Transpressional granite-emplacement model: Structural and magnetic study of the Pan-African Bandja granitic pluton (West Cameroon)

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The Pan-African NE–SW elongated Bandja granitic pluton, located at the western part of the Pan-African belt in Cameroon, is a K-feldspar megacryst granite. It is emplaced in banded gneiss and its NW border underwent mylonitization. The magmatic foliation shows NE–SW and NNE–SSW strike directions with moderate to strong dip respectively in its northern and central parts. This mostly, ferromagnetic granite displays magnetic fabrics carried by magnetite and characterized by (i) magnetic foliation with best poles at 295/34, 283/33 and 35/59 respectively in its northern, central and southern parts and (ii) a subhorizontal magnetic lineation with best line at 37/8, 191/9 and 267/22 respectively in the northern, central and southern parts. Magnetic lineation shows an ‘S’ shape trend that allows to (1) consider the complete emplacement and deformation of the pluton during the Pan-African D₂ and D₃ events which occurred in the Pan-African belt in Cameroon and (2) reorganize Pan-African ages from Nguessi Tchakam *et al.* (1997) compared with those of the other granitic plutons in the belt as: 686 ± 17 Ma (Rb/Sr) for D₁ age of metamorphism recorded in gneiss; and the period between 604–557 Ma for D₂–D₃ emplacement and deformation age of the granitic pluton in a dextral ENE–WSW shear movement.

1. Introduction

Spatial and temporal relationships between granites and regional tectonic structures suggest granite emplacement during compression rather than extension in many convergent orogenic belts (Hutton 1997; Brown and Solar 1998). Granite emplacement and deformation during regional tectonic events is

a challenging study, because granitic rocks do not always develop mesoscopic scale deformation fabrics. However, microstructural studies of granites can help to identify magmatic or solid-state deformation fabrics (Simpson 1985; Paterson *et al.* 1989; Bouchez *et al.* 1992).

Detailed lithotectonic study of the Pan-African orogeny (mainly along the N–S, N30°E and N70°E

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shear zones) in Cameroon (figure 1) reveals that it is marked by the emplacement of many plutonic massifs of granitic composition. The petrology and mesoscopic to microscopic structural features of a few granites have been studied (the Ngondo plutonic complex, the west-Tibati pluton, the two-mica granites from the Nkambé area and the Fomopéa

granitic pluton (figure 2), respectively by Tagné-Kamga (2003), Njanko *et al.* (2006), Tetsopgang *et al.* (2006) and Kwékam *et al.* (2010). However, their tectonic evolution remains poorly understood, due to lack of detailed structural data (e.g., anisotropy of magnetic susceptibility study on rocks). Indeed, the application of the anisotropy

Figure 1. (a) Geological sketch map of Central-North Africa (western Gondwana) (Ngako *et al.* 2008; redrawn and re-interpreted from Küster and Liegeois 2001); 1 = Craton; 2 = Inferred Craton; 3 = Pan-African remobilization; 4 = Neoproterozoic juvenile crust; (b) Pan-African structural map of Cameroon (Ngako *et al.* 2008; modified and re-interpreted from Toteu *et al.* 2001). Large grey arrow represents syn-D₁₋₃ regional main stress direction. Thick lines = shear zone (SZ): BSZ = Balché SZ; BNMB = Boule Noir-Mayo Balé; CCSZ = Central Cameroon SZ; GGSZ = Godé-Gormaya SZ; MNSZ = Mayo Nolti SZ; RLSZ = Rocher du Loup SZ; SSZ = Sanaga SZ. I: Paleo-proterozoic basement and Pan-African syntectonic granitoids; II: Meso- to Neoproterozoic volcano-sedimentary basins.

Figure 2. West Cameroon geological map showing the Bandja granitic pluton and neighbouring (Fomopéa and Batié-Bangou) plutons (Dumort 1968).

of magnetic susceptibility (AMS) to the study of granitoids has led to a better understanding of the tectonic history of plutons elsewhere and recently in Cameroon (Kankeu *et al.* 2009; Njanko *et al.* 2010; Kankeu *et al.* 2012; Dawai *et al.* 2013). Moreover, AMS is a widely accepted technique and a number of studies have investigated the relationship between AMS fabric and strain (Hrouda and Janak 1976; Borradaile 1988; Rochette *et al.* 1992; Tarling and Hrouda 1993; Borradaile and Henry 1997; Mamtani *et al.* 1999).

The aim of this paper is to combine field structures, microstructures and magnetic data to reconstruct the kinematic of emplacement of the Bandja Pan-African pluton and show its role in the Pan-African history of the west Cameroon.

2. Regional geological setting

2.1 The Pan-African belt in Cameroon

The Pan-African orogenic belt of Cameroon (figure 1) is one of the two main domains (together with the Archaean Ntem Complex) proposed by previous research works for the Precambrian basement rocks

in Cameroon. It is characterized by medium- to high-grade metamorphism, polycyclic deformation, possible reworking of older crust and generation of new granitic magmas. The Pan-African orogenic belt is also known as Pan-African North Equatorial Fold Belt (Nzenti *et al.* 1988) or Pan-African Belt of Central Africa (PBCA; Penaye *et al.* 1993; Toteu *et al.* 2001).

According to Ngako and Njonfang (2011), PBCA is a three-plate collision belt involving three major landmasses. The model proposed by these authors includes: the São-Francisco-Congo Craton (SFCC), the Eastern Saharan Block (ESB) and the West African Craton (WAC) (figure 1a). Collision in the north-south direction involved ESB and the northern margin of the SFCC originally differentiated into a basin and a range province. This collision generated an indent and intense deformation in the Cameroon domain (PBCA), following penetration of the Saharan rigid prong into the SFCC active margin between 640 and 580 Ma (Ngako and Njonfang 2011). Successive tectonic events recorded in this active margin involved: (i) crustal thickening, (ii) left- and right-lateral conjugate wrench movements, and (iii) right-lateral wrench

movements in the N70°E to EW direction. According to Ngako and Njonfang (2011), structural and kinematic data show that, although collision between the Trans-Sahara active margin and the WAC started at ca. 630 Ma, deformation in north-western Cameroon was mostly controlled by a NNE–SSW stress direction until ca. 590 Ma. Further deformation in this domain is recorded by a regional clockwise rotation compatible with a NW–SE stress direction suggesting that the late tectonic event was the only one controlled by the prominent active role of the WAC.

PBCA comprises three lithotectonic domains (figure 1b): the northern Cameroon domain, the central Cameroon domain and the southern Cameroon domain.

The northern Cameroon domain or Poli Group, also known as west Cameroon domain (WCD, figure 1b; Toteu *et al.* 2004; Penaye *et al.* 2006) is limited to the south by the Buffle Noir-Mayo Baléo (BNMB) shear zone. It is characterized by Meso- to Neo-proterozoic volcano-sedimentary basins that were deformed and metamorphosed into schists and high-grade gneisses (Nzenti *et al.* 1988). It represents an early Neoproterozoic back-arc basin formed between 830 and 665 Ma (Toteu *et al.* 1990, 2006; Penaye *et al.* 2006), that includes: detrital and volcanoclastic deposits, metavolcanics (tholeiitic basalts and calc-alkaline rhyolites), and pre-, syn- to late-tectonic calc-alkaline intrusions (diorites, granodiorites and granites). These intrusions, emplaced between 660 and 580 Ma (Toteu *et al.* 2001), form a NNE–SSW corridor.

The central Cameroon domain, to which belongs the Bandja pluton, also known as Adamawa domain, is located between the BNMB shear zone to the north and the Sanaga shear zone (SSZ) to the south (figure 1b). It includes huge Pan-African batholiths and large scale Paleoproterozoic remnants that were emplaced and metamorphosed during the Pan-African tectonic evolution. Massifs are often made up of syntectonic granitoids.

The southern Cameroon domain is limited to the north by the Sanaga shear zone to the south it thrusts onto the Congo Craton. This domain represents a syntectonic basin, for which deposition age is younger than 625 Ma (U–Pb dating of detrital zircons, Toteu *et al.* 2006). It includes metasediments (shales, greywackes, minor quartzites, dolomites and evaporites) and pre- to syn-tectonic alkaline to transitional intrusions represented by pyroxenites, pyroxene-amphibole and pyroxene-plagioclase rocks (Nzenti 1998); scarce outcrops of serpentinized ultramafic rocks associated with gabbros, diorites and mafic dykes are also found (Seme Mouangue 1998; Nkoumbou *et al.* 2006). All these rocks were metamorphosed in the HP-HT granulite facies at ca. 620 Ma (U–Pb zircon

age by Penaye *et al.* 1993) prior to exhumation and thrusting over the Congo craton.

Many authors have proposed models to explain the emplacement of granitoids within the Pan-African belt. These models evoke the transpressional context (Njiéak *et al.* 2008 for the Batié granitic complex, Djouka-Fonkwé *et al.* (2008) for the Bafoussam granitoids, Kankeu *et al.* (2009) for the Lom basin granites) as well as the transtensional context (Nguessi Tchakam *et al.* (1997) for the Bandja magmatic complex, Tagné Kamga (2003) for the Ngondo plutonic complex, Tchameni *et al.* (2006) for the Ngaoundéré Pan-African granitoids, and Kwékam *et al.* (2010) for the Fomopéa Pan-African plutonic complex) for granitoids emplacement.

2.2 Geology and geochronology of the area

The west Cameroon region (figure 2) is underlined by pre-, syn- to post-tectonic granitoids that have been subdivided into three main types, based on their relationships with orogenic deformational phases:

- (1) 630–620 Ma pre- to syn-D₁ granitoids;
- (2) 600–580 Ma syn-D₂ granitoids; and
- (3) 550 Ma post-orogenic granitoids (U/Pb ages, Toteu *et al.* 2001).

Using CHIME (chemical Th–U–total Pb isochron method) on zircon and allanite crystals in rocks, Tetsopgang *et al.* (1999, 2008), in the Nkambé granitoids, determined an age of 532±35 Ma on allanite and 523±45 Ma on zircon in the biotite hornblende orthogneiss and an age of 569±12 Ma in hornblende–biotite granite. Tagné Kamga (2003) in the Ngondo plutonic complex suggests an older continental crust during the genesis of the magma with little or no addition of mantle derived magma to the crust for the 600 Ma granitoids. Tchameni *et al.* (2006) obtained ca. 615–575 Ma (Th–U–Pb age on monazite) on the Ngaoundéré granitoids and suggested a differentiation of mafic magma from an enriched subcontinental lithospheric mantle with possible crustal assimilation. Njiéak *et al.* (2008) determined in the Bangou–Batié granitic pluton 632–602 Ma (U–Pb on zircon) and proposed a syn-kinematic emplacement of the pluton along a crustal scale NNE to ENE trending strike-slip shear zone. Kwékam *et al.* (2010) obtained U–Pb ages of 621–613 Ma on the Fomopéa granitic complex and proposed a model whereby linear lithospheric delamination occurred along the Central Cameroon Shear Zone (CCSZ) in response to post-collisional transpression. This delamination induced the partial melting of the mantle and old lower crust. According to these latter authors, the

emplacement of numerous post-collisional Neoproterozoic plutons along the CCSZ during the Pan-African orogeny indicates that this process was of paramount importance. Recent research works of Dawai *et al.* (2013) and Mosoh Bambi *et al.* (2013) respectively, for the Guider quartz-syenite (northern Cameroon) and Ekomédion granites (south-western Cameroon) determined a U–Pb age of 593 Ma on zircon in quartz-syenite and 578 Ma in granites. (Mosoh Bambi *et al.* 2013 concluded for a crustal origin of the magma.)

These granitoids, cross-cut by gabbroic dykes (Kwékam *et al.* 2010), are partially covered with basaltic and trachytic lavas. Early data from the granitoids yielded ages in the 550–700 Ma range

(Nguessi Tchakam and Vialette 1994; Djouka-Fonkwé *et al.* 2008; Njiéak *et al.* 2008; Kwékam *et al.* 2010). Recent Th–U–Pb monazite dating in the Bafoussam region by Djouka-Fonkwé *et al.* (2008) yielded 558–564 Ma emplacement ages of two mica granitoids. The metamorphic host rocks, orthogneiss (hornblende–biotite gneiss) and amphibolites were reworked during the Pan-African orogeny (Njiéak *et al.* 2008; Kwékam *et al.* 2010).

The Bandja granitic pluton has NE–SW elongated shape with a long axis around 25 km and a short axis not more than 6 km (figure 3). Its outcrops cover roughly 80 km². Outcrops are of variable quality and granites often correspond to topographic elevations. Outcrops of the gneissic

Figure 3. Geological map of the study area showing the sampled sites.

basement are scarce, and contacts with the pluton are generally lacking.

Dumort (1968) represents the Bandja granitic pluton as a sheet of magmatic rock that comprises a porphyritic facies at its northeastern part, while its southwestern part is made of anatectic rocks (figure 2). It is stuck between the Fomopéa granitic pluton (Kwékam *et al.* 2010; Njanko *et al.* 2010) and the Bangou–Baham porphyritic granitic pluton. It is affected at its western border by the ductile Fotouni–Fondjomekwet mylonitic zone (FFMZ; Njanko *et al.* 2010). The Bandja granitic pluton is dominantly porphyritic in nature. According to Nguessi Tchakam *et al.* (1997), it comprises two rock groups: (i) a highly deformed group, including mylonites (called orthogneiss and charnokites) and banded gneiss, and (ii) a less deformed group including diorite, monzonite, granodiorite, alkali feldspar megacryst granite and fine-grained granite, the so-called Bandja porphyritic granite. In the field, this latter petrographic group is not really very well organized and distinctively mappable; those rocks are then regrouped under alkali feldspar megacryst granites.

According to Nguessi Tchakam and Vialette (1994) and Nguessi Tchakam *et al.* (1997), monzonite and granites from Bandja granitic pluton are metaluminous. The geochemical behaviour is consistent with (i) a common origin of these rocks and (ii) a potassic calc-alkaline magmatism of orogenic context, close to the syn-collisional to post-collisional domain (Pearce *et al.* 1984; Lagarde *et al.* 1992). The emplacement of orthogneiss is dated with an age of 686 ± 17 Ma (Rb/Sr) (Lamilen 1989); an age of 640 ± 15 Ma (U/Pb, Pb/Pb on zircons) dates the emplacement of charnockites; and an age of 557 ± 8 Ma (Rb/Sr) dates the emplacement of K-feldspar megacryst granites (Nguessi Tchakam and Vialette 1994). These ages are similar to those of syntectonic rocks of the Pan-African belt (604 Ma; Penaye *et al.* 1993) and give a good relation between different Pan-African phases of deformation: 687–633 Ma (earlier-D₁), 604–580 Ma (syn-D₂) and late at 557 Ma (Penaye *et al.* 1993).

3. Materials and methods

In this study, we use classical field methods and anisotropy of magnetic susceptibility (AMS) method.

Oriented cylinder samples were drilled, directly in the field, from 88 different sites (figure 3) distributed among the granitic pluton, the mylonitic zone and the banded gneiss of the country rocks: 64 sites in feldspar megacryst granites, 14 sites in mylonites and 10 sites from banded gneiss. A total of 363 specimens have been analyzed in this study.

In classical field method, the petrography is carried out using thin sections from remaining oriented cores sampled for AMS study. Structural elements and kinematic indicators (folds, foliations, stretching lineations, S-C structures, ...) are recognizable at a metric or centimetric scale and can be used to infer the kinematic during the emplacement. These data were statistically analyzed using Stereonet software (Allmendinger's Stereonet program) with conventional techniques.

Today, measurement of AMS is a structural analysis powerful tool (Bouchez 1997, 2000) to determine petrofabric orientation in rocks, even in rocks that are visually isotropic. AMS principles are described in various research works (Borradaile and Henry 1997; Bouchez 1997, 2000). We, therefore present here elements to understand the emplacement of Bandja magmatic complex.

Two or three oriented cores were collected at each site. Each core yielded at least two cylindrical samples, hence providing an average of four specimens per site. Each individual sample is 22 mm in length and 25 mm in diameter (the standard size for magnetic measurements). AMS measurements were then performed on a Kappabridge susceptometer KLY-3S (Agico Ltd., Czech Republic); working at a low alternating field ($\pm 4 \times 10^{-4}$ T, 920 Hz) with a sensitivity of about 2×10^{-7} SI, allowing anisotropy discrimination below 0.2% over a wide range of susceptibilities. The orientations of the principal axes K_i ($i = 1$ to 3) of the average AMS ellipsoid for a given site are obtained by a classical eigenvector calculation between the individual AMS measurements K_{ij} (specimens $j = 1$ –4). The magnetic susceptibility is measured for different orientations of the cylindrical specimen and is used to calculate the intensity of the three principal axes of the magnetic susceptibility ellipsoid K_1 , K_2 and K_3 . AMS is a second-rank tensor expressed by its principal eigenvectors and eigenvalues $K_{\max} = K_1 > K_{\text{int}} = K_2 > K_{\min} = K_3$, respectively representing the maximum, intermediate and minimum axes of the magnetic susceptibility ellipsoid.

The long axis of the ellipsoid K_1 defines the magnetic lineation and the short axis K_3 defines the pole of the magnetic foliation (the plane formed by K_1 and K_2 axes). In plutonic rocks, the magnetic fabric is usually coaxial with the mineral fabric. When a granite has a so-called 'paramagnetic' behaviour, K_3 represents the pole of the foliation marked by the preferred orientation of the main Fe-bearing silicate mineral (namely biotite and amphibole), and K_1 represents the biotite lineation defined as the axis of rotation, or zone axis, of the biotite foliation (Bouchez 2000). It is worth to notice that, in these rocks, very small quantity of ferromagnetic material may be present as

Table 1. Summary of magnetic scalar and directional data on the Bandja granitic pluton. K_1, K_2 and K_3 are the maximum, intermediate and minimum susceptibility intensities respectively; $K_m = (K_1 + K_2 + K_3)/3$ is the mean magnetic susceptibility; P' is the anisotropy degree (Jelinek 1981), $T = (2 \ln(K_2/K_3)/(\ln(K_1/K_3)) - 1)$ is the Jelinek's shape parameter (Jelinek 1981); N is the number of analyzed specimens; Dec: declination in degrees; Inc: inclination in degrees.

Site	Lat. N(°)	Long. E(°)	N	Mean AMS parameters			Mean eigenvectors					
				Km (10 ^{−6})	P'	T	K ₁		K ₂		K ₃	
							Dec (°)	Inc (°)	Dec (°)	Inc (°)	Dec (°)	Inc (°)
Mylonites												
TJ1	5.3152	10.2322	4	406	1.18	0.06	207	7	314	68	115	22
TJ3	5.3166	10.2375	8	51	1.14	0.33	38	2	307	42	130	48
TJ4	5.3158	10.2322	4	1241	1.32	0.12	215	9	329	69	124	19
TJ14	5.32	10.2133	4	692	1.21	0.02	227	6	330	66	135	23
TJ20	5.2997	10.2327	4	13131	1.65	0.09	235	9	142	81	145	2
TJ21	5.303	10.2361	4	7285	1.64	0.22	22	2	117	70	289	20
TJ25	5.3347	10.2094	4	954	1.13	0.15	25	54	334	43	302	19
TJ26	5.328	10.2038	3	547	1.14	0.76	205	11	33	78	298	3
TJ28	5.3302	10.1922	4	1026	1.22	0.26	52	7	118	63	315	25
TJ30	5.2727	10.1897	4	337	1.06	0.20	220	15	316	49	127	50
TJ33	5.2811	10.1755	3	350	1.17	0.07	51	12	172	69	318	19
AY55	5.2397	10.1905	4	278	1.10	−0.64	39	3	136	73	307	17
AY56	5.2566	10.1722	4	322	1.10	−0.21	40	4	306	52	133	37
AY57	5.2827	10.2125	4	311	1.09	−0.60	53	4	204	86	323	2
Banded gneiss												
AY43	5.2252	10.255	4	219	1.40	0.15	35	14	129	23	277	66
AY44	5.2072	10.2497	4	740	1.11	−0.34	182	1	91	37	273	53
AY45	5.2208	10.2616	4	247	1.18	−0.06	12	4	104	17	287	74
AY47	5.2288	10.2625	4	119	1.63	0.09	21	0	112	15	290	75
AY48	5.2275	10.2716	4	22463	1.78	0.66	1	6	105	67	269	22
AY49	5.2152	10.2722	4	390	1.09	0.37	176	3	82	25	274	65
AY50	5.2122	10.2747	4	12833	1.61	0.26	54	1	143	3	288	86
AY51	5.2122	10.2747	4	1100	1.16	0.51	142	1	44	16	232	77
AY52	5.2080	10.2680	4	2236	1.34	0.11	173	7	44	24	300	79
AY79	5.1777	10.1833	6	1109	1.23	0.79	181	36	9	54	272	4
K-feldspar megacryst granites												
Domain I												
AY17	5.2675	10.2269	4	1081	1.08	−0.39	33	6	297	84	296	7
AY18	5.2666	10.22	4	658	1.13	0.07	207	4	117	11	287	79
AY23	5.2569	10.2086	4	1466	1.10	0.26	75	35	200	43	322	32
AY24	5.2605	10.2127	4	1120	1.09	0.36	76	55	239	45	322	10
AY25	5.2597	10.2166	4	1015	1.05	−0.05	145	49	357	40	263	10
AY26	5.2641	10.2208	4	1251	1.06	−0.46	210	4	317	76	116	15
AY27	5.2658	10.213	4	1227	1.17	0.50	105	1	195	12	6	78
AY28	5.2722	10.2244	4	994	1.06	−0.27	81	43	322	34	211	32
AY29	5.3066	10.2666	4	787	1.14	−0.35	52	18	175	62	309	20
AY30	5.3022	10.2647	4	671	1.07	0.27	18	33	227	54	117	14
AY31	5.2858	10.2483	4	2725	1.15	−0.16	208	6	93	77	300	13
AY32	5.2919	10.2602	4	2784	1.19	−0.17	210	7	86	78	301	10
AY33	5.2816	10.2444	4	161	1.06	−0.15	234	7	112	75	326	12
AY34	5.2816	10.2444	4	620	1.05	−0.09	204	6	111	41	301	50
AY35	5.2813	10.2455	4	802	1.06	−0.33	48	16	142	14	270	69
AY36	5.2794	10.2394	4	99	1.08	0.05	56	16	36	28	177	62
AY37	5.2697	10.2475	4	446	1.07	0.51	144	5	53	5	281	84
AY38	5.275	10.2308	4	2413	1.07	−0.02	49	28	181	50	299	24
AY39	5.2813	10.225	4	477	1.10	0.45	39	7	146	67	306	22
AY40	5.2741	10.2177	4	512	1.10	0.39	29	4	126	65	297	25

Table 1. (Continued).

Site	Lat. N(°)	Long. E(°)	N	Mean AMS parameters			Mean eigenvectors					
				Km (10 ⁻⁶)	P'	T	K ₁		K ₂		K ₃	
							Dec (°)	Inc (°)	Dec (°)	Inc (°)	Dec (°)	Inc (°)
AY41	5.2858	10.23	4	62	1.11	0.22	31	5	133	67	299	24
AY42	5.2922	10.24	4	359	1.08	0.58	31	35	175	50	288	18
AY58	5.308	10.3066	4	1343	1.11	0.03	190	51	340	34	79	14
AY59	5.3105	10.3027	4	2089	1.14	0.50	211	62	3	27	101	5
AY60	5.3058	10.303	4	4527	1.16	0.23	91	14	283	71	181	11
AY61	5.3083	10.2961	4	684	1.14	0.32	2	3	228	86	92	3
AY62	5.3069	10.2933	6	4657	1.30	0.46	185	26	231	56	84	20
AY63	5.3183	10.2897	4	5625	1.37	0.40	65	26	85	35	358	1
AY64	5.3044	10.2802	4	6832	1.35	0.13	217	11	123	21	333	67
AY65	5.3086	10.2819	4	290	1.08	-0.04	111	1	21	14	212	76
AY66	5.3005	10.2822	4	527	1.05	0.31	317	25	66	34	199	45
AY67	5.2727	10.2655	5	9469	1.38	0.36	207	19	112	14	351	67
AY68	5.2755	10.2636	4	17295	1.33	0.38	290	34	159	43	37	26
AY69	5.278	10.2583	5	15511	1.58	-0.24	301	53	77	25	301	53
AY70	5.2777	10.2602	4	35836	1.95	0.22	29	4	251	84	119	4
AY71	5.2841	10.263	6	18196	1.73	0.12	216	10	38	81	306	1
AY72	5.2913	10.2641	5	662	1.07	0.44	7	23	98	1	189	67
AY73	5.2877	10.25	4	486	1.07	-0.24	90	62	230	22	327	18
AY74	5.2608	10.2525	4	4129	1.22	0.57	243	52	340	5	74	38
AY80	5.2602	10.2252	4	598	1.07	0.62	275	52	12	5	107	33
AY81	5.2533	10.218	4	768	1.11	0.35	235	77	251	12	55	36
Domain II												
AY1	5.2447	10.2166	4	120	1.06	-0.50	13	12	104	14	243	14
AY2	5.2436	10.2227	4	3104	1.18	0.20	56	10	166	64	323	30
AY3	5.2363	10.2133	4	381	1.07	-0.30	18	4	113	43	276	46
AY4	5.2327	10.2102	4	376	1.07	-0.04	189	1	101	69	278	34
AY5	5.2283	10.213	4	598	1.10	0.40	196	2	100	69	289	21
AY6	5.2269	10.2102	4	362	1.10	0.00	195	17	8	74	105	1
AY7	5.2258	10.2083	4	153	1.04	0.12	179	19	291	48	76	36
AY8	5.225	10.2047	4	2254	1.13	0.12	207	4	117	11	267	78
AY9	5.2213	10.2016	4	2555	1.20	0.10	189	13	50	74	281	10
AY10	5.2133	10.1961	4	3339	1.20	-0.02	193	6	52	83	283	5
AY11	5.2275	10.203	4	2353	1.19	0.02	197	8	104	22	305	67
AY12	5.2355	10.1997	4	5320	1.21	-0.36	176	26	79	14	324	60
AY13	5.2336	10.1911	4	4638	1.18	-0.32	177	23	82	10	328	65
AY14	5.23	10.1977	4	708	1.03	0.08	226	85	328	13	220	17
AY15	5.2375	10.2063	4	322	1.06	-0.17	196	6	103	27	301	62
AY16	5.2402	10.2052	4	1493	1.13	-0.26	203	4	313	78	112	11
AY19	5.2208	10.1933	3	946	1.07	-0.75	181	3	274	64	90	26
AY20	5.2177	10.1925	3	1412	1.03	-0.18	338	9	69	21	233	69
AY21	5.2297	10.1872	4	772	1.02	-0.24	173	42	27	51	291	17
Domain III												
AY75	5.2086	10.1808	5	887	1.03	-0.50	290	34	129	63	36	31
AY76	5.1986	10.1788	4	561	1.04	-0.22	228	8	121	66	31	24
AY77	5.2077	10.1883	4	3370	1.05	-0.16	348	24	145	64	171	81
AY78	5.1911	10.1997	5	611	1.11	0.35	263	10	153	4	350	86

tiny inclusions in silicate minerals (Pignotta and Benn 1999). According to Gregoire *et al.* (1998), when a granite has ferrimagnetic or ferromagnetic (*sensu lato*) behaviour (i.e., magnetite-bearing granites), K₃ defines the pole of the average flattening plane and K₁, the elongation direction

of the shape-preferred orientation of magnetite. Therefore, the foliations and lineations obtained by magnetic methods can be used as indicatives of the mineral fabrics.

The relationship between tensor axes, normalized by means of Jelinek's method (1978, table 1) was studied using: (i) the anisotropy degree P' according to Jelinek (1981), which shows the intensity of the preferred orientation of minerals, and (ii) the shape parameter, $T = (2 \ln(K_2/K_3)/\ln(K_1/K_3)) - 1$, which varies between -1 (prolate ellipsoids) and $+1$ (oblate ellipsoids).

Information on magnetic mineralogy is of crucial importance in magnetic studies of rocks (Petrovsky and Kapicka 2006). Standard analytical methods and sensitive thermomagnetic analyses are used to determine temperature dependence of magnetic parameters as basis of determination of magnetic second-order phase transition temperatures. Although limited by several drawbacks, the most serious being thermally-induced transformations of the original minerals, this method provides useful information about the presence of magnetite minerals, and additional knowledge on the prevailing grain size distribution or degree of substitution. According to Tarling and Hrouda (1993), the contribution of magnetic mineralogy to rock susceptibility is very important in magnetic anisotropy investigation because the minerals show different behaviour in different geological situations. One of the methods for the resolution of the rock susceptibility into its ferromagnetic and paramagnetic components is based on the investigation of the temperature variation of susceptibility. The thermomagnetic curves give information about the temperature changes of susceptibility in the initial part of the thermomagnetic curves of the ferromagnetic minerals (Hrouda *et al.* 1997). Although the susceptibility temperature variation can be used in principle for the susceptibility resolution into ferromagnetic and paramagnetic components, the application must be made with care, because of possible problems concerning the susceptibility *vs.* temperature relationship for the ferromagnetic minerals.

To ground the interpretation of AMS results, it is necessary to know which minerals are carrying the susceptibility and in which proportion (Rochette *et al.* 1992; Benn *et al.* 1999). Namely, hysteresis loops were used to estimate the proportion carried by paramagnetic minerals and estimate the type and grain size of the ferromagnetic minerals. Thermomagnetic analyses further allowed to determine the Curie point of the ferromagnetic minerals (following Petrovsky and Kapicka 2006).

Samples were measured for AMS (1) in the laboratory of magnetism at the University Chouaïb Doukkali of El Jadida in Morocco, and (2)

in the 'Laboratoire de Géologie-Minéralogie-Pétrophysique et Tectonique' of the University of Ouagadougou in Burkina-Faso. Thermomagnetic analyses were obtained using a CS2 apparatus coupled to the KLY-3S Kappabridge instrument (Agico, Czech Republic) in the Laboratoire Géosciences Environnement Toulouse (GET; France) and hysteresis analyses were carried out using a Micromag VSM on 1 cc cubes in CEREGE UMR6635 Aix-Marseille Université CNRS Europole de l'Arbois Aix-en-Provence (France).

The raw magnetic data for each of the 88 sites concerning the study area are reported in table 1.

4. Results

4.1 Petrography

K-feldspar megacryst granites are the main petrographic component of the pluton. They are greyish or leucocratic and pinkish, and coarse- to medium-grained to fine-grained (average grain size <3.8 mm). They contain phenocrysts of alkali feldspar (figure 4b, c, e, f) responsible for a noticeable mineral preferred orientation acquired during the magmatic stage or later. In this post-magmatic case, porphyroclasts of feldspar are moulded in a fine-grained matrix, sometimes with quartz ribbons showing evidences of dynamic recrystallization. Other minerals are quartz, plagioclase and variable amount of hornblende, biotite and accessory minerals as zircon, apatite, sphene, epidote and oxides. Myrmekite are generally abundant at the contact between plagioclase and K-feldspar (figure 4b). The textures are granoblastic heterogranular to mylonitic (figure 4h).

Banded gneiss outcrop at Bania and Babouantou. Rocks are dark grey in colour and composed of clinopyroxene, pargasitic and hastingsitic hornblende, biotite and plagioclase. Accessory minerals are zircon, apatite, sphene, allanite and oxides.

Mylonites are found at the northwestern part of the study area (Fondjomekwet and Fotouni). They are greyish, or sometimes leucocratic, banded, fine-grained, with quartz, K-feldspar, biotite, plagioclase, garnet, muscovite, cordierite, sillimanite and monazite. Their mineral composition is indicative of a metapelite protolith that underwent mylonitization under mid-pressure amphibolite facies conditions. These mylonites are the one described by Njanko *et al.* (2010) in the FFMZ. Beside mylonites, Njanko *et al.* (2010) have described, in the FFMZ, protomylonites on the southeastern border of the Fomopéa granitic pluton. They belong to the pluton body and are medium- to coarse-grained with quartz, K-feldspar, plagioclase and chlorite, corresponding to the deformation of the plutonic rocks in greenschist facies conditions.

Figure 4. Field photographs and microphotographs (crossed polars) of microstructures in feldspar megacryst granite: (a) A view of Bandja granitic pluton from Bandja main road; (b) Submagmatic microstructure (AY20), noted (i) the microfault in feldspar filled with quartz and (ii) myrmekite abundance; (c) Feldspar megacryst granite from Bakoven (AY14), noted the stretched granodioritic xenolith; (d) Incipient solid-state deformation (AY7); (e) Magmatic foliation (S) due to the preferred orientation of K-feldspar megacrysts in granite; (f) S-C sinistral microstructure showing (i) the rotation of feldspar megacryst and (ii) biotite crystal folded in 'S' shape (AY32); (g) Localized sinistral microshear zones (AY7); (h) Mylonitic texture (AY1). Bt: biotite, Hbn: hornblende, Kfs: K-feldspar, Myr: myrmekite, Pl: plagioclase, Qtz: quartz, S: foliation, C: shear planes.

4.2 Structures

4.2.1 Mesostructural observations

Structures observed in the field are foliations, S/C structures, stretching lineation and folds. Foliation is observed in banded gneiss, granites and mylonites (figure 5).

In banded gneiss, the foliation is the result of alternation of white (quartz and feldspar rich) and dark (biotite and amphibole rich) layers. It varies between N05°E and N19°E strikes with low to moderate dips (23°–37°) towards the SE or NW

and shows best poles at 289/53, 277/66 and 82/62 (figure 5).

In granite, the magmatic foliation is characterized by preferred orientation of minerals as quartz, feldspar, biotite and amphibole. It varies between N16°E and N54°E strikes with moderate to strong dips towards the SE and shows best poles at 296/23, 313/35, 299/43 and 297/40. This magmatic foliation shows NE–SW strike direction in the northern part of the pluton and NNE–SSW strike directions in its central part (figure 5). The foliation in banded gneiss seems to deflect to

Figure 5. Field foliations and lineations map showing lower hemisphere projection diagrams for foliation poles (contour intervals = 2%) and stretching lineation (circle with tail).

fit the elliptical geometry of the Bandja granitic pluton.

In mylonites, the mylonitic foliation shows homogeneous NE–SW strikes with moderate to very strong dips towards NW or SE. Best poles are at: 302/45 in Fotouni, 318/30 and 317/2 in Fondjomekwet (figure 5).

S/C structures are observed in the Fotouni–Fondjomekwet mylonitic zone and on the western border of the granitic pluton and scattered in the pluton body. In the mylonitic zone, they are consistent with a dextral sense of motion, also confirmed by typical sigma-type porphyroclasts and their crystallization tails. In granite, it is not easy to determine the sense of the motion.

Stretching lineation is observed and measured in the Fotouni–Fondjomekwet mylonitic zone where it is marked by quartz and biotite stretched crystals on the mylonitic foliation planes. It shows NE–SW azimuth with low plunges ($<10^\circ$; best lines at 49/5 and 56/9; figure 5).

The morphology of the folds points to asymmetric fold shape with SE vergence that have developed long western limbs and thin short eastern limbs with dominant Z-folds on long limbs. Fold axes (best line at 35/6) and mineral stretching lineations are sub-horizontal and strike NE–SW as mylonitic foliation that dips moderately to strongly towards the NW or SE.

4.2.2 Microstructural observations

In accordance with modern structural studies in granites (Paterson *et al.* 1989; Bouchez *et al.* 1992), detailed microstructural observations have been performed in rocks. Samples from Bandja feldspar

megacryst granite show submagmatic to solid-state deformation microstructures. Submagmatic deformation microstructures are marked by (i) feldspar microcracks filled with quartz and (ii) myrmekite crystals (figure 4b) developed on the border of K-feldspar megacrystals. The solid-state deformation microstructures are marked by quartz crystals that have strong undulatory extinction attesting to intracrystalline deformation. Some samples show chessboard texture in quartz (figure 4g, h) in which square subgrains with boundaries parallel to both prism and basal planes attest the deformation at high temperature (Blenkinsop 2000). Deformation twins in feldspar, S-C structures observed in granites (figure 4d, f) and mylonites (figure 4g) and kinked biotites are noted. Besides, ductilely deformed feldspar, recrystallized feldspars are also observed. All the above microstructures imply that the granite developed intense deformation in the solid-state and at rather high temperatures.

4.3 Magnetic mineralogy

4.3.1 Hysteresis

Fifteen representative 1 cc samples (for about 1 cm³ volume) have been measured (table 2 and figure 6). The ferromagnetic contribution was calculated by subtracting the high field slope, mostly paramagnetic, to the hysteresis curve that combines both ferromagnetic (*sensu lato*) and paramagnetic contributions. Hysteresis loop shapes and parameters are typical of magnetite or other spinel oxides. The comparison of high field susceptibility (Khf) to low field susceptibility (Ko), measured on the same sample with the same orientation on

Table 2. *Hysteresis parameters for a selection of representative 1 cc samples, together with low susceptibility parameters. High and low field susceptibilities are expressed in volumic 10^{-6} units using a fixed density of 2.7. Ms is in Am²/kg. Model low field susceptibility is derived from Ms using theoretical Ms/K ratio for MD magnetite.*

Site	m	Ms	Mrs/Ms	Bcr/Bc	Bcr	Bc	Ko (μ SI)	Khf	Ko model	%para	%para model
AY27	1.57	37.5	0.06	7.3	47.1	6.5	1070	208	849	19	24
AY35	1.58	11.6	0.13	2.4	24.0	10.0	724	491	690	68	71
AY59	1.50	31.3	0.03	8.9	34.8	3.9	832	137	672	16	20
AY61	1.26	118.3	0.09	4.3	45.0	10.4	2330	83	2105	4	4
AY62	1.76	168.3	0.01	9.9	11.9	1.2	4375	148	3024	3	5
AY63	1.35	748.3	0.03	4.7	12.1	2.6	23019	131	12918	1	1
AY70	1.36	626	0.06	2.6	7.5	2.9	23552	700	11397	3	6
AY71	1.51	522	0.01	7.0	8.4	1.2	14722	396	9317	3	4
AY73	1.49	528	0.02	12.1	20.6	1.7	12572	232	9255	2	3
AY75	1.44	23.5	0.25	2.6	73.0	28.0	860	468	869	54	54
AY76	1.63	2.3	0.08	2.7	29.0	10.8	556	521	560	94	93
AY77	1.44	134.4	0.02	8.1	23.5	2.9	3000	254	2551	8	10
AY78	1.46	47.9	0.04	7.9	38.6	4.9	1172	239	1058	20	23
AY79	1.57	22.9	0.17	5.0	93.0	18.6	944	447	838	47	53
AY80	1.53	13.4	0.04	7.7	46.0	6.0	496	308	537	62	57

Figure 6. (a) M_r/M_s vs. H_{cr}/H_c (hysteresis ratios, Day *et al.* 1977) diagram of representative samples in K-feldspar megacryst granite, with boundaries of single domain (SD), pseudo-single-domain (PSD) and multi-domain (MD) after Day *et al.* (1977) and Dunlop (1986). (b) Example of hysteresis loops for samples with paramagnetic (AY76), PSD (AY75) and MD (AY77) behaviour.

the Kappabridge, allows to quantify the relative contribution of paramagnetic minerals to K_o . Alternatively, to overcome the calibration problem between VSM and Kappabridge, we calculate a model K_o based on saturation magnetization (M_s) and K_{hf} following Benn *et al.* (1999). Both methods lead to similar paramagnetic relative contribution. This contribution varies from 47 to 94% for $K_o < 1000 \mu\text{SI}$, except one sample, AY59, with minor paramagnetic contribution. Still, the ferromagnetic contribution is significant in all samples, except AY76, for which AMS must be entirely carried by iron-bearing silicates. For the other samples, as the anisotropy of magnetite may be much stronger than the one of silicates, it is still likely that AMS is carried by magnetite even if paramagnetic contribution to K_o is dominant. For samples with $K_o > 1000 \mu\text{SI}$, the paramagnetic contribution is minor (up to 20% on two samples) to negligible. The loop parameters reflect the state of the magnetic domains in magnetite. A plot of the saturation ratio (M_r/M_s ; M_r is the remanence at saturation and M_s the magnetization at saturation) vs. the hysteresis ratio (B_{cr}/B_c where B_{cr} is the remanent coercive force and B_c the coercive force), or Day's diagram (Day *et al.* 1977; figure 6a), provides an indication of the size of magnetite grains. Our specimens fall into the PSD (pseudo-single domain) and MD (multi-domain) fields. Once transposed into grain sizes, this indicates that magnetite ranges between 0.1 (PSD) and $>1.0 \mu\text{m}$ (MD). Samples AY27, AY79 and AY61 likely point towards the mixture of hematite and magnetite contribution to remanence. However, the contribution of hematite to susceptibility in these

samples must be negligible based on the low specific susceptibility of hematite compared to magnetite.

Progressively, samples were heated up to 700°C and cooled to room temperature. Thermomagnetic curves of high susceptibility samples (figure 7) have quite similar shapes, suggesting a similar type of magnetic mineralogy for all parts of the intrusion. Most curves show a significantly higher susceptibility on cooling (not for samples AY10 and AY67 in figure 7a and b), indicative of neo-formation of magnetic minerals starting around $300^\circ\text{--}400^\circ\text{C}$ (probably maghemite converted to hematite). They all show a Curie point around 580°C with a sharp decrease in susceptibility in all the heating curves, corresponding to the Curie temperature of pure magnetite. The remaining susceptibility above 600°C is likely a combination of paramagnetic contribution and residual magnetite signal due to the use of a too large sample mass resulting in part of the sample being cooler than temperature probe. Therefore, it is confirmed that pure magnetite is the main carrier in our high susceptibility samples.

4.4 AMS data

AMS analysis gives well-defined magnetic fabrics for all sites in Bandja magmatic pluton and its country rocks (banded gneiss) as well as in mylonites (table 1; figure 8).

4.4.1 Magnetic susceptibility

The bulk magnetic susceptibility magnitude (K_m) varies from 51 to $35836 \mu\text{SI}$ (table 1; figure 9a)

Figure 7. K–T curves (susceptibility *vs.* temperature) for representative samples (AY10, AY67, AY62, AY27, AY21, AY16).

suggesting, in the study area, the presence of both (i) dominant ferromagnetic behaviour *sensu lato* ($K_m > 500 \mu\text{SI}$) dominated by the signal of magnetite that represents 72% of sites and (ii) dominant paramagnetic behaviour ($K_m < 500 \mu\text{SI}$) probably dominated by the signal of iron-bearing silicates (Rochette 1987; Bouchez 2000) that represents 28% of the sites. K_m values range from 62 to 35836 μSI in feldspar megacryst granites, indicating 79% of sites with ferromagnetic behaviour and 21% of sites with paramagnetic behaviour (figure 9b). The lowest value belongs to site AY41 situated at the western border of the pluton in contact with the mylonites and the highest value belongs to site AY70 nearby the NNE–SSW fracture in the northeastern part of the pluton. In banded amphibole gneiss, K_m varies from 119 to 22463 μSI . K_m values range from 51 to 13131 μSI in mylonites, indicating 50% of sites with ferromagnetic behaviour.

In spite of the fact that fresh samples were obtained in the fields, both paramagnetic and ferromagnetic behaviours are identified in the same petrographic unit and sometimes in the same site, indicating an uneven distribution of magnetite.

There is no particular organization of both behaviours in the granitic pluton.

4.4.2 Anisotropy degree

The anisotropy degree P' varies from 1.02 to 1.95 for all sampled sites (table 1; figure 10a). In granite, P' varies from 1.02 to 1.95. The very high values of P' are located in the northeastern part of the pluton. In mylonites, P' varies from 1.06 to 1.65. The site TJ3, that shows the very low value of K_m (53 μSI) also shows low value of P' (1.14). In banded gneiss, P' varies from 1.09 to 1.78. The kink in P' *vs.* K_m plot (figure 10c) confirms that the paramagnetic contribution becomes important below $K_m = 1000 \mu\text{SI}$, with P' around 1.1, following Rochette *et al.* (1992). The continuous increase of P' *vs.* K_m for $K_m \gg 1000 \mu\text{SI}$ may indicate that anisotropy of magnetite is enhanced by interaction (Gregoire *et al.* 1998).

P' values lower than 1.15 represents 73% of sites in feldspar megacryst granites, 20% of sites in banded gneiss and 53% of sites in mylonites (figure 10b). According to Rochette *et al.* (1992)

Figure 8. Projection diagrams (lower hemisphere) for AMS data; box represents $K_{\max}$, triangle represents K_{int} and circle represents $K_{\min}$; full symbols (box, triangle and circle) represent the averages.

Figure 8. (Continued.)

Figure 9. (a) Contour map of the magnetic susceptibility (Km in μSI unit) of the Bandja granitic pluton and (b) susceptibility histograms.

and Bouchez (1997, 2000), P' values lower than 1.15 may correspond to paramagnetic dominant rocks (also characterized by Km values below 1000 μSI), although ferromagnetic dominant rocks may also show low values due to low preferred orientation of magnetite grains.

The sites AY70 and AY71 that show the highest values of Km also show the highest values of P' and are concentrated along a fracture at the northeastern part of the pluton. In all petrographic units, the site that shows the highest value of Km also shows the highest value of P' , but sites that show the lowest value of Km do not show the lowest value of P' .

4.4.3 Shape parameter (T)

The Jelinek's (1981) shape parameter (T) of the AMS ellipsoid is presented in table 1 and figure 11. About 12% of sites show oblate-shape ellipsoid, while 5% of sites show prolate-shape ellipsoid and 83% of sites a triaxial-shape ellipsoid. In mylonites, T indicates 7% of sites with an oblate-shape ellipsoid, 13% of sites with a prolate-shape ellipsoid and 80% of sites with a triaxial-shape ellipsoid. In feldspar megacryst granites, T indicates 8%, 2% and 90%, respectively for oblate-shape, prolate-shape and triaxial-shape ellipsoids and in banded gneiss, T indicates 20% of sites with oblate-shape

Figure 10. (a) Contour map of the anisotropy degree (P') of the Bandja granitic pluton and (b) anisotropy degree histogram; and (c) P' vs. Km semi-log diagram.

ellipsoid and 80% of sites with triaxial-shape ellipsoid. The obtained T parameter correlates well with the AMS projection diagrams. It indicates either K_1 as axis of K_2 and K_3 in a prolate-shape ellipsoid, or K_3 as axis of K_1 and K_2 in an oblate-shape ellipsoid, or the grouping together of axis K_1 , K_2 or K_3 in a triaxial-shape ellipsoid.

4.4.4 Magnetic foliations

70% of sites in banded gneiss show magnetic foliation dips between 0° and 30°, 10% between 30° and 60° and 20% between 60° and 90°.

General orientations of magnetic foliations in the Bandja feldspar megacryst granite allow to distinguish three different domains (figure 12) called domain I in the northeastern part of the pluton,

domain II in its central part and domain III in its southern part. 24% of sites show magnetic foliation dips between 0° and 30°, 24% between 30° and 60° and 52% between 60° and 90°. Domain I shows magnetic foliation projection diagrams striking NE–SW with a best pole at 295/34 and domain II shows magnetic foliation projection diagrams striking NNE–SSW with a best pole at 283/33, while domain III shows a NW–SE striking direction with best pole at 35/59.

In mylonites, azimuths and plunges of magnetic foliations are well organized in NE–SW strike and NW or SE dipping direction with moderate to very high values. The best pole is at 129/6. 79% of sites show magnetic foliation dips between 60° and 90°, while 21% of sites show dips between 30° and 60°.

Figure 11. T vs. P' diagram.

Figure 12. Magnetic foliation map and projection diagrams for foliation poles (lower hemisphere, contour intervals = 2%).

Figure 13. (a) Magnetic lineation map and projection diagrams of K_1 AMS parameter (lower hemisphere, contour intervals = 2%) and (b) lineation plunges histogram.

4.4.5 Magnetic lineations

In banded gneiss and mylonites, magnetic lineations indicate very homogeneous low plunges (90% and 87% of sites respectively) with moderate plunges (30°–60°), poorly represented (10% and 13%, respectively).

In feldspar megacryst granite, K_1 presents mostly low plunges (0°–30° for 75% of sampled sites; figure 13). Moderate plunges represent 20% of sites, while strong plunges (60°–90°) represent 5% of sites. Magnetic lineations show different behaviours in the three previous domains as magnetic foliation. Domain I shows NE–SW trending magnetic lineations (best line at 37/8), while domain II shows N–S (best line at 191/9) trending magnetic lineations and domain III, E–W trending magnetic lineations (best line at 267/22). These trending magnetic lineations point to an S-form trail as magnetic foliation trends.

5. Interpretation

5.1 Structures and microstructures

Figure 5 indicates magmatic foliation plane strikes varying from the northern to the southern part of the pluton, with moderate to strong dips towards SE. The Bandja feldspar megacryst granite shows weakly deformed to protomylonitic microstructures. Thin sections exhibit megacrysts surrounded by anhedral aggregates of quartz. However, feldspar megacryst microcracks filled with quartz and/or feldspar are likely related to the submagmatic stage and are indicative of melt migration during deformation (Bouchez *et al.* 1992). Microstructural observations point to the development of the pluton in subsolidus conditions and during a continuum from high to low-temperature conditions. Quartz crystals have strong undulatory extinction with chess-board texture in which

square subgrains with boundaries parallel to both prism and basal planes and stepped grain boundaries attest the deformation at high temperature (Mainprice *et al.* 1986). Feldspars show deformation twins indicating that they underwent deformation and recrystallization above 450°–500°C (Simpson 1985; McCaffrey *et al.* 1999) and kinked biotites are noted. Myrmekite, which has been inferred as a deformation induced texture (Simpson and Wintsch 1989) and microcline twinning in K-feldspar (Vernon 2000) are also present in granite. S–C structures in the whole pluton witness either dextral, or sinistral transcurrent tectonics that occur in granite or along the northwestern border of the pluton. It is not really possible to dissociate submagmatic to solid-state deformation in the whole pluton and all samples seem to illustrate solid state or mylonitic deformations as: crystal plastic deformation/recrystallization of feldspar, myrmekite, S–C structures and crystal plastic deformation of quartz, from ribbons of equant polygonal grains to dynamically recrystallized grains. A continuous deformation from submagmatic to solid-state and mylonitic deformation is recorded in the Bandja granitic pluton.

Njanko *et al.* (2010) in the neighbouring area of the Bandja granitic pluton described three phases of deformation: a D₁ phase responsible of the emplacement of biotite hornblende granite (BHG) magma with NNE–SSW stretching direction that reflect the tectonic strain at that time; a N–S sinistral D₂ phase which correspond to the emplacement of the biotite monzogranite (BmG) and a younger dextral D₃ phase linked to the functioning of Fotouni–Fondjomekwet Mylonitic Zone (FFMZ), that is the mylonitic zone of the northwestern border of the Bandja granitic pluton.

5.2 Magnetic data and emplacement of granite

According to the thermomagnetic analysis, K–T curves indicate the presence of magnetite as main susceptibility carrier event if certain low susceptibility samples reveal the paramagnetic component. The predominance of magnetite in samples allows to envisage that the high ferromagnetic behaviour of the granitic unit is closely linked to the presence of magnetite MD in rocks. Sites that show very high magnitude of magnetic susceptibility, also show very high values of the anisotropy degree ($P' > 1.1$). On the other hand, sites with very low magnitude of magnetic susceptibility, do not always present low values of the anisotropy degree. This indicates that the P' parameter (usually the quantitative strain intensity indicator) is also influenced by the presence of magnetite in the form of PSD or MD grains in rocks than by the strain itself. This is supported by the semi-logarithmic diagram

of the magnetic susceptibility K_m vs. anisotropy degree P' (figure 10c), where samples show a hyperbola plot. According to Archanjo *et al.* (1994), P' depends weakly on K_m occasionally, suggesting that rock-composition controls P' .

Magnetic fabric axes are parallel to the mineral fabric axes and these axes recorded the strain (flattening plane) to which the magma was subjected after its complete crystallization (high-temperature solid-state microstructures). The magnetic foliation and lineation in the three domains of the granitic pluton show different orientations resulting in a sigmoidal path. According to Njanko *et al.* (2010), the sigmoidal trajectories of magnetic lineation observed in biotite monzogranite of the Fomopéa granitic pluton correspond to a sinistral sense of motion linked to the D₂ phase of deformation recorded in this neighbouring area. This sinistral D₂ event predates the dextral D₃ phase recorded in the FFMZ.

5.3 Discussion on age and geodynamic implication

The geological history of the Bandja granitic pluton should take into account: (i) different ages obtained by Nguessi Tchakam *et al.* (1997), (ii) the available Pan-African ages and the evolution of the Pan-African belt in Cameroon. According to Njiéak *et al.* (2008), structural and geochronological data from the Batié pluton (BP), in the continuity north of the Bandja granitic pluton, the migmatitic complex of Foubot (MCF), and the Bangoua metagranitoid complex (BMC) are provided to put constraints on the tectonics of the N30°E strike segment of the belt. BMC is dated 638 ± 2 Ma (U–Pb age on zircon) and the BP is dated 602 ± 1.4 Ma (U–Pb age on zircon). Tagné Kamga (2003) dates the Ngondo plutonic complex (also emplaced along N30°E strike shear zone) at around 600 Ma. These plutons are emplaced during the Neoproterozoic D₂ Pan-African event. In the same order, Kwékam *et al.* (2010) determined, on the Fomopéa granitic pluton, ages: 622–613 Ma for the biotite hornblende granitoid corresponding to D₁ Pan-African event (Njanko *et al.* 2010); 613–590 Ma for the biotite granitoid and corresponding to the D₂ Pan-African event (Njanko *et al.* 2010). The Rb–Sr ages obtained for the Bandja granites (557 ± 18 Ma) are strikingly younger than the U–Pb ages obtained on neighbouring plutons and seem to correspond to the noticeable perturbation of the Rb–Sr isotopic system, hence the 572 ± 48 Ma age obtained by Kwékam *et al.* (2010) using the same method. The S-shape of the magnetic foliation and lineation trends in the Bandja pluton can allow us to consider the emplacement of the pluton in dextral shear context.

Figure 14. Sketch showing the tectonic history of the Bandja granitic pluton. FGP = Fomopéa granitic pluton; BGP = Bandja granitic pluton; FFMZ = Fotouni-Fondjomekwet mylonitic zone.

Sure enough, Ngako *et al.* (2003, 2008) and Ngako and Njonfang (2011) bring up the problem of left lateral wrench movement (613–585 Ma) in the Pan-African belt and the sinistral shear event (613–590 Ma) accompanying the emplacement of granitoids in the belt. This lateral wrench motion develops the Buffle Noir Mayo Baleo (BNMB) shear zone (figure 1b), the Mayo Nolti shear zone (MNSZ), the Godé-Gourmaya shear zone (GGSZ) in the northern part of the belt and certainly the Rocher du Loup shear zone (RLSZ) along the southwestern coast of Cameroon. It appears as one of the three main tectonic events related to Pan-African collision and post-collision evolution identified in Cameroon, after the crustal thickening was initiated at 630 Ma (Ngako and Njonfang 2011). According to Nguessi Tchakam and Vialette (1994) and Nguessi Tchakam *et al.* (1997), the Bandja granitic pluton units (charnockite and K-feldspar megacryst granite) are completely emplaced between 604 and 557 Ma. These ages can be reorganized as: (i) 686 ± 17 Ma, age of metamorphism of banded gneiss, basement of K-feldspar megacryst granite. This age is close to 687–633 Ma (earlier- D_1) in the belt; (ii) 604–557 Ma, as period of emplacement of the K-feldspar megacryst granite and its deformation through the dextral Pan-African D_3 last event, recorded in the FFMZ, on the western part of the pluton. This reorganization seems in accordance with the tectonic evolution of the PBCA in Cameroon, to emplace the Bandja granitic pluton in a tectonic context initiated from the sinistral shear event of the Pan-African D_2 to the dextral Pan-African D_3 shear event, with the functioning of the Central Cameroon Shear Zone (CCSZ; Ngako *et al.* 2003, 2008; Ngako and Njonfang 2011). It also gives a good correlation with different tectonic events described in the Pan-African belt: crustal thickening and subsequent N–S to NNE–SSW sinistral wrench movement (630–530 Ma) and right lateral wrench movement (ca. 585–540 Ma).

According to Njiéak *et al.* (2008), the intrusion of the Batié porphyritic granite was dated at 602 ± 1.4 Ma. Njanko *et al.* (2010) dated the D_2

N–S striking sinistral deformation bands between 613 and 590 Ma that integrate the 602 ± 1.4 Ma (U–Pb on zircons; Njiéak *et al.* 2008) on Batié porphyritic granite. The period ca. 602–590 Ma corresponds to the late Pan-African tectonomagmatic stage of the Batié area (Njiéak *et al.* 2008) and adjacent southern Bandja region. Magma emplacement of the Bandja feldspar megacryst granite is likely co-eval with movements along transcurrent dextral shear zones (figure 14).

6. Conclusion

The major conclusion of our work is that Bandja granitic pluton has a close relationship with granitic pluton of Fomopea and Batié pluton. This relationship can be guided through new results from the systematic study of magnetic fabric and microstructures that help to understand the emplacement of the Bandja pluton. AMS of Bandja pluton is controlled by ferromagnetic minerals that typically include MD magnetite. Moreover, continuous low field thermomagnetic curves (K–T curves) confirm magnetite as the main susceptibility carrier. The shape and orientation of the AMS ellipsoids defined a dominant triaxial-shape ellipsoid. The organization of T parameter diagram (T *vs.* P') correlates with the AMS projection diagrams of K_1 , K_2 and K_3 . The quantitative strain intensity indicator P' is also linked to the magnetite distribution in rocks than to the strain itself. The fabrics of the Bandja granitic pluton were acquired at the solid state deformation at high temperatures. Magnetic foliation and magnetic lineation trend an S-shape and allow to conclude that the complete emplacement and deformation of the pluton extends from the Pan-African D_2 event to the dextral ENE–WSW Pan-African D_3 shear event that occurred in the Pan-African belt in Cameroon and was related to the functioning of the Bandja N30°E strike-slip shear zone that showed a dextral sense of motion.

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