO and MgO are very low (< 0.4 wt.%, except one sample with a CaO content of 1.25 wt.%). Na_2O , K_2O and P_2O_5 are not constituents of the studied heavy minerals. Conversely, high Cr, Zr, Nb, V, Hf contents are noted. The conversion into oxides gives values in the range of major elements (ZrO_2 : 0.29->1.35 wt.%, V_2O_5 : 0.13-0.17 wt.%, Nb_2O_5 : 0.11-0.23 wt.%, HfO_2 : 0.01-0.16 wt.%, Cr_2O_3 : 0.05-0.07 wt.%). These additive major elements improve the sum of oxides from 82.48-96.23 to 84.09-97.49 wt.%. Some HFSE elements have low contents (Ta : 40-97 ppm, Sn : 35-61 ppm, Y : 7-134 ppm) compare with Nb, V, Hf values. Base metals have various contents (Pb : 12-46 ppm, Zn : 16-125 ppm) while others (Cu, Sc, Co, Ag, As, Cd, Li, Mo, Ni, Tl) have negligible contents.

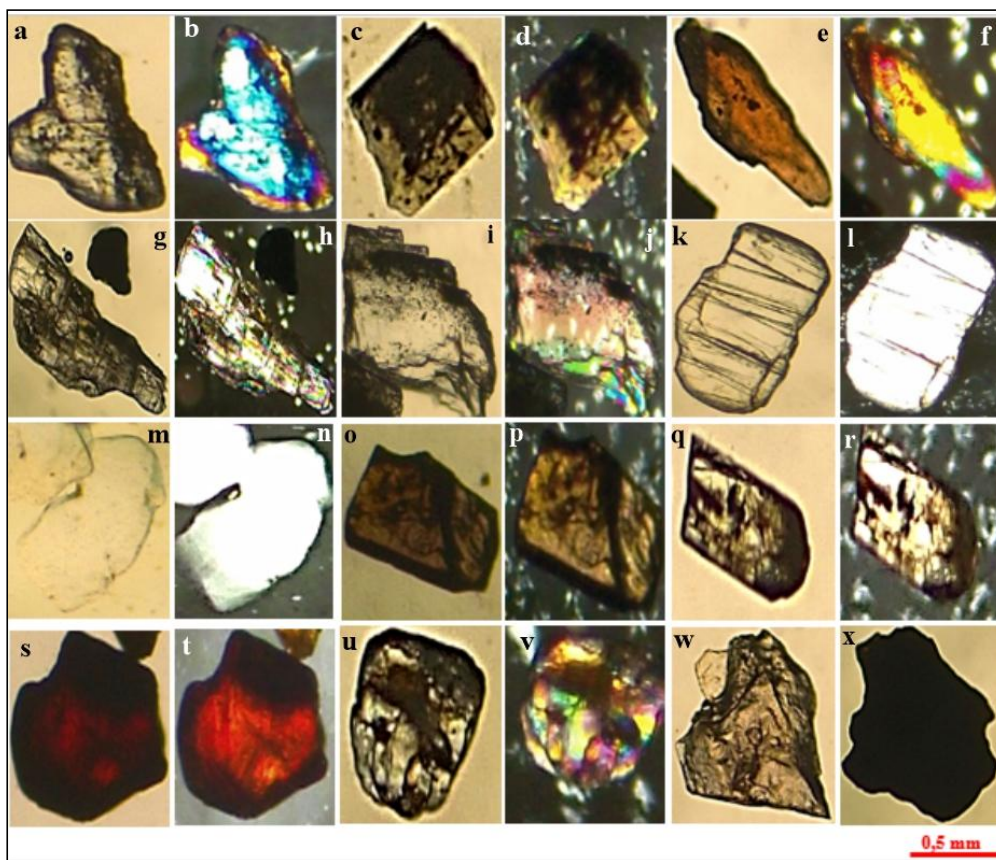


Figure 4. Heavy minerals. a) Actinolite (plane light, PL), b) Actinolite (plane polarized light, PPL), c) Anatase PL, d) Anatase PPL ; e) Staurotide PL, f) Staurotide PPL, g) Kyanite PL, h) Kyanite PPL, i) Diopside PL, j) Diopside PPL, k) Chloritoid PL, l) Chloritoid PPL, m) Zoisite PL, n) Zoisite PPL, o) Tourmaline PL, p) Tourmaline PPL, q) Zircon PL, r) Zircon PPL, s) Rutile PL, t) Rutile PPL, u) Augite PL, v) Augite PPL, w) Garnet; x) opaque mineral

Table 1: Abundances of heavy mineral species in the concentrates from the alluvia from Medoumou-Ebol area, Cameroon

Samples	MED	DJA1	DJA2	AYE	MBI	YEB	AND	EBO	ESA	WOU	YEL	NYO
Rutile	27	70	11	48	23	60	75	38	50	40	40	26
Opaques	57	10	40	42	51	20	10	24	32	15	10	51
Zircon	8	8	9	-	12	4	4	30	10	35	30	4
Tourmaline	0	4	2	2	4	5	2	-	2	2	8	-
Zöisite	2	1	0	3	6	2	4	1	2	3	-	1
Kyanite	1	1	9	2	-	1	1	5	-	3	2	-
Actinolite	1	-	-	-	-	-	-	-	-	-	-	1
Staurotide	2	1	6	-	-	1	1	-	-	-	-	4
Anatase	2	-	-	-	2	-	-	-	-	-	-	1
Kyanite	1	1	9	2	-	1	1	5	-	3	2	-
Chloritoïd	-	1	6	-	2	2	1	1	2	-	-	-
Diopside	-	1	13	3	-	1	2	0	2	1	5	4
Garnet	-	1	2	-	-	4	1	1	0	1	4	3
Augite	-	-	2	-	-	-	-	-	-	-	-	-
Total	100	100	100	100	100	100	100	100	100	100	100	100

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206 **Table 2.** Chemical compositions of heavy mineral concentrates

Sample	AND 1	AYE	DJA 1	DJA 2	EBD	ESA	MBI	MED1	NYO2	YEB	YEL 1	WOU
SiO ₂	28.1	20.1	19.6	27.5	29.9	33.8	20.4	26.3	35.4	26.4	38.6	34.7
Al ₂ O ₃	2.45	3.29	7.19	9.54	4.27	2.65	3.7	1.98	6.98	4.48	8.8	2.08
Fe ₂ O ₃	0.81	22.3	3.85	1.9	0.67	7.09	1.6	1.38	17.05	10.2	0.74	0.79
CaO	0.02	0.02	0.02	0.12	0.03	0.03	0.02	0.02	0.26	1.25	0.02	0.03
MgO	0.1	0.09	0.08	0.16	0.1	0.14	0.08	0.11	0.28	0.37	0.12	0.09
Na ₂ O	0.02	0.02	0.01	0.03	0.02	0.04	0.04	0.03	0.03	0.07	0.02	0.01
K ₂ O	<0.01	0.02	0.02	0.03	<0.01	0.04	0.05	0.03	0.05	0.11	0.02	0.02
Cr ₂ O ₃	0.055	0.062	0.057	0.044	0.051	0.064	0.05	0.053	0.073	0.049	0.051	0.056
TiO ₂	59.3	37.4	51.8	42.3	50.3	48.6	58.3	57.8	33.1	49.2	44.4	54
MnO	0.01	0.08	0.02	0.03	0.01	0.02	0.01	0.01	0.1	0.17	0.01	0.01
P ₂ O ₅	<0.01	0.03	0.03	0.03	0.04	0.04	0.01	0.01	0.12	0.02	0.03	0.02
SrO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BaO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
LOI	0.58	1.36	0.78	0.8	0.41	1.65	0.62	0.38	2.79	0.14	0.15	0.44

Total	91.45	84.77	83.46	82.48	85.8	94.16	84.88	88.1	96.23	92.47	92.96	92.25
Ba	30.1	14.5	25.5	22.2	21.3	18.8	23.8	16.7	32.9	48.7	14.4	11.8
Ce	48.1	27.4	61.2	181	92.9	24.4	11.5	21.8	134.5	16	151.5	50.7
Cr	395	449	406	383	366	464	356	371	520	354	361	392
Cs	0.03	0.05	0.03	0.03	<0.01	0.02	0.07	0.04	0.08	0.11	<0.01	<0.01
Dy	3.78	1.8	1.8	4.51	13.85	2.92	0.89	2.39	4.47	4.37	6.82	9.74
Er	4.53	1.85	1.68	3.95	18.55	3.56	0.97	2.88	3.78	3.79	8.22	11.65
Eu	0.59	0.32	0.72	2.15	0.99	0.27	0.13	0.41	0.83	0.26	0.77	0.96
Ga	5.6	9.4	9	11.6	5.8	6.9	7.7	6.9	13.8	4.4	9.9	4.4
Gd	3.35	1.52	2.81	8.83	8.37	1.76	0.65	1.8	5.87	1.66	7.14	5.72
Hf	296	103	108	233	1360	271	56.2	182.5	181	80.9	691	773
Ho	1.02	0.46	0.43	1.06	4.18	0.83	0.25	0.68	1.04	1.16	1.88	2.75
La	23.5	12.4	31.6	90.3	44.3	11.1	6.2	10.6	67.3	7.1	75.5	24.2
Lu	1.54	0.61	0.57	1.23	6.48	1.28	0.35	1	1.05	0.81	3.02	4.04
Nb	1310	887	1580	1355	1300	1155	1575	1345	798	1410	1200	1275
Nd	19	10.1	22.5	69	37.6	8.9	3.5	8.5	54.6	6	58.1	20.8
Pr	5.29	2.82	6.49	19.6	10.15	2.46	1.14	2.44	15.3	1.62	16.45	5.58
Rb	0.8	1.3	1.2	1.6	0.6	1.3	2	0.9	1.4	2.9	0.6	0.6
Sm	3.6	1.82	4.01	11.95	7.6	1.71	0.71	1.75	9.25	1.16	9.93	4.82
Sn	55.5	41.6	56.2	45.5	52.5	49.8	61.4	57.3	35.2	49.7	51.3	45
Sr	6.2	6.5	7.8	9.6	6.1	7.5	8.7	7.1	12.6	10.2	6.8	5.2
Ta	73.8	42.3	65.9	91.5	84.9	74.9	74.8	70.7	54	91.7	40.6	75.4
Tb	0.52	0.28	0.34	0.97	1.64	0.34	0.13	0.33	0.81	0.47	1.04	1.19
Th	20.7	17.15	18.15	35.3	50.9	18.15	7.6	11.7	38.8	7.27	44.1	36.1
Tm	0.89	0.36	0.34	0.76	3.8	0.71	0.18	0.6	0.66	0.6	1.66	2.39
U	9.77	4.2	4.77	9.87	31.5	7.78	2.48	5.57	7.97	2.71	17.25	21.5
V	902	900	916	717	838	926	967	910	792	877	738	710
W	40.6	24.2	33.3	59.9	56.7	45.1	24.5	32.5	38.3	34.5	63.1	60.5
Y	31.7	13.2	12.5	30.7	134	25.6	7.1	20.3	31.2	32.9	58.6	84
Yb	7.84	3.09	2.93	6.34	32.1	6.32	1.79	4.95	5.76	4.54	14.8	19.9
Zr	>10000	3970	4150	9300	>10000	>10000	2160	7120	7270	3160	>10000	>10000
Ag	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
As	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5

Cd	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Co	1	5	<1	4	<1	2	<1	1	4	9	1	<1
Cu	5	11	9	8	5	18	8	7	72	11	3	4
Li	<10	<10	<10	10	<10	<10	<10	<10	<10	10	<10	<10
Mo	1	4	1	<1	1	12	<1	1	3	<1	1	<1
Ni	<1	3	1	13	<1	2	<1	<1	8	<1	2	<1
Pb	16	12	22	22	16	8	21	18	46	9	17	14
Sc	6	9	7	5	10	11	4	5	25	18	5	9
Tl	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Zn	30	35	56	77	16	30	36	28	74	215	25	25

3.3. Mineral chemistry and dating

3.3.1. Rutile chemistry

This study relies on twenty-two EPMA analyses (Table 3) and twenty-three laser ablation analyses of rutile grains. Chemical compositions of the rutile obtained from EPMA show high TiO₂ concentrations ranging from 97.37 wt.% up to 100 wt.% with a mean value at 99.31 wt.%. Rutile TiO₂ concentrations obtained by LA-ICP-MS (Table 4) are high, but they display a limited range (TiO₂ : 97.13-98.51 wt.%) except one analysis which shows high FeO content 13.00 wt.%). The latter composition may likely correspond to a mixture of rutile and ilmenite or hematite, ilmenite form exsolution in rutile (Nzeusseu Nandjou et al., 2025) and rutile-hematite symplectite are reported (Tan et al., 2015). When this exceptional composition is discarded, the mean value is 97.97 wt.%. In the EPMA data, accessory oxides are FeO (0.19-0.65 wt.%) and V₂O₃ (0.03-0.38 wt.%). Among trace elements obtained by LA-ICP-MS method, Nb, Ta, Cr, V, and Sn display high concentration values to be considered as major elements (Table 5). Rare earth concentrations are very low and disparate in the detrital rutile grains of Medoumou-Ebol area.

Table 3: EMPA rutile compositions and chemical formulae

Analyses	1	2	3	4	5	6	7	9	10	11
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SiO ₂	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.00
TiO ₂	99.95	99.66	98.99	99.72	99.61	98.20	99.56	97.78	99.67	99.91
Al ₂ O ₃	0.05	0.04	0.03	0.05	0.02	0.10	0.02	0.06	0.04	0.03
MgO	0.03	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
FeO	0.44	0.49	0.51	0.39	0.34	0.52	0.44	0.65	0.30	0.30
MnO	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
CaO	0.03	0.01	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.02
Na ₂ O	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.01
K ₂ O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr ₂ O ₃	0.03	0.07	0.03	0.05	0.03	0.10	0.06	0.11	0.03	0.04
CoO	0.00	0.00	0.01	0.00	0.02	0.02	0.00	0.00	0.00	0.00
NiO	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00
SrO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO ₂	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V ₂ O ₃	0.27	0.28	0.26	0.11	0.23	0.38	0.24	0.36	0.26	0.29
P ₂ O ₅	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01
Total	100.83	100.55	99.83	100.32	100.31	99.34	100.34	98.98	100.34	100.62
Si	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ti	0.995	0.995	0.995	0.996	0.996	0.993	0.996	0.993	0.996	0.997
Al	0.001	0.001	0.000	0.001	0.000	0.002	0.000	0.001	0.001	0.000
Mg	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe ³⁺	0.005	0.005	0.006	0.004	0.004	0.006	0.005	0.007	0.003	0.003
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Na	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr	0.000	0.001	0.000	0.001	0.000	0.001	0.001	0.001	0.000	0.000
Co	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ba	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V	0.003	0.003	0.003	0.001	0.002	0.004	0.003	0.004	0.003	0.003
P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	1.002	1.002	1.002	1.001	1.002	1.002	1.002	1.003	1.001	1.001

225

226 Table 3 End

Analyses	12	13	14	16	17	19	21	22	23	24
SiO ₂	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.01
TiO ₂	99.55	100.28	99.33	99.76	99.51	99.82	98.99	98.77	97.36	99.68
Al ₂ O ₃	0.03	0.04	0.03	0.03	0.03	0.05	0.06	0.06	1.21	0.05
MgO	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
FeO	0.19	0.14	0.27	0.23	0.22	0.31	0.49	0.51	0.41	0.31
MnO	0.02	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.02	0.00

CaO	0.01	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.00	0.06
Na ₂ O	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K ₂ O	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00
Cr ₂ O ₃	0.07	0.09	0.07	0.09	0.04	0.06	0.06	0.06	0.06	0.05
CoO	0.02	0.03	0.00	0.00	0.00	0.01	0.00	0.03	0.01	0.00
NiO	0.00	0.00	0.03	0.00	0.01	0.01	0.00	0.00	0.00	0.00
SrO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO ₂	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V ₂ O ₃	0.31	0.31	0.28	0.23	0.22	0.33	0.20	0.21	0.21	0.19
P ₂ O ₅	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02
Total	100.23	100.91	100.03	100.35	100.07	100.62	99.84	99.67	99.28	100.39
Si	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ti	0.997	0.998	0.997	0.997	0.997	0.996	0.994	0.994	0.982	0.996
Al	0.000	0.001	0.000	0.000	0.001	0.001	0.001	0.001	0.019	0.001
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe ³⁺	0.002	0.002	0.003	0.003	0.002	0.003	0.005	0.006	0.005	0.003
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Na	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr	0.001	0.001	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.001
Co	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ba	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V	0.003	0.003	0.003	0.002	0.002	0.004	0.002	0.002	0.002	0.002
P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	1.002	1.001	1.002	1.001	1.001	1.002	1.002	1.002	1.006	1.002

227

228 **Table 4:** Laser ablation analyses of rutile and chemical formulae

	P1A-01	P1A-02	P5B-03	P7A-04	P11A-05	P18A-06	P18A-07	P15B-09	P15A-10	P12A-11	P14A-12
Point	01LA	02LA	03LA	04LA	05LA	06LA	07LA	09LA	10LA	11LA	12LA
SiO ₂	0.62	0.59	0.68	0.74	0.67	0.66	0.62	0.66	0.63	0.65	0.71
TiO ₂	98.03	98.01	98.34	97.13	98.51	98.47	97.46	85.09	98.37	97.87	97.54
Al ₂ O ₃	0.11	0.09	0.04	0.07	0.04	0.03	0.02	0.11	0.04	0.06	0.08
MgO	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.14	0.01	0.01	0.02
FeO	0.43	0.51	0.40	0.78	0.28	0.19	1.16	12.98	0.31	0.51	1.04
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
CaO	0.03	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.03	0.00
Na ₂ O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K ₂ O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr ₂ O ₃	0.05	0.05	0.03	0.08	0.07	0.06	0.09	0.07	0.06	0.06	0.04

CoO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SrO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO ₂	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V ₂ O ₃	0.19	0.18	0.14	0.25	0.22	0.28	0.29	0.17	0.22	0.19	0.17
P ₂ O ₅	0.03	0.03	0.02	0.03	0.03	0.02	0.02	0.04	0.03	0.02	0.02
Total	99.49	99.48	99.67	99.11	99.83	99.80	99.69	99.37	99.68	99.40	99.62
Si	0.008	0.008	0.009	0.010	0.009	0.009	0.008	0.009	0.008	0.009	0.009
Ti	0.986	0.986	0.987	0.982	0.988	0.988	0.981	0.877	0.988	0.986	0.980
Al	0.002	0.001	0.001	0.001	0.001	0.000	0.000	0.002	0.001	0.001	0.001
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000
Fe ³⁺	0.005	0.006	0.004	0.009	0.003	0.002	0.013	0.147	0.003	0.006	0.011
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Ca	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Na	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000
Co	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ba	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
V	0.002	0.002	0.001	0.003	0.002	0.003	0.003	0.002	0.002	0.002	0.002
P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	1.002	1.002	1.001	1.003	1.001	1.001	1.004	1.040	1.001	1.002	1.004

Table 5: Trace elements analyses of alluvial rutile and related chlorite from Medoumou-Ebol area, west of Akonolinga, Cameroon

Rutile	Chlorite
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Nº	1	2	3	4	5	6	7	8	9	10	11	12
Points	11A-5	12A-11	14A-12	15A-10	15B-09	18A-06	18A-07	1A-01	1A-02	5B-03	7A-04	15B-08
Li	0.08	0.00	0.04	0.10	0.57	0.00	0.07	0.17	0.00	0.00	0.04	10.18
Be	0.00	0.00	0.23	0.16	0.30	0.00	0.04	0.06	0.00	0.00	0.20	0.28
B	5.47	1.00	0.00	0.00	8.52	5.44	6.60	3.08	0.00	2.00	4.41	2.71
Sc	4.80	7.60	1.83	8.45	7.47	2.13	12.29	4.46	4.86	9.13	3.91	22.91
V	1508	1262	1140	1500	1180	1926	1998	1266	1239	939	1709	1384
Cr	491	421	295	393	478	433	622	324	345	220	567	833
Co	0.00	0.05	0.24	0.05	4.50	0.05	1.24	0.00	0.00	0.00	0.64	2.28
Ni	1.45	0.00	0.00	0.00	0.86	2.90	0.00	0.00	0.07	1.55	0.00	29.67
Cu	2.25	1.60	1.82	1.56	6.75	1.95	1.81	1.93	1.48	1.86	2.58	30.37
Zn	5.57	4.63	249.50	4.66	290.04	5.22	9.82	5.47	4.42	4.52	6.62	59.33
Ga	0.20	0.62	0.90	0.89	0.96	1.35	0.70	1.24	0.80	0.67	1.25	67.14
Rb	0.17	0.00	0.40	0.33	0.10	0.33	0.00	0.00	0.00	0.00	0.00	41.48
Sr	0.09	0.07	0.10	0.10	0.82	0.10	0.13	0.08	0.06	0.11	0.06	20.73
Y	0.00	0.00	0.02	0.01	0.37	0.01	0.04	0.00	0.00	0.00	0.00	4.09
Zr	98.7	90.6	122.1	79.7	65.9	31.3	167.5	87.0	89.8	104.8	88.8	173.4
Nb	534	3470	1640	1556	1007	763	1174	2795	2894	1715	5186	36
Mo	1.27	0.76	0.40	0.81	1.96	0.38	6.27	1.13	0.34	0.84	0.65	24.85
Ag	0.00	0.00	0.04	0.09	0.00	0.01	0.00	0.00	0.05	0.06	0.03	0.18
Cd	0.14	0.23	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.02
Sn	88.72	83.09	56.31	76.07	66.91	47.37	60.90	80.42	77.47	61.92	104.4 ₉	11.49
Sb	0.43	0.42	2.50	0.80	1.30	1.41	0.63	0.00	0.02	1.14	0.37	6.79
Cs	1.27	0.00	0.00	0.00	0.35	1.52	0.00	0.19	0.00	0.81	0.00	3.66
Ba	0.0	0.1	0.1	0.0	1.1	0.0	0.0	0.0	0.1	0.1	0.3	147.9
La	0.01	0.00	0.00	0.00	0.82	0.04	0.05	0.03	0.00	0.01	0.07	12.90
Ce	0.00	0.04	0.01	0.01	2.08	0.01	0.06	0.01	0.00	0.03	0.11	66.26
Pr	0.00	0.00	0.00	0.00	0.25	0.00	0.03	0.00	0.00	0.00	0.01	3.41
Nd	0.05	0.00	0.03	0.00	0.43	0.00	0.00	0.00	0.03	0.00	0.05	12.33
Sm	0.00	0.00	0.00	0.00	0.06	0.00	0.15	0.00	0.00	0.00	0.03	2.94
Eu	0.01	0.00	0.00	0.00	0.28	0.00	0.01	0.00	0.02	0.00	0.01	0.45
Gd	0.00	0.00	0.08	0.01	0.17	0.10	0.00	0.00	0.00	0.11	0.00	1.10
Tb	0.00	0.03	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.02	0.00	0.14
Dy	0.03	0.02	0.03	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.02	0.77
Ho	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.21
Er	0.01	0.01	0.00	0.00	0.07	0.03	0.00	0.01	0.00	0.00	0.01	0.45
Tm	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Yb	0.02	0.00	0.02	0.00	0.06	0.02	0.00	0.00	0.00	0.00	0.02	0.79
Lu	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Hf	4.99	4.44	6.17	3.85	3.75	1.44	3.60	4.51	4.41	5.18	4.36	3.96
Ta	31.3	142.2	104.5	59.5	52.6	56.8	54.9	144.3	131.8	121.9	188.2	1.42
W	36.9	89.6	119.2	104.5	135.4	48.2	44.6	96.7	94.2	45.0	166.6	6.51

Hg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tl	0.02	0.01	0.01	0.00	0.00	0.01	0.03	0.00	0.06	0.00	0.04	0.41
Bi	0.00	0.05	0.00	0.00	0.35	0.02	0.04	0.00	0.00	0.00	0.00	11.73
Pb	0.0	0.0	0.0	0.0	4.7	0.0	0.0	0.0	0.0	0.0	2.1	165.8
Th	0.0	0.0	0.0	0.0	4.1	0.0	0.2	0.0	0.0	0.0	1.7	105.5
U	0.13	0.21	0.10	0.59	0.52	8.62	16.51	0.19	0.23	0.24	0.18	3.46
V ₂ O ₃	0.22	0.19	0.17	0.22	0.17	0.28	0.29	0.19	0.18	0.14	0.25	0.20
Cr ₂ O ₃	0.07	0.06	0.04	0.06	0.07	0.06	0.09	0.05	0.05	0.03	0.08	0.12
Nb ₂ O ₅	0.08	0.50	0.23	0.22	0.14	0.11	0.17	0.40	0.41	0.25	0.74	0.01
SnO ₂	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00

3.3.2. U-Pb rutile age

Thirty-six rutile La-ICP-MS geochronology data are listed on Table 6. U contents show two ranges, one at low values (0.10-0.53 ppm, 21 samples) and other at high values (3.95-16 ppm, 15 samples). Two ranges of Th values are also recorded (0.0-0.0009 ppm, 30 samples) and (0.0026-2.30 ppm, 6 samples). U/Th values show many ranges : 57-78, 264-883, 1269-3129, exceptionally 27666. The ²⁰⁴Pb contents are very low (0-1.12 ppm). Because of the low U contents of twenty-three (23) samples out of thirty-six (36) samples, only thirteen (13) data were considered for age calculation. The data displayed on table 6 yield an age range from 525 ± 41 to 601 ± 50 Ma. On the Terra-Wasserburg diagram (figure not shown), the lower intercept yields a concordant age of 506 ± 12 Ma with MSWD = 0.93 while the upper intercept is at 4951 ± 0 Ma, a meaningless age. The mean histogram age is 547 ± 14 Ma at 95% confidence with MSWD = 1.3 and probability = 0.19 (figure not shown). The age of 506 ± 12 Ma is far from the 525-601 Ma range provided by the rutile crystal analyses. After a close inspection of the data, three population of ages were distinguished and they yielded three concordia ages of 588 ± 27 Ma (n=3), 549 ± 12 Ma (n=9) and 518 ± 11 Ma (n=6) and corresponding similar weighted mean ²⁰⁶Pb-²³⁸U ages of 588 ± 27 Ma and MSWD = 0.3, 549 ± 12 Ma with MSWD = 0.41 and 518 ± 11 Ma with MSWD = 0.2, respectively (Fig. 5).

Table 6: U-Pb LA-ICP-MS isotopic data of alluvial rutile of Medoumou-Ebol area, Cameroon

Contents				Ratios				Ages (Ma)				
²⁰⁴ Pb	²⁰⁸ Pb	Th	U	U/Th	²⁰⁶ Pb/ ²³⁸ U	2σ	²⁰⁷ Pb/ ²³⁵ U	2σ	²⁰⁶ Pb/ ²³⁸ U	2σ	²⁰⁷ Pb/ ²³⁵ U	2σ

P1A-01	0.20	0.01	0.001	0.25	264								
P1A-02	0.000	0.01	0.001	0.26	410								
P1A-03	0.71	0.00	0.003	0.24	78								
P11A-04	0.70	0.00	0.003	0.15	57								
P11A-05	0.000	0.00	0.000	0.16	417								
P18A-06	0.50	0.01	0.037	16.0	432	0.088	0.005	0.886	0.179	540	27	572	103
P18A-07	0.029	0.01	0.047	14.4	305	0.086	0.005	0.630	0.133	528	28	452	83
P18A-08	0.19	0.01	0.003	3.95	1269	0.088	0.008	0.723	0.272	538	44	386	141
P18A-13			0.000	11.1		0.092	0.007	0.789	0.261	566	42	367	159
P18A-14			0.005	11.5	3129	0.091	0.006	0.701	0.218	561	36	386	139
P18A-15	0.11		0.015	8.56	883	0.095	0.009	0.888	0.276	580	50	475	176
P18A-16	0.044	0.71		7.44		0.093	0.008	0.882	0.313	571	44	330	186
P18A-17	0.32	0.65	0.003	6.25	2978	0.099	0.009	0.665	0.344	601	50		
P18A-18		0.42	0.003	4.52	1919	0.087	0.009	0.567	0.450	535	52		
P18A-19			0.01	8.76	2649	0.090	0.008	0.566	0.257	552	48	247	174
P18A-20	0.14			5.14		0.089	0.010	0.593	0.362	540	56		
P18A-21		1.45	0.08	13.8	244	0.090	0.008	0.709	0.228	553	47	434	153
P18A-22		0.95	0.00	9.67	27666	0.086	0.007	0.565	0.233	525	41	249	161
P18A-23	48.0	45.8	28.3	2.81	0.1	2.697	0	206.5	0	8429	0	5816	0
P18A-24		0.070	0.000	0.53									
P18A-25	0.049	0.07	0.001	0.39									
P18A-26	0.23	0.069	0.001	0.36									
P18A-27	0.32	0.054	0.010	0.29									
P18A-28	0.059	0.030	0.000	0.07									
P15A-09	0	0.001	0	0.27									
P12A-12	0.08	0.013	0.0000	0.22									
P14A-10	1.12	0.000	0.003	0.10	40								
P14A-11	0.51	0.003	0.002	0.13	69								
P3A-37	0.	0.01	0	0.12									
P3A-38	0.036	0.23	0.45	0.11	0.24								
P3A-39	0.000	0.024	0.000	0.12									
P3A-40	00	0.24	2.30	0.10	0.04								
P3A-41	0.26	0.93	0.52	0.11	0.22								
P3A-42				0.12									
P3A-43													
P3A-44	0.036	0.23	0.45	0.11	0.24								

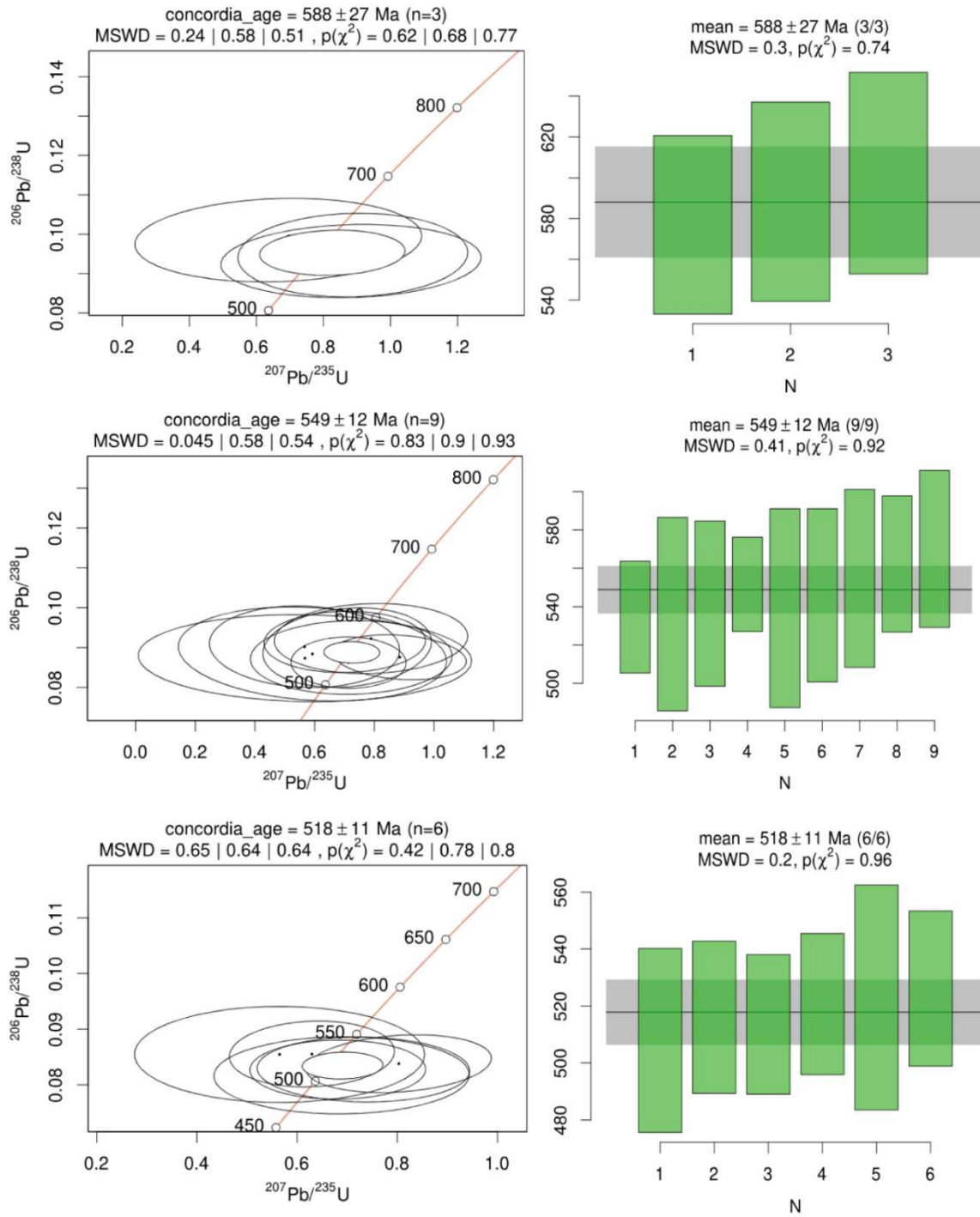


Fig. 5

Figure 5: U-Pb concordia graphs and related histograms with weighted mean ages of detrital rutile from Medoumou-Ebol area.

3.3.3. Garnet

Observations of garnet grains on epoxy mount (Figs. a, b, c, d) show many types of relation between garnet and rutile. Rutile occurs as minute crystals in garnet (Fig. 6b). Garnet appears as a lath crosscutting a rutile crystal (Fig. 6c). At other sections, the crystals of the two mineral species exhibit a peculiar feature made up of interpenetrated lobes (Fig. 6d). Four analyses were realized to know their chemical characteristics and to gauge the partition of element between rutile and garnet in the case of interpenetrated grains, a feature that can be attributed to a possible concomitant crystallisation. The main chemical characteristics of these garnet grains are their high FeO (29.35-29.42 wt.%) and Al₂O₃ (18.47-21.00 wt.%) contents. On the contrary, MgO (1.12-1.20 wt.%), TiO₂ (0.02 wt.%) and other oxides contents are very low (table 7). Structural formula were calculated on the basis of 24 anions. These analyses exhibit chemical complexity where the cation proportions at the octahedral and dodecahedral sites are ideal following the recasting procedure (Locock 2008). Molar proportions of 29 garnet end-members (15 species and 14 hypothetical end-members) were calculated using a microsoft excel spreadsheet program (Locock 2008). The results listed on table 7 reveal that the prevalent molecule is almandine (60.33-68.47 mol.%) followed by grossular (15.79-22.30 mol.%). Finally, the garnet composition can be summarized as follows : Alm_{60.3-68.5}Gr₁₅₋₂₃Sp_{7.8-8.2}And_{0.7-1.5}Uv_{0.18}. It can be classified as grossular and spessartine-rich almandine. All the analyzed crystals contain trace amounts of morimotoïte end-member. One analysis contains conspicuous 2.81 mol.% of majorite that is difficult to explain. It is suggested that the laser ablation beam may have sampled unknown micro-inclusions and the garnet. The garnet compositions are presented in the Al+Sp-Gr+An-Py ternary diagram (Fig. 7a) and compared with the compositions of garnet of the neighbouring micaschists and high-grade gneiss from Awaé-Ayos (Olinga et al., 2010), mica schists and amphibolites from Boumnyebel (Yonta et al., 2009) and metagabbros from Mamb (Fuh et al., 2021a). The compositions of the studied garnet are closer to Gr+An-Al+Sp axis than the garnet compositions of other meta-sedimentary and meta-igneous rocks of the PYG.

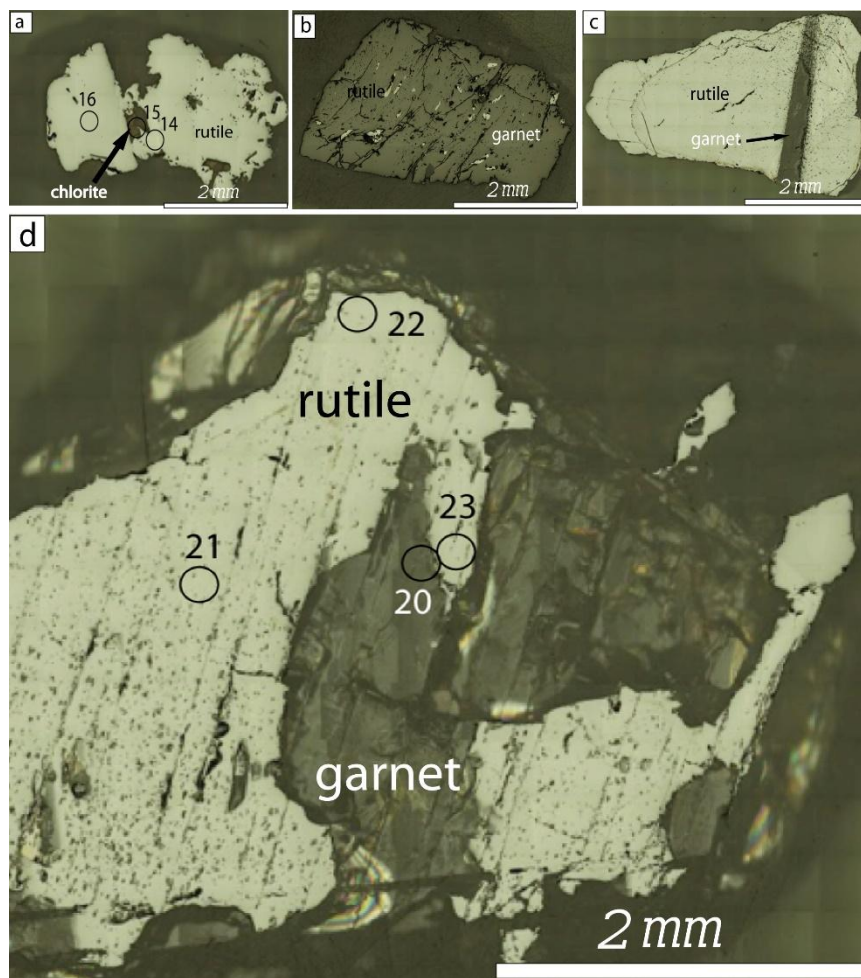


Fig. 6: Microtextures of detrital rutile from Medoumou-Ebol area. a: amoeboid chlorite inclusion in rutile; b: inclusions of minute rutile crystals in garnet; c: lath of garnet crosscutting a rutile crystal; d: garnet-rutile intergrowth.

Table 7: Garnet compositions and chemical formulae on the basis of 24 O

Points	8	15	18	20
SiO ₂	35.99	34.99	37.00	36.99
TiO ₂	0.02	0.02	0.02	0.02
Al ₂ O ₃	18.47	20.85	20.68	20.85
FeO	29.35	29.35	29.42	29.35
MgO	1.12	1.12	1.20	1.12
MnO	3.42	3.42	3.45	3.42
CaO	6.76	7.89	7.92	7.89
Na ₂ O	0.00	0.00	0.00	0.00
K ₂ O	0.00	0.00	0.00	0.00
Cr ₂ O ₃	0.05	0.05	0.05	0.05
CoO	0.00	0.00	0.00	0.00
NiO	0.01	0.01	0.02	0.01

SrO		0.00	0.00	0.00	0.00
BaO		0.00	0.00	0.00	0.00
V ₂ O ₃		0.00	0.00	0.00	0.00
P ₂ O ₅		0.00	0.00	0.00	0.00
Total		95.19	97.71	99.76	99.71
Si		6.114	5.761	5.965	5.966
Ti		0.003	0.003	0.003	0.003
Al		3.698	4.047	3.930	3.965
Fe ²⁺		4.097	3.527	3.839	3.848
Fe ³⁺		0.069	0.480	0.127	0.104
Mg		0.287	0.305	0.298	0.275
Mn		0.492	0.477	0.471	0.467
Ca		1.231	1.392	1.368	1.364
Na		0.000	0.000	0.000	0.000
K		0.000	0.000	0.000	0.000
Cr		0.007	0.007	0.007	0.007
Co		0.000	0.000	0.000	0.000
Ni		0.002	0.002	0.002	0.002
Sr		0.000	0.000	0.000	0.000
Ba		0.000	0.000	0.000	0.000
V		0.000	0.000	0.000	0.000
P		0.000	0.000	0.000	0.000
Total		16.007	16.007	16.010	16.007
end-members					
Henritermierite	Ca ₃ Mn ³⁺ ₂ Si ₂ (H ₄)O ₁₂				
<i>Hythite</i>	Mn ²⁺ ₃ Mn ³⁺ ₂ Si ₃ O ₁₂				
Katoite	Ca ₃ Al ₂ (H ₄) ₃ O ₁₂				
<i>PCa garnet</i>	Ca ₃ Al ₂ (O) ₃ F ₁₂				
<i>PMn garnet</i>	Mn ₃ Al ₂ (O) ₃ F ₁₂				
<i>Yttrogarnet</i>	Y ₃ Al ₂ Al ₃ O ₁₂				
<i>Kimzeyite</i>	Ca ₃ Zr ₂ SiAl ₂ O ₁₂				
<i>Kimzeyite-Fe</i>	Ca ₃ Zr ₂ SiFe ³⁺ ₂ O ₁₂				
<i>Tin garnet</i>	Ca ₃ SnFe ²⁺ Si ₃ O ₁₂				
Schorlomite	Ca ₃ Ti ₂ SiFe ³⁺ ₂ O ₁₂				
<i>Schorlomite-Al/Hutcheonite</i>	Ca ₃ Ti ₂ SiAl ₂ O ₁₂				
Morimotoite	Ca ₃ TiFe ²⁺ Si ₃ O ₁₂	0.13	0.06	0.07	0.06
<i>NaTi garnet</i>	Na ₂ CaTi ₂ Si ₃ O ₁₂				
<i>Morimotoite-Mg</i>	Ca ₃ TiMgSi ₃ O ₁₂				
<i>Morimotoite-Fe</i>	Fe ²⁺ ₃ TiFe ²⁺ Si ₃ O ₁₂				
Majorite	Mg ₃ MgSiSi ₃ O ₁₂	2.81			
<i>Sc garnet</i>	Ca ₃ Sc ₂ Si ₃ O ₁₂				
Goldmanite	Ca ₃ V ₂ Si ₃ O ₁₂				
<i>Yamatoite / Momorite</i>	Mn ²⁺ ₃ V ₂ Si ₃ O ₁₂				
Uvarovite	Ca ₃ Cr ₂ Si ₃ O ₁₂	0.17	0.16	0.18	0.16
Knorringite	Mg ₃ Cr ₂ Si ₃ O ₁₂				
Spessartine	Mn ²⁺ ₃ Al ₂ Si ₃ O ₁₂	8.20	7.95	7.78	7.79
Pyrope	Mg ₃ Al ₂ Si ₃ O ₁₂	0.00	4.58	10.00	4.49

Almandine	$\text{Fe}^{2+}_3\text{Al}_2\text{Si}_3\text{O}_{12}$	68.47	60.33	60.87	64.49
Grossular	$\text{Ca}_3\text{Al}_2\text{Si}_3\text{O}_{12}$	15.79	22.30	18.47	21.52
Andradite	$\text{Ca}_3\text{Fe}^{3+}_2\text{Si}_3\text{O}_{12}$	1.49	0.67	2.02	0.99
Calderite	$\text{Mn}^{2+}_3\text{Fe}^{3+}_2\text{Si}_3\text{O}_{12}$				
Skiagite	$\text{Fe}^{2+}_3\text{Fe}^{3+}_2\text{Si}_3\text{O}_{12}$				
Khoharite	$\text{Mg}_3\text{Fe}^{3+}_2\text{Si}_3\text{O}_{12}$				
Remainder		2.94	3.95	0.64	0.51
Total		100	100	100	100

3.3.4. Chlorite

Chlorite occurs as a xenomorph inclusion in rutile (Fig. 6a). The main oxides are SiO_2 (27.9 wt.%), Al_2O_3 (21.0 wt.%) and FeO (45.4 wt.%). Other oxide contents are very low (MgO , CaO , Na_2O and K_2O : 0.18, 0.19, 0.28 and 0.77 wt.%, respectively) except TiO_2 (2.01 wt.%). The low CaO , Na_2O , K_2O , SrO , BaO contents (0.07 wt.%) fulfil the criteria of good chlorite analyses (De Caritat et al., 1993). Chemical formula on the basis of 28 oxygen atoms is listed on table 8. $\text{Fe}/\text{Fe}+\text{Mg}$ ratio is closed to that of Fe-chlorite ($\text{Fe}_{7.81}\text{Mg}_{0.06}\text{Mn}_{0.01}\text{K}_{0.2}\text{Al}_{2.81}\text{O}_{20}(\text{OH})_{16}$), a di-trioctahedral chlorite. On the $\text{Al}^{\text{IV}}/(\text{Si}+\text{Al}^{\text{IV}})$ versus $\text{Mg}/(\text{Mg}+\text{Fe})$ diagram (Fig. 7b), the classification of this chlorite falls under iron-rich chamosite (Yavuz et al., 2015). The compositions of chlorite from ophiolites of Memel area, Cameroon (Kundu et al., 2022) and those from BIF of Mafé, Cameroon (Nkoumbou et al., 2017) are shown for comparison. Compared with related rutile, chlorite displays high affinity for many elements such as Li, Be, Sc, Cr, Co, Cu, Zn, Ga, Rb, Sr, Y, Zr, Mo, Ag, Ba, Ce, Pr, Gd, Tm, Th, U, Bi, and Pb, while coexisting rutile displays an affinity only for B, Nb, Sn, Ta, and W. This is well illustrated by the values of ratios of rutile content/chlorite content and vice versa to highlight cases where the tenor in one mineral is more than a hundred times lower than in the other (Table 9). It is worth to note that these ratio should be handle with care because rutile crystallized at 575-625 °C while chlorite crystallized at 303-400 °C as stated below, thus they are not contemporaneous. The spectrum of this chlorite inclusion in rutile shows enrichment in LREE decreasing towards MREE and HREE (Fig. 7c). It exhibits a positive Ce anomaly ($\text{Ce}/\text{Ce}^* = 2.43$) and a negative Eu anomaly ($\text{Eu}/\text{Eu}^* = 0.75$), keeping in mind that this chlorite is an exotic solitary inclusion in a grain of detrital rutile. Crystallization temperature of chlorite determined using R^{2+} -Si diagrams (not shown) with 25°C and 100 °C steps (Bourdelle and Cathelineau, 2015) are 350 and 400 °C, respectively.

Table 8: Chlorite composition and chemical formula on the basis of 28 O

08LA	
SiO ₂	27.88
TiO ₂	2.01
Al ₂ O ₃	21.00
FeO	45.44
MgO	0.18
MnO	0.07
CaO	0.19
Na ₂ O	0.28
K ₂ O	0.77
Cr ₂ O ₃	0.12
CoO	0.00
NiO	0.00
SrO	0.00
BaO	0.02
V ₂ O ₃	0.20
P ₂ O ₅	0.42
Total	97.53
Si	5.731
Ti	0.288
Al	5.088
Mg	0.055
Fe	7.811
Mn	0.013
Ca	0.041
Na	0.002
K	0.201
Cr	0.02
Co	5E-05
Ni	6E-04
Sr	3E-04
Ba	0.001
V	0.034
P	0.073
Total	19.36

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	15B9/ 15B8 Ru/Chl	15A10/ 15B8	15B8/ 15B9 Chl/Ru	15B8/ 15B10
Li	0.06	0.01	17.98	99.71
Be	1.05	0.58	0.95	1.73
B	3.14	0.00	0.32	
Sc	0.33	0.37	3.07	2.71
V	0.85	1.08	1.17	0.92
Cr	0.57	0.47	1.74	2.12
Co	1.97	0.02	0.51	45.77
Ni	0.03	0.00	34.48	
Cu	0.22	0.05	4.50	19.51
Zn	4.89	0.08	0.20	12.73
Ga	0.01	0.01	70.08	75.15
Rb	0.00	0.01	416.24	124.55
Sr	0.04	0.01	25.22	198.97
Y	0.09	0.00	11.09	524.77
Zr	0.38	0.46	2.63	2.17
Nb	28.20	43.60	0.04	0.02
Mo	0.08	0.03	12.68	30.63
Ag	0.00	0.48		2.07
Cd	0.10	0.00	10.50	
Sn	5.83	6.62	0.17	0.15
Sb	0.19	0.12	5.23	8.54
Cs	0.10	0.00	10.51	
Ba	0.01	0.00	135.14	13862.50
La	0.06	0.00	15.69	
Ce	0.03	0.00	31.79	11050.97
Pr	0.07	0.00	13.62	713.10
Nd	0.03	0.00	28.76	
Sm	0.02	0.00	47.45	
Eu	0.61	0.00	1.63	
Gd	0.15	0.01	6.53	184.07
Tb	0.09	0.00	11.34	
Dy	0.19	0.00	5.19	
Ho	0.08	0.00	12.90	
Er	0.15	0.00	6.57	
Tm	0.05	0.05	21.49	21.63
Yb	0.07	0.00	14.31	
Lu	0.20	0.00	4.92	
Hf	0.95	0.97	1.06	1.03
Ta	36.95	41.75	0.03	0.02
W	20.79	16.04	0.05	0.06
Hg				

Tl	0.00	0.00		
Bi	0.03	0.00	33.85	11843.83
Pb	0.03	0.00	34.95	19936.11
Th	0.04	0.00	25.93	
U	0.15	0.17	6.68	5.85

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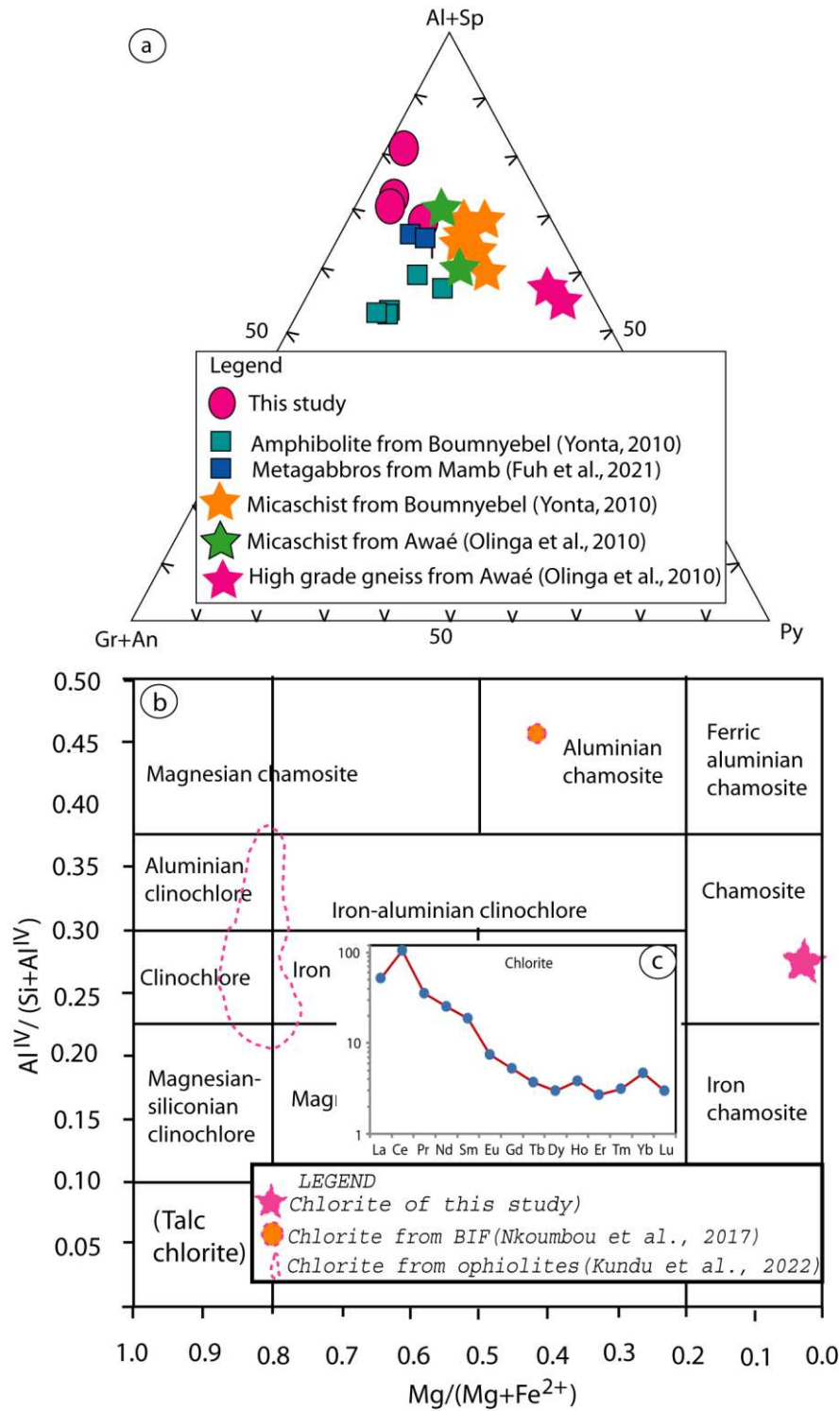


Fig. 7: (a) Gr+An versus Al+S versus Py ternary diagram showing the compositions of detrital garnet from Medoumou-Ebol area. Other compositions garnet from micaschists, gneiss, amphibolite and metagabbro are reported for comparison. The studied garnet is iron-rich, (b) Al^{IV}/(Si+Al^{IV}) versus Mg/(Mg+Fe²⁺) diagram for the nomenclature of chlorite of Medoumou-Ebol area, (c) chlorite REE pattern (normalization values from Pourmand et al., 2012)

4. Discussion

4.1. Signification of U-Pb rutile age

Several authors have already attempted to date the detrital rutile from the alluvial deposits of the PYG. They noted that dating alluvial rutile grains is difficult due to the small proportion of reliable data obtained from analyses (e.g. Stendal et al., 2006). Bineli et al. (2020) obtained only 53 good analyses out of 120 analyses. Four groups of ages (719 ± 32 Ma, $n=2$ analyses; 661 ± 21 Ma, $n=9$; 630 ± 6 Ma, $n=4$; and 561 ± 15 Ma, $n=24$) were reported in rutile grains collected west and east of Yaoundé, and were interpreted in terms of four main Neoproterozoic rutile growth events in the PYG. The youngest age of 522 ± 6 Ma was attributed to lead loss during Ediacaran tectonism (Bineli et al., 2020). In this study, 36 LA-ICP MS U-Pb analyses of rutile grains were performed, but only 13 analyses were of good quality and used in dating. Alluvial rutile of Medoumou-Ebol yielded a U-Pb age range from 507 ± 41 Ma to 601 ± 50 Ma. Three concordia ages of 588 ± 27 Ma, 549 ± 12 Ma and 518 ± 11 Ma and corresponding similar weighted mean ages were obtained from the data (figure 5). The ages recorded in detrital rutile of Medoumou-Ebol area partially overlap, within error, with the last two growth periods ($583\text{--}581 \pm 13$ Ma and 561 ± 8 Ma) of rutile crystals in the medium-grade schists of the Yaoundé Pan-African Group above-mentioned. The peculiar aspect of the data presented here is that all these ages are revealed by a single rutile crystal. The deduced crystal growth episodes are shown in (figure, 8). The concordia display similar characteristics with no evidence of late perturbation after crystallisation (figure 5). Indeed, most works dealing with dating the Pan-African formations used zircon crystals and the results show that the last event occurred around 550 Ma, e.g. Batié Pan-African granitoids emplaced during a wide range between 630 and 547 Ma (e.g. Kwékam et al., 2020). Few recent works using *in-rock* and detrital rutile show a wide range of ages from 719 ± 32 Ma to 522 ± 6 Ma. It is well known that the temperature closure of zircon is > 900 °C, while that of rutile is ca 600 °C (Cherniack, 2000). Based on the cooling rates ($3.8\text{--}1.7$ °C/Ma) determined in previous study (Bineli et al., 2020) and an arbitrary acceleration of 2 %/Ma, the rutile closure at 600 °C may occur at least 47.5 Ma after the closure of zircon U-Pb system in the same rock. It is very tempting to suggest that the 518 ± 11 Ma age belongs to the waning stage of the Pan-African metamorphism. More investigation is necessary to solve this enigma.

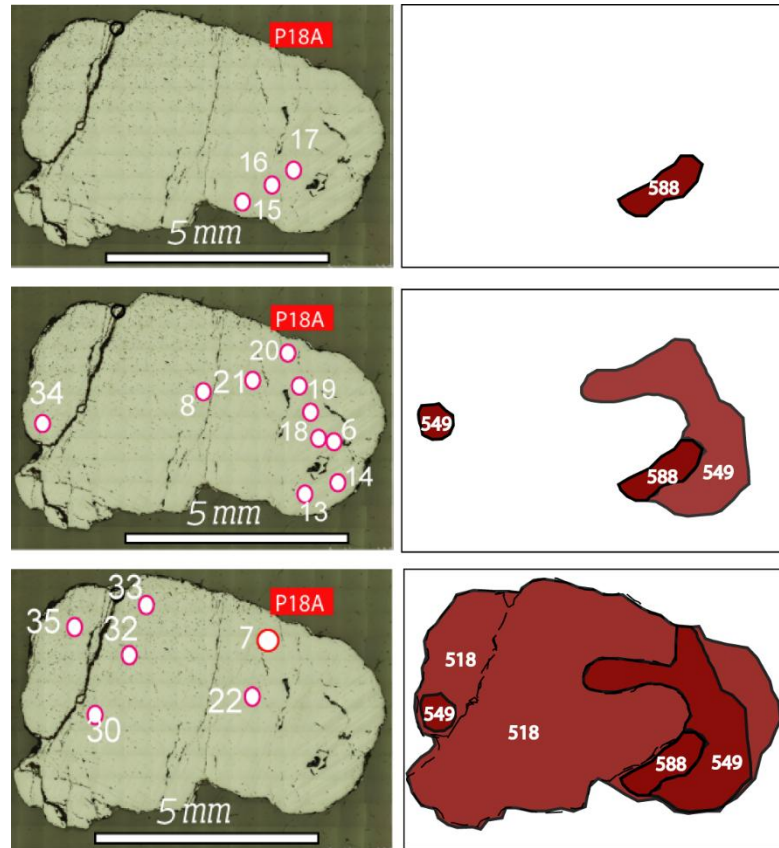


Figure 8: Illustration of rutile crystal growth in three episodes as deduced from U-Pb LA-ICP-MS data

In summary, a long period (601-518 Ma) of the history of the pan-African orogeny has been recorded in a single rutile crystal from the Medoumou-Ebol alluvium. At the regional scale, similar U-Pb ages yielded by monazite of garnet-kyanite micaschists and migmatites from Boumnyebel area, West of Yaoundé (653, 622 Ma, Yonta et al., 2009), and metasediments of Yaoundé (613, 605, 586 Ma, Owona et al., 2011) are recorded. Other ages are registered in metamorphic amphibole and biotite of the metagabbro of Mamb, west of Yaoundé (Ar-Ar : 601 ± 3 Ma - 280 ± 4 Ma, Fuh et al., 2021a), in a granite intrusion at Colomines gold district, East-Cameroon (K-Ar : 617 ± 15 - 543 ± 13 Ma, Fuh et al., 2021b) and two micas granite around Nyos, West Cameroon (U-Pb : 620 ± 9 - 561 ± 3 Ma, Li et al., 2017).

4.2. Provenance

Cr versus Nb diagram (Fig. 9) was used to determine the provenance of the alluvial rutile from Medoumou-Ebol area. This diagram shows the limit between the field of rutile issued from metapelitic rocks and the field of rutile that has crystallized in the metamafic rocks (Zack et al., 2004b; Meinhold et al., 2008). All analyses of rutile from Medoumou-Ebol area plot in the field of metapelitic rutile. The data of alluvial rutile from

other areas of the Yaoundé Pan-African group (Stendal et al., 2006; Ngo Bidjeck et al., 2020) are plotted here for comparison. Some of these rutile crystals occupy the field of metamafic rutile (Fig. 9). Also, Fe content of rutile can be used as an indicator of metamorphic origin since metamorphic rutile contains mostly > 1000 ppm Fe (Zack et al., 2004b; Meinhold et al., 2008). The Fe contents of the investigated rutile grains range from 1484 to 8987 ppm (ESM3) leading to the conclusion that the studied rutile grains were derived from the alteration of metamorphic rocks. In addition, the $\log(\text{Cr}/\text{Nb})$ ratio values show distinct domains for rutile from metamafic source lithologies from metapelitic (Zack et al., 2004b). All the analyzed alluvial rutile grains from Medoumou-Ebol area have negative values of $\log(\text{Cr}/\text{Nb})$ ratio, typical of metapelitic source lithology. But Meinhold et al. (2008) warned that the method is applicable, except for rutile displaying very low Cr and very low Nb (< 800 ppm) contents. One crystal of the studied rutile shows low Nb content (11A-5: 534 ppm, table 3a). Another crystal shows a Nb-poor core (18A-6: 763 ppm) and a Nb-rich rim (18A-7: 1174 ppm, Table 3a). Such a variation was reported in a metamorphic rutile from ultrahigh-pressure quartzite in the Sulu orogen, China (Gao et al., 2014).

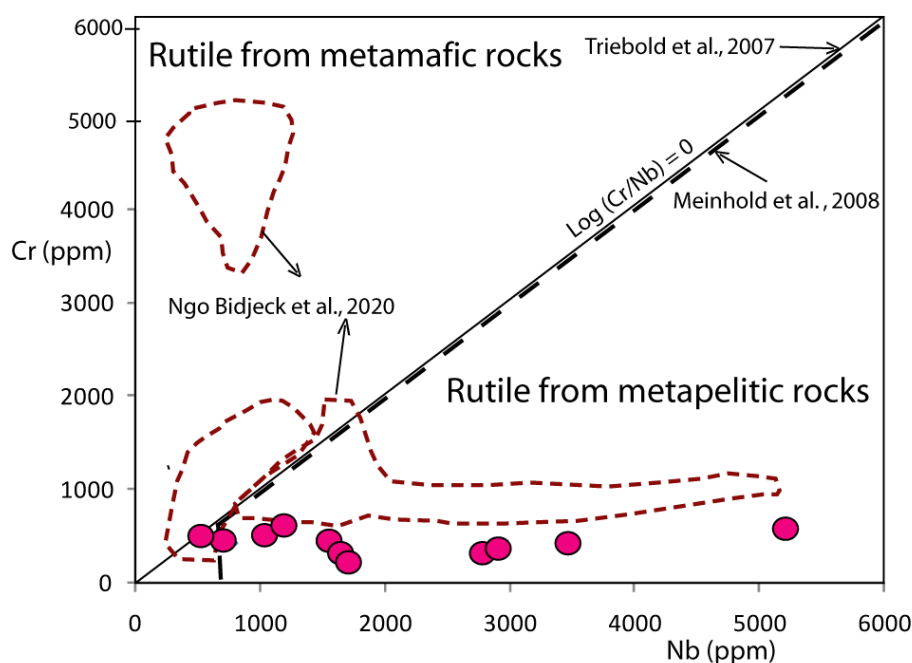


Fig. 9: Cr *versus* Nb diagram showing the metapelitic provenance of alluvial rutile from Medoumou-Ebol area, Cameroon (Meinhold et al., 2008). Cr contents of the studied rutile are lower than the data of Ngo Bidjeck et al. (2020).

4.3. Assessment of metamorphic conditions

4.3.1. Garnet geobarometry

Wu (2019) observed a negative relationship between the Fe/Ca ratio of the garnet from metapelites and pressure, deducing that net-transfer including intracrystalline Fe-Ca is pressure-sensitive. Based on this relationship, he developed a garnet geobarometer applicable to metapelites. Keeping in mind the metapelitic origin of the detrital rutile crystals of Medoumou-Ebol area, the metapelite garnet geobarometer is used here to determine their crystallization pressures. The compositions of garnet crystals from the Medoumou-Ebol area meet the criteria required for using the garnet geobarometer, with the value of $X_{Ca} = [Ca/(Fe+Mg+Ca+Mn)]$ comprised between 0.02 and 0.29. The results indicate a narrow crystallization pressure range from 10.11 to 10.37 kbars (Table 10). For comparison, the same geobarometer was applied to the compositions of garnet crystals from the mica schists of Awaé-Ayos (Olinga et al., 2010), a region near the Medoumou-Ebol area, and the results obtained (9.5 and 10.0 kbars) are slightly lower than the pressures of detrital rutile. The garnet crystals from the mica schists of Boumnyebel, west of Yaoundé, yield a crystallization pressure range from 10.11 to 10.40 kbars. A cross-section in a garnet crystal from the Maboye migmatites located 15 km NW of Boumnyebel shows a core-to-rim decreasing pressure from 10.55 to 9.95 kbars which can be reconciled with a crystallization during exhumation (Mvondo et al., 2003; Nkoumbou et al., 2014 ; Fuh et al., 2021; Kundu et al., 2022).

4.3.2. Rutile geothermometry

Many geothermometers have been established for the calculation of the crystallisation temperature of rutile. Zack et al. (2004a) presented an empirically calibrated Zr-in-rutile thermometer expressed as:

$$T(^{\circ}C) = 127.8 \times \ln(Zr_{ppm}) - 10 \quad (1)$$

With an error of $\pm 50^{\circ}C$. This equation yielded the crystallization temperature of the studied rutile crystals ranging from 525 to 650°C.

The second equation established by Watson et al. (2006) is expressed as:

$$T(^{\circ}C) = \frac{4470}{7.36 - \log_{10}(Zr_{ppm})} - 273 \quad (2)$$

With an error of $\pm 20^{\circ}C$. The results range from 490 to 600°C for the crystallisation of rutile of Medoumou-Ebol area.

The thermometer established in the α -quartz field at a pressure of 10 kbar (Tomkins et al., 2007) is expressed as follows:

$$T (^{\circ}\text{C}) = \frac{83.9 + 0.410 \times P}{0.1428 - R \times \ln(\text{Zr}_{\text{ppm}})} - 273 \quad (3)$$

within an error of $\pm 30^{\circ}\text{C}$. Pressure value (10.37 kbar) of garnet-rutile intergrowth above-mentioned was used in this equation. The values of temperature yielded range from 499 to 609 $^{\circ}\text{C}$ (Table 10).

All the results are summarized in histograms (Fig. 10a) and a binary diagram (Fig. 10b). The histograms show a unimodal distribution with an identical mode value (562.5 $^{\circ}\text{C}$). The temperature values obtained using the three geothermometers are similar—within the error—or even identical. This similarity is illustrated in Figure 10 by the overlap of most of the results from the three equations. It should be noted that below 500 $^{\circ}\text{C}$, the empirical Zr-in-rutile geothermometer designed by Zack et al. (2004a) yields lower temperature values than the other two geothermometers established by Watson et al. (2006) and Tomkins et al. (2007). The histograms show a unimodal distribution with an identical mode value (562.5 $^{\circ}\text{C}$). Compared with the narrow temperature range (514-530 $\pm 30^{\circ}\text{C}$) of alluvial rutile crystals investigated by Ngo Bidjeck et al. (2020), the values obtained on rutile from Medoumou-Ebol cover a large interval (490-609) with an exceptional low value at 430 $\pm 50^{\circ}\text{C}$. The highest values are similar to those exhibited by Zr of in-situ rutile of gneiss and mica schists (Ngo Bidjeck et al. 2020). The results are similar to those yielded by rutile from heavy mineral concentrates of west and east of Yaoundé. Moreover, they are comparable to the temperatures between 609 and 623 $^{\circ}\text{C}$ yielded by ten garnet-biotite pairs from mica schist of west of Yaoundé (Stendal et al., 2006). At a regional scale, the results from this study matches very well the distribution of Zr-in rutile temperatures mapped by Knudsen et al. (2013) except the high 700-900 $^{\circ}\text{C}$ range which corresponds to the exhumed Yaoundé migmatites (Fig. 1b).

A summary of P-T conditions of detrital rutile and garnet from Medoumou-Ebol area is shown in Fig. 11. The temperature range spans from the grt + st + ms + chl + qtz field through the grt + ky + ms + chl + qtz field up to the grt + ky + ms + qtz field. The P-T conditions of micaschists of the neighbouring Awae-Ayos area (Olinga et al., 2010), and micaschists and gneiss of Boumnyebel (Yonta et al., 2009, Stendal et al., 2006) are plotted for comparison. Micaschists of Awae-Ayos are at lower pressures while micaschists and gneiss from Boumnyebel recorded a wide range of pressure (8-10 kbar) that includes the narrow range of Medoumou-Ebol area.

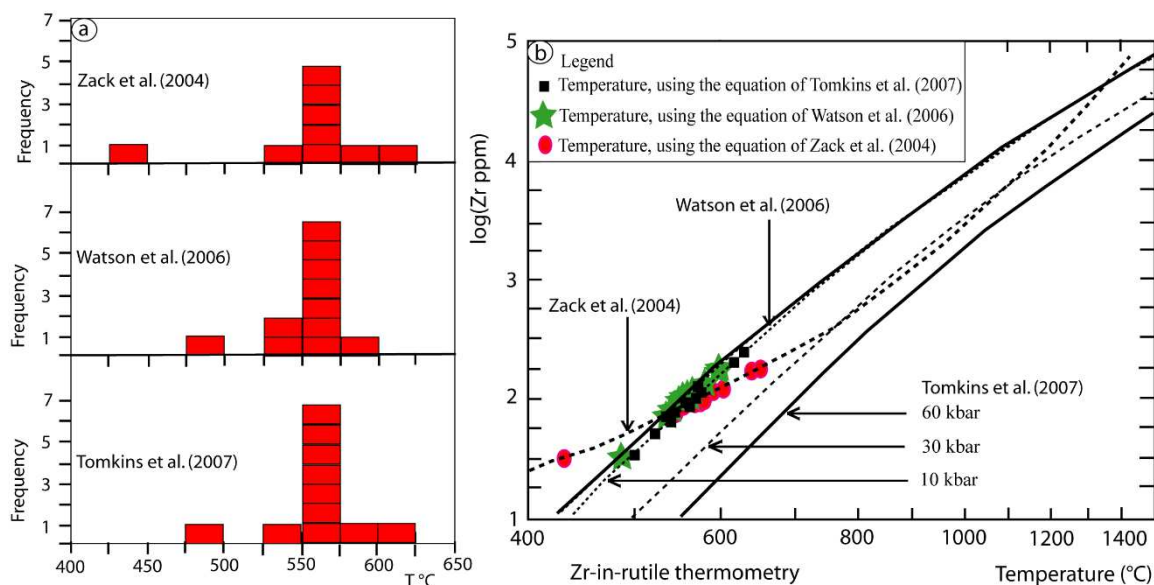


Fig. 10: (a) Histograms of temperatures and (b) $\log Zr_{(ppm)}$ versus Temperature ($^{\circ}C$) diagram where most values obtained from Watson et al. (2006) and Tomkins et al. (2007) overlap

Table 10: Temperatures of crystallization of rutile from Medoumou-Ebol area, and pressure estimates according to Wu (2020). (Zr-in-rutile thermometry; Z: equation of Zack et al. (2004a); W: equation of Watson et al. (2006); T: equation of Tomkins et al. (2007) at 10.34 kbar in the field of stability of α -quartz)

Sample	T ($^{\circ}C$)			P (kbar)	
	Z	W	T	Analysis	
	$\pm 50^{\circ}C$	$\pm 20^{\circ}C$	$\pm 30^{\circ}C$	N $^{\circ}$	
P11A-05	577	560	570	8	10.11
P12A-11	566	554	564	15	10.32
P14A-12	604	575	584	18	10.37
P15A-10	550	546	556	20	10.30
P15B-09	525	534	543		
P18A-06	430	489	499		
P18A-07	644	597	607		
P1A-01	561	552	561		
P1A-02	565	554	563		
P5B-03	585	564	574		
P7A-04	563	553	563		

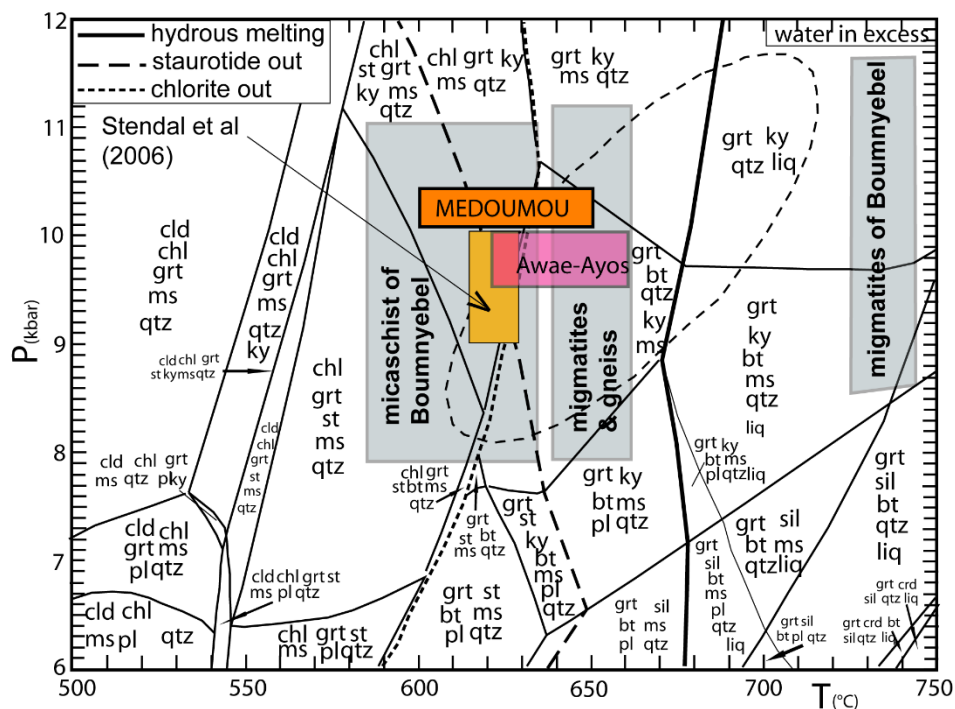
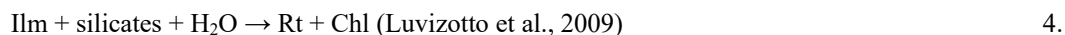


Fig. 11: P-T pseudosection (adapted from Yonta et al., 2009) and plot of pressure revealed by garnet geobarometry (Wu, 2019) and temperature obtained through Zr-in-rutile thermometry (Zack et al., 2004a; Watson et al., 2006; Tomkins et al., 2007). Other data of micaschists from Awae-Ayos (Olinga et al., 2010) and Boumnyebel area (Stendal et al., 2006; Yonta et al., 2009) are plotted for comparison (see text)

4.5. Advantages of microtextures

4.5.1. Chlorite inclusion in rutile.

Figure 6a shows an amoeboid-shaped chlorite inclusion in a rutile crystal. In medium-grade metasedimentary rocks from Erzgebirge (Germany), progressive crystallization of rutile and related chlorite at the expense of ilmenite is reported (Luvizotto et al., 2009). It is suggested that the Fe released from the breakdown of ilmenite is used, together with the elements available in matrix minerals (quartz and phyllosilicates), to crystallize chlorite according to the simplified metamorphic reaction:



In the light of such evolution evidenced in equation 4, the association rutile-chlorite (Fe-rich) of Fig. 6a can be considered as the products of the breakdown of ilmenite during prograde metamorphism of the source metapelite.

4.5.2. Rutile inclusion in garnet

Many garnet crystals exhibit rutile inclusions (e.g. Fig. 6b). This microtexture is common in garnets from mica schists (e.g. Yonta et al., 2009; Tinkam and Ghent, 2005; Sengün et al., 2017). It generally corresponds to phases that occurred earlier or during the crystallization of the garnet.

4.5.3. Garnet band in rutile.

Garnet showing straight boundary with rutile is a peculiar feature (figure 6c). Such straight contact (and triple joint at nearly 120 °C in rocks) suggests an equilibrium paragenesis at upper-amphibolite and granulite facies metamorphism (Barbey et al., 1990). The crystallization pressure of this garnet band is 10.111 kbars revealing that garnet and related rutile crystallized at great depth (may be > 30 km), likely at the lower crust level. An alternative explanation may be a thrusting or collisional environment where compressive stress is notable (Fig. 1b).

4.5.4. Interpenetrated garnet-rutile

In the interpenetrated garnet-rutile microtexture (Fig. 6d), the relationships between the different lobes suggest two possible metamorphic processes: (i) sometimes, the rutile-garnet contact looks like a crystallization of one at the expense of the other. This can only be considered in the case of pseudomorphism without reaction byproducts; (ii) the second, more likely interpretation, is the concomitant crystallization of garnet and rutile. The interpenetration of the crystals is interpreted in terms of microtexture dictated by the forms and the locations, in the protolith, of the minerals at the expense of which the garnet and rutile grew.

Conclusions

The results of the study of the chemistry of rutile and related minerals from the alluvia of Medoumou-Ebol area shed light on many features of metamorphic processes of the Pan-African Yaoundé group. Each type of data leads to specific conclusions.

1. Microtextures have preserved the characteristic features of the prograde metamorphic phase (chlorite inclusions in rutile) and the peak phase such as straight garnet-rutile contacts and garnet-rutile intergrowth textures attributable to an upper-amphibolite-facies paragenesis.
2. U-Pb isotopic data reveal that a rutile crystal formed during three episodes: 588 Ma, 549 Ma, and 518 Ma. The age marking the end of Pan-African metamorphism—and thus the Pan-African orogeny—previously established at 550 Ma via U-Pb zircon dating, is pulled to 518 Ma; this is likely due to the closure of the rutile U-Pb system at a temperature (600°C) lower than that of zircon (>900°C).

3. Chemical analyses show that garnet crystals interlocked with rutile are grossular and spessartine-rich almandine. Chlorite inclusion in rutile is an iron-rich chamosite.
4. Cr-Nb contents of the alluvial rutile in the Medoumou-Ebol area point to a metapelitic source.
5. Zr-in-rutile thermometry and Fe-Ca-in garnet barometry yielded P-T conditions ranges of 10.11-10.37 kbar, and 601-507°C corresponding to the upper-amphibolite facies.

Acknowledgements: This paper is a part of a Ph.D in preparation by the first author. The first author greatly appreciates the help of Pr Ndjigui Paul-Désiré during fieldwork.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authorship:

Kuika Badel Christel: acquisition of data, analysis and interpretation of data, drafting the article, revision of the manuscript; **Fuh Calistus Gentry:** conception and design of the study, revising the article; **Gomah-Pettry Jean Richard:** Data curation, revising the manuscript; **Tchakounté Numbem Jacqueline:** Data curation, revising the manuscript; **Charles Nkoumbou:** conception and design of the study, revising and final approval of the version to be submitted, revision of the manuscript.

References

- Assomo Ngono, G. S., Ganwa A. A., Ntomba S. M. & Ndjigui P. D. (2021). Provenance, nature, and U-Pb zircon geochronology of Ngaye rocks (Adamawa-Yadé shield, Central Cameroon): New insights into the evolution of Archean crust within the Pan-African belt. *Geological Journal*, 1-23, DOI:10.1002/gj.4231
- Axelsson, E., Pape, J., Berndt, J., Corfu, F., Mezger, K. & Raith, M. M. (2018). Rutile R632 – a new natural reference material for U-Pb and Zr determination. *Geostandards and Geoanalytical Research*, 42, 319-338 <https://doi.org/10.1111/ggr.12213>
- Barbey, P., Macaudière, J. & Nzenti J. P. (1990). High pressure dehydration melting of metapelites. Evidence from the migmatites of Yaoundé (Cameroon). *Journal of Petrology*, 31, 401-427
- Bessoles, B. & Trompette, R. (1980). Géologie d'Afrique : La chaîne panafricaine, 'zone mobile d'Afrique centrale' (partie sud) et zone soudanaise. *Mém BRGM, Orléans*, 92, 394p
- Bineli Betsi T., Ngo Bidjeck L. M., Mvondo, H., Mama Nga, L. N. Y., Molotouala, C. A. & McFarlane, C. (2020). Rutile LA-ICP-MS U–Pb geochronology and implications for tectono-metamorphic evolution in the Yaoundé Group of the Neoproterozoic Central African Orogeny. *Journal of African Earth Sciences*, 171, 103939
- Bourdelle, F. & Cathelineau, M. (2015). Low-temperature chlorite geothermometry: a graphical representation based on a $T-R^{2+}$ -Si diagram. *European Journal of Mineralogy*, 27, 617-626
- Bourdelle, F., Parra, T., Chopin, C. & Beyssac, O. (2013). A new chlorite geothermometer for diagenetic to low-grade metamorphic conditions. *Contribution to Mineralogy and Petrology*, 165, 723-735
- Caron, V., Ekomane, E., Mahieux, G., Moussango, P. & Ndjeng, E. (2010). The Mintom Formation (new): sedimentology and geochemistry of a Neoproterozoic, paralic succession in south-east Cameroon. *Journal of African Earth Sciences*, 57, 367-385
- Caron, V., Mahieux, G., Ekomane, E., Moussango, P., Babinski, M. (2011). One, two or no record of late Neoproterozoic glaciation in South-East Cameroon? *Journal of African Earth Sciences*, 59, 111-124
- Cherniak, D. J. (2000). Pb diffusion in rutile. *Contribution to Mineralogy and Petrology*, 139, 198-207
- De Caritat, P., Hutcheon, I., Walshe, J. L. (1993). Chlorite geothermometry: a review. *Clays and Clay Minerals*, 41, 219-239

539 Donkeng Sahazang, R., Fuh, C. G., Makougni Ngonbeu, L.L. & Nkoumbou, C. (2025). Petrography and
 540 geochemistry of the REE-rich BIFs of the southern part of the Nkom massif, north of Edea, Nyong complex,
 541 Cameroon. *Journal of African Earth Sciences*, 229, 105700

542 Fuh, C.G., Nkoumbou, C., Tchakounte, N. J., Kundu O. M. & Tchouankoue, J. P. (2021a) Petrology, geochemistry,
 543 Ar-Ar isotopes of an arc related calc-alkaline pluton from Mamb (Pan-African Yaounde group, Cameroon):
 544 A testimony to the subduction of a hot oceanic crust. *Lithos*, <https://doi.org/10.1016/j.lithos.2021.105973>

545 Fuh, CG, Tchakounté, N. J., Kundu, O.M., Tchop, J.L. & Nkoumbou, C. (2021b). Four Pan-African plutonic sets
 546 of the Colomines gold district (East-Cameroon): Petrogenesis, K-Ar dating and geodynamic significance.
 547 *Journal of African Earth Sciences* 181, 104220

548 Ganwa, A. A., Wolfgang, F., Wolfgang, S., Ekodeck, G. E., Kongyuy Shang, C. & Ngako, V. (2008). Archean
 549 inheritances in the pyroxene–amphibole-bearing gneiss of the Méiganga area (Central North Cameroon):
 550 Geochemical and $^{207}\text{Pb}/^{206}\text{Pb}$ age imprints. *C.R. Geoscience*, 340, 211-222. doi:10.1016/j.crte.2007.12.009

551 Gao, X. Y., Zheng, Y.F., Xia X .P. & Chen, Y.X. (2014). U-Pb ages and trace elements of metamorphic rutile
 552 from ultra high-pressure quartzite in the Sulu orogen. *Geochimica et Cosmochimica Acta*, 143, 87-114

553 Hu, Z. C., Zhang, W., Liu, Y.S., Gao, S., Li, M., Zong, K. Q., Chen, H. H., Hu, S.H. (2015). “Wave” signal-
 554 smoothing and mercury-removing device for laser ablation quadrupole and multiple collector ICPMS
 555 analysis: application to lead isotope analysis. *Analytical Chemistry*, 87, 1152-1157

556 Knudsen, C., Penaye, J., Mehlsen, M., McLimans, R. K. & Kalsbeek, F. (2013). Titanium minerals in Cameroon.
 557 *Geol Surv Den Greenl Bull*, 28, 73-76. Open access: www.geus.dk/publications/bull.

558 Kundu O.M., Minyem, D., Tamen, J., Nkoumbou, C., Fuh, C. G. & Tchakounte, N.J. (2022). Petrology of
 559 ophiolites of Memel, Nsimé-Kellé and Mapan (Yaoundé group): Evidence of the geodynamic evolution of
 560 the Pan-African orogeny in South Cameroon. *Journal of African Earth Sciences*, 191, 104537

561 Li, X. H., Chen, Y., Tchouankoue, J. P., Liu, C. Z., Li, J., Ling, X. X., Tang, G. Q. & Liu, Y. (2017). Improving
 562 geochronological framework of the Pan-African orogeny in Cameroon: New SIMS zircon and monazite U-
 563 Pb age constraints. *Precambrian Research*, 294, 307-321

564 Locock, A. J. (2008). An Excel spreadsheet to recast analyses of garnet into end-member components, and a
 565 synopsis of the crystal chemistry of natural silicate garnets. *Computers & Geosciences*, 34, 1769-1780

566 Ludwig, K. R. (2003). ISOPLOT 3.00: A Geochronological Toolkit for Microsoft Excel. Berkeley Geochronology
 567 Center, California, Berkeley, 39 pp.

568 Lueder, M., Hermann, J., Tamblyn, R., Rubatto, D., Lanari, P. & Markmann, T. A. (2025). Intra-grain variability
 569 of hydrogen and trace elements in rutile. *Chemical Geology*, 671, 122480,
 570 <https://doi.org/10.1016/j.chemgeo.2024.122480>
 571 Meinhold, G., Anders, B., Kostopoulos, D., Reischmann, T. (2008). Rutile chemistry and thermometry as
 572 provenance indicator: an example from Chios Island, Greece. *Sedimentary Geology*, 203, 98-111
 573 Mvondo, H., den Brok, S. W. J. & Mvondo Ondo, J. (2003). Evidence for symmetric extension and exhumation
 574 of the Yaoundé nappe (Pan-African fold belt). *Journal of African Earth Sciences*, 36, 215-231
 575 Nédélec, A., Macaudière, J., Nzenti, J. P. & Barbey, P. (1986). Evolution structurale et métamorphique des schistes
 576 de Mbalmayo (Cameroun). Implication pour la suture de la zone mobile pan-africaine d'Afrique Centrale,
 577 au contact du craton du Congo. *Comptes Rendus de l'Académie des Sciences, Paris*, 303, 75-80
 578 Ngako, V., Affaton, P. & Njongfang, E., (2008). Pan-African tectonics in north-western Cameroon: implication
 579 for the history of western Gondwana. *Gondwana Research*, 14, 509-522.
 580 Ngako, V., Njongfang, E., 2011. Plates amalgamation and plate destruction, the western Gondwana history. In:
 581 Closson, D. (Ed.), *Tectonics*. (ISBN 978-953-307-545-7, InTech. Available from:
 582 [http://www.intechopen.com/books/tectonics/plates-amalgamation-and-plate-destruction-the-](http://www.intechopen.com/books/tectonics/plates-amalgamation-and-plate-destruction-the-westerngondwana-history)
 583 [westerngondwana-history](http://www.intechopen.com/books/tectonics/plates-amalgamation-and-plate-destruction-the-westerngondwana-history)).
 584 Ngamy Kamwa, A., Tchakounté, J. N., Nkoumbou, C., Owona, S., Tchouankoue, J. P. & Mvondo Ondo, J.
 585 (2019). Petrology and geochemistry of syncollisional Pan-African granitoid intrusion in the Archaean
 586 Adamawa-Yade crust: the Yoro-Yangben massif, (Sw-Bafia, Cameroon). *Journal of African Earth*
 587 *Sciences*, 150, 401-414
 588 Ngo Bidjeck, L. M., Bineli Betsi, T., Mama Nga, L. N. Y., Ngo Belnoun, R., Molotouala, C. A., McFarlane, C. &
 589 Bitom, L. D. (2020). Geochemistry of rutile from the Pan-African Yaoundé metamorphic group:
 590 Implications for provenance and conditions of formation. *Journal of African Earth Sciences*, 170, 103912
 591 Nkoumbou, C., Barbey, P., Yonta-Ngouné, C., Paquette, J. L. & Villiéras, F. (2014). Pre-collisional geodynamic
 592 context of the southern margin of the Pan-African fold belt in Cameroon. *Journal of African Earth Sciences*,
 593 99, 245-260
 594 Nkoumbou, C., Fuh, C. G., Tchakounte, N. J., Belle Ekwe, Y. V. & Nwagoum, K. C.S. (2017). Petrology and
 595 geochemistry of REE-rich Mafé banded iron formations (Bafia group, Cameroon). *C R Geoscience*
 596 349:165-174

597 Nkoubou, C., Njopwouo, D., Villieras, F., Njoya, A., Yonta Ngouné, C., Ngo Ndjock, L., Tchoua, F., Yvon, J.
598 (2006b). Talc indices from Boumnyebel (Centre-Cameroon), physico-chemical characteristics and
599 geochemistry. *Journal of African Earth Sciences*, 45, 61-73

600 Nkoubou, C., Yonta Ngouné, C., Villieras, F., Njopwouo, D., Yvon, J., Ekodeck, G. E., Tchoua, F. M. (2006b).
601 Découverte de roches à affinité ophiolitique dans la chaîne panafricaine au Cameroun: les talcschistes de
602 Ngoung, Lamal Pougué et Bibodi Lamal, *C R Géoscience*, 338, 1167-1175

603 Nzenti, J. P., Barbey, P., Macaudière, J. & Soba, D. (1988). Origin and evolution of late precambrian high-grade
604 Yaoundé gneisses. *Precambrian Research*, 38, 91-109

605 Nzesseu Nandjou, V., Bineli Betsi, T., Belinga Belinga, C., Ekomane, E. & Kelepilé, T. (2025). Rutile U-Pb ages
606 and implications for the extension of the timing of the Eburnean overprint in the Ntem Complex (southern
607 Cameroon) portion of the Congo Craton. *Journal of African Earth Sciences*, 221, 105459,
608 <https://doi.org/10.1016/j.jafrearsci.2024.105459>

609 Olinga, J. B., Minyem, D., Mpesse, J. E. & Ekodeck, G. E. (2010). Deformation history of the Yaoundé Group in
610 the Awae-Ayos area (Southern-Cameroon): Evidence for Pan-African thrust tectonics. *Journal of the*
611 *Cameroon Academy of Science*, 9, 33-46

612 Owona, S., Schulz, B., Ratsbacher, L., Mvondo-Ondoa, J., Ekodeck, G. E., Tchoua, F. & Affaton, P. (2011). Pan-
613 African metamorphic evolution in the southern Yaounde Group (Oubanguide Complex, Cameroon) as
614 revealed by EMP-monazite dating and thermobarometry of garnet metapelites. *Journal of African Earth*
615 *Sciences*, 59, 125-139

616 Paton, C., Hellstrom, J., Paul, B., Woodhead, J. & Hergt, J. (2011). Iolite: Freeware for the visualisation and
617 processing of mass spectrometric data. *Journal of Analytical Atomic Spectrometry*, 26, 2508-2518

618 Pourmand, A., Dauphas, N., Ireland, T. J. (2012). A novel extraction chromatography and MC-ICP-MS technique
619 for rapid analysis of REE, Sc and Y: Revising CI-chondrite and Post-Archean Australian Shale (PAAS)
620 abundances. *Chemical Geology*, 291, 38-54

621 Sengün, F., Zack T. & Topuz G. (2017). Rutile geochemistry of eclogites and associated garnet-mica schists in the
622 Biga Peninsula, NW Turkey, *Chimie der Erde*, 77, 3:503-515.

623 Stendal, H., Toteu, S. F., Frei, R., Penaye, J., Njel, U. O., Bassahak, J., Nni, J., Kankeu, B., Ngako, V., Hell, J. V.
624 (2006). Derivation of detrital rutile in the Yaoundé region from the Neoproterozoic Pan-African belt in the
625 southern Cameroon (Central Africa). *Journal of African Earth Sciences*, 44, 443-458

626 Tan, W., Wang, C. Y., He, H., Xing, C., Liang, X. L. & Dong, H. (2015). Magnetite-rutile symplectite derived
 627 from ilmenite-hematite solid solution in the Xinjie Fe-Ti oxide-bearing, mafic-ultramafic layered intrusion
 628 (SW China). *American Mineralogist*, 100, 2348-2351
 629 Tchakounté, J., Eglinger, A., Toteu, S. F., Zeh, A., Nkoubou, C., Mvondo-Ondoa, J., Penaye, J., de Wit, M.,
 630 Barbey, P. (2017). The Adamawa-Yadé domain, a piece of Archaean crust in the Neoproterozoic Central
 631 African Orogenic Belt (Bafia area, Cameroon). *Precambrian Research*, 299, 210-229
 632 Tchakounté, N. J., Fuh, C. G., Ngamy, K. A., Metang, V., Mvondo Ondoa, J. & Nkoubou, C. (2021). Petrology
 633 and geochemistry of the Pan-African high-K calc-alkaline to shoshonitic-adakitic Bapé plutonic suites
 634 (Adamawa-Yade block, Cameroon): evidence of a hot oceanic crust subduction. *International Journal of*
 635 *Earth Sciences*, 110, 2067-2090
 636 Tinkam D.K. & Ghent E.D., (2005). Estimating P-T conditions of garnet growth with isochemical phase diagram
 637 sections and the problem of effective bulk-composition. *The Canadian Mineralogist*, 43, 35-50.
 638 Tomkins, H. S., Powell, R. & Ellis, D. J. (2007). The pressure dependence of the zirconium-in-Rutile thermometer.
 639 *J Metamorph Geol*, 25, 703-713
 640 Tonje, J. C., Ndjigui, P. D., Nyeck, B., Bilong, P. (2014). Geochemical features of the Matomb alluvial rutile from
 641 the Neoproterozoic Pan-African belt, southern Cameroon. *Chemie der Erde*, 74, 557-570
 642 Toteu, F. S., de Wit, M., Penaye, J., Drost, K., Tait, J. A., Houketchang Bouyo, M., Van Schmus, W. R., Jelsma,
 643 H., Moloto-A-Kenguemba, G. R., da Silva Filho, A. F., Lerouge, C. & Doucouré, M. (2022).
 644 Geochronology and correlations in the Central African Fold Belt along the northern edge of the Congo
 645 Craton: New insights from U-Pb dating of zircons from Cameroon, Central African Republic, and south-
 646 western Chad. *Gondwana Research*, 107, 296-324
 647 Toteu, S. F., Penaye, J. & Poudjom Djomani, Y. (2004). Geodynamic evolution of the Pan-African belt in central
 648 Africa with special reference to Cameroon. *Canadian Journal of Earth Sciences*, 41, 73-85
 649 Vic, G., Bernard, J., Chevillard, M., Bailly, L., Ndongue, C., Itard, Y., Melleton, J., Martelet, G., Kouokam, E.,
 650 Fournier, E., Couëffé, R. & Keutia, D. (2025). Country-scale lithogeochemical interpretation of stream
 651 sediment dataset in central Cameroon: Toward an integrated tool to support national geophysics surveys
 652 and geological mapping programs. *Applied Geochemistry*, 183, 106321,
 653 <https://doi.org/10.1016/j.apgeochem.2025.106321>
 654 Watson, E. B., Wark, D.A., Thomas, J. B. (2006). Crystallization thermometers for zircon and rutile. *Contribution*
 655 *to Mineralogy and Petrology*, 151, 413-433

656 Wu, C.-M. (2019). Original calibration of a garnet geobarometer in metapelites. *Minerals*, 9, 540,
657 doi:10.3390/min9090540

658 Yavuz, F., Kumral, M., Karakaya, N., Karakaya, M. Ç. & Yıldırma, D. K. (2015). A Windows program for
659 chlorite calculation and classification. *Computers & Geosciences*, 81, 101-113

660 Yonta-Ngoune, C., Nkoumbou, C., Barbey, P., Le Breton, N. & Montel, J. M. (2009). Geological context of the
661 Boumnyebel talcschists (Cameroon): Inferences on the Pan-African Belt of Central Africa. *CR Géoscience*,
662 342, 108-115

663 Zack, T., Moraes, R., Kronz, A. (2004a). Temperature dependence of Zr in rutile: empirical calibration of a rutile
664 thermometer. *Contribution to Mineralogy and Petrology*, 148, 471-488, [https://doi.org/10.1007/s00410-](https://doi.org/10.1007/s00410-004-0617-8)
665 004-0617-8

666 Zack, T., Voney Natten, H., kronz, A. (2004b). Rutile geochemistry and its potential use in quantitative provenance
667 studies. *Sedimentary Geology*, 171, 37-58

668 Zhang, L., Wu, J. L., Tu, J. R., Wu, D., Li, N., Xia, X. P., Ren, Z. Y. (2019). RMJG Rutile: A New natural reference
669 material for microbeam U-Pb dating and Hf isotopic analysis. *Geostandards and Geoanalytical Research*,
670 44, 133-145