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K-feldspar megacrysts in Uwet Granodiorite: "late stage" crystals?

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ABSTRACT

The "Uwet Granodiorite" is a term referring to Pan-African granitoids (granodiorites) occurring in the Uwet area – Oban massif, SE Nigeria (8° 00' – 8° 30'E and 5 ° 00' – 5 ° 30'N). These rocks were emplaced by magmatic stoping and assimilation, and possible products of the mixing of more than one magma series and or contamination. Several authors have proposed suggestions on the processes and timing of megacrysts formation in granitoids. Structural, petrographical and chemical studies from this work strongly favour a magmatic/phenocrystic origin for the K-feldspar megacrysts in Uwet granodiorite. These evidences also show that the phenocrysts were formed at liquidus temperature in the presence of abundant liquid. These results agree with similar studies from other parts of the world.

Keywords: crystallization; Oban massif; Uwet granodiorite; magma mixing; granitoids.

INTRODUCTION

Uwet area (Fig. 1) is in the western part of the Oban Massif, which is a part of the western prolongation of the Cameroon Mountains into the Cross-River Plains of SE Nigeria, and also a part of the Precambrian mobile belt of Nigeria. This area is more properly delineated by the co-ordinates 8 ° 00' – 8 ° 30'E and 5 ° 00' – 5 ° 30'N, which lies between the West African Craton and the Gabon-Congo Craton.

The term "Uwet Granodiorite (UG)" refers to Precambrian crystalline granitoids in the Uwet area, SE Nigeria with zircon age of 617 ±2Ma [1], which corresponds to those of similar syntectonic Pan-African Older Granites emplaced in the Nigerian basement [2]. These syn-tectonic granitoids which are coarse-grained and largely undeformed granitoids are the most dominant intrusive rock type in the western Oban Massif. They occur as intrusive in the crystalline basement (gneisses, schists and migmatites). The sills of unmetamorphosed dolerites, small micro-granite intrusions [3], and pegmatites appear as associated rocks within basement [4]. Detailed geochemical evaluation of the UG [4; 1] have shown that they: (a) have a wide range of Fe number which indicates differences in the source rock composition of the rocks; (b) are products of the possible mixing of more than one magma series and or must have been contaminated at emplacement; (c) were emplaced most likely by magmatic stoping and assimilation; and (d) are mainly ferroan, alkaline and strongly peraluminous.

Two varieties of the UG occur: – the porphyritic and the non-porphyritic.

The origin of K-feldspar megacrysts in granitic rocks has thrown up considerable conflicting theories. The principal ones have been: (1) that the megacrysts are phenocrysts which crystallized directly from a magmatic melt as a primary phase [5; 6] or (2) that the megacrysts are porphyroblasts that must have grown from a water-rich fluid phase under subsolidus conditions [7; 8]. Another point of debate is the time of crystallization of the megacrysts. According to [9; 10; and 11], K-feldspar megacrysts in granitoids are younger than the groundmass, that is, they grow later than the crystallization of the groundmass during a prolonged cooling history that extended even to the subsolidus temperature. A contrasting view believes that the megacrysts grow earlier at the liquidus and liquidus-solidus temperature [12; 13; and 14] and that K-feldspar megacrysts are magmatic, and they begin to grow when enough liquid is available to allow the magma to erupt to the surface.

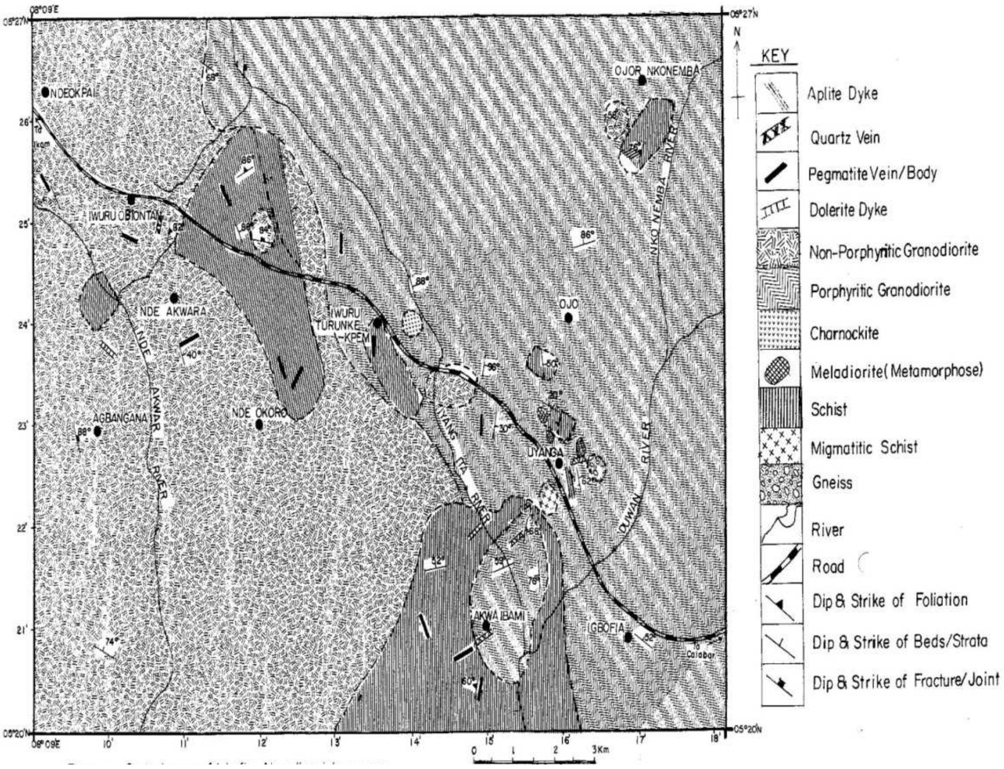

Figure 1 Geologic map of study area (Uwet area: part of western Oban massif).

Enrichment of potassium that allows the crystallization of K-feldspar megacrysts in magmatic processes results when dense, early-crystallized minerals (pyroxene, olivine and calcic plagioclase) lacking potassium, settle to the bottom of magma chambers, and the residual melts containing potassium displaces upwards to the chamber top to concentrate K and form rock types like biotite-bearing gabbro, diorite, and/or tonalite or biotite- and K-feldspar bearing granodiorite, quartz monzonite, and/or granite. Further enrichment is enhanced at the late stage of magma crystallization when residual hydrothermal fluids enriched in K, Na, and Fe moves upward along boundaries of early formed crystals carrying potassium. The potassium in such hydrous fluids can replace early-crystallized plagioclase to form k-feldspars which could become k-feldspar megacrysts [15; 16].

Not much has been done or said on the origin, source and or formation of the megacrysts of the Uwet granodiorites. [17] believes that Na^+ and K^+ enrichment is as a result of the rejuvenation of the basement rocks during the Pan-Afrcan Orogeny, which possibly triggered off K^+ and Na^+ metasomatism that must have led to crystallization of k-feldspar megacrysts. [1] also suggested that it took long (about 108Ma) for the granodiorite to cool and this indicates that the cooling was very slow and as such explains the abundance of K-feldspar megacrysts on the granodiorites.

This paper looks at the growth of K-feldspar megacrysts present in Uwet granodiorite (UG) – their likely source or process (es) that led to their crystallization (magmatic or metasomatic?). Evidences will be drawn from physical observations, petrographical studies and structural characteristics.

MATERIALS AND METHODS

Over 30 exposed outcrops of the porphyritic Uwet Granodiorites were studied with particular interest in the physical behaviour of the feldspar megacrysts occurring in them. Length and width of the megacrysts, as well as their orientations were measured. While their association with one another and with the host rock was noted. Samples were taken for petrographic analysis. The physical data obtained (length, width, and orientation of megacrysts) were analysed using simple computer statistical tools.

RESULTS AND DISCUSSION

Conspicuous megacrysts abound on the porphyritic variety of the Uwet granodiorite. These pinkish to whitish megacrysts with rectangular shapes, range in size from 0.5cm x 1.0cm to 2.8 cm x 4.0 cm and occupy 20% to > 70% of the total rock mass. In thin sections, these megacrysts show uniform distribution of crystals with simple twinning. Petrographical analyses have shown these megacrysts to be K-feldspar [4]. The preferred orientations of these megacrysts are in the NE-SW, NW-SE and N-S direction but the most preferred trend is NW-SE. Sometimes these megacrysts are in such good alignment as to give a linear fabric to the rock – though this varies from place to place.
If the Uwet granodiorite were deformed rocks, the issue would have been more complicated as many questions would need be answered such as: when did the crystals form – before, during or after deformation?; what process or processes could have led to their formation – magmatism or metasomatism?; has there been any change in their crystal size during and or after deformation? But for undeformed rocks (UG) the debate is less intense except of course for the question on the time of formation of the megacrysts – was it at liquidus temperature or solidus?

Evidences in support of an igneous (liquidus) origin for the megacrysts in Uwet granodiorites:

(i) Euhedral shape of megacrysts: The megacrysts of the UG have rectangular euhedral shapes (Fig. 2). And it has been found that K-feldspar megacrysts present in granitoids of igneous origins, possesses mesoscopically euhedral shapes [18; 19; 20]. This is in contrast to K-feldspar porphyroblasts in metamorphic rocks where euhedral shapes of K-feldspar megacrysts are uncommon or unknown [21], although sometimes euhedral crystals less than 1mm can grow in wet fine-grained sedimentary environments [22]. Also observed is that the megacrysts have irregular edges on a microscopical level. These irregular edges are believed to be as a result of the outgrowths that are crystallographically continuous with K-feldspar grains in the groundmass [23; 18; 24; 25; and 26]. This is a pointer that large K-feldspar megacrysts grow before a substantial amount of the other minerals crystallizes and it results when there is a change from free euhedral growth to impeded interstitial growth [27].

(ii) Alignment of megacrysts in the rocks: As seen in Fig. 3, the K-feldspar megacrysts are oriented in a major NW-SE direction. Sometimes these megacrysts locally make a linear alignment. This dimensional alignments are regarded as primary magmatic flow structures in granitoids of igneous origin, which involves a planar dimensional (and hence crystallographic) orientation of the feldspar tablets and is commonly related to the margins of the intrusions or to local turbulent fluid patterns [28; 29; 30; 31; 32; 33; 34; 35; 25; 5]. This simply means that the megacrysts were free to flow in certain direction before the rock solidified.

Figure 2, showing the euhedral rectangular shape of megacrysts in UG

(iii) Deflection of megacrysts around enclaves: Figure 4 also shows aligned megacrysts that are deflected around a dark enclave in the UG. This is also consistent with the theory of magmatic flow in igneous intrusions [21].

(iv) Association of xenoliths and megacrysts: Figure 5 depicts an association of enclaves with abundant large K-feldspar crystals in the UG. It is inferred that such association may represent a crowding together of solid materials present in the early stages of magma consolidation- and this strongly negates the theory of porphyroblastic origin for the megacrysts. Also worth mentioning is that the xenoliths are lenticular [31; 36].

(v) Assembling of megacrysts: Another observation (Fig. 6) is that the megacrysts do not interfere with one another (that is they do not grow into each other) even in areas where they are so closely aggregated as to be in actual contact. This implies that the megacrysts were "assembled after completion", which supports an igneous origin for these megacrysts as simultaneous in situ growth of megacrysts (at solidus stage) would have caused the megacrysts to grow into each other [37].

Figure 3 showing the alignment of megacrysts in Uwet granodiorite

Figure 4 showing clearly how the megacrysts are deflected around an enclave in a granitoid (Uwet granodiorite)

Figure 5 showing how megacrysts and enclaves/xenoliths associate together in a "crowding" manner.

Figure 6, The megacrysts are assembled in close contact but do not grow into each other.

(vi) The Ba content of megacrysts and groundmass K-feldspar: The Ba and Sr content of the K-feldspar megacrysts in the UG has been found [38; 4] to be more than that of the K-feldspar in the groundmass. This most likely suggests that the megacrysts were crystallized earlier than the groundmass or were formed at higher temperature as earlier crystallized minerals in a melt tend to have more Ba and Sr [5; 39; 40; 41; 42; 43; 44; 45; 46]. [6], also suggested that more Ba must have been available for larger earlier crystallized megacrysts as it was found that the Ba content of large K-feldspar megacrysts increases with size of the megacrysts in the granite of southeast Bohemian massif, which supports a magmatic origin for the megacrysts [27; 20; 41].

(vii) The size of inclusions in the megacrysts: Petrographic studies show that inclusions of quartz in the megacrysts of the UG are much smaller than similar grains in the surrounding rock. This suggests that inclusions in the megacrysts were incorporated relatively earlier in the crystallization history of the magma, while the groundmass crystals still had time to grow and form larger grains [47; 26; 5; 25; 48]. [49], found that the K-feldspar megacrysts in the Criffell – Dalbeatie Pluton, Scotland, are larger and more abundant towards the centre of the granitoid and that plagioclase and biotite inclusions decreases in size. This he suggested "indicating that the k-feldspar began to crystallize at progressively earlier stages towards the centre of the intrusion", thereby strongly favouring a magmatic origin for the megacrysts.

(viii) The absence of myrmekite in mineralogy: Myrmekite, which is the clue to a subsolidus metasomatic history in rocks, is conspicuously missing in the mineralogy of the UG samples. This invalidates any idea of the megacrysts in the UG to have been formed at a solidus temperature. Another factor in support of liquidus temperature formation is the undeformed nature of the UG. According to [15], megacrysts formed at solidus temperature is made possible by the aid of deformation and fractures present in the rock so that K-bearing fluids can be introduced by metasomatism. Since the UG are largely undeformed, the possibility of the megacrysts been formed by metasomatic process or at solidus temperature is most unlikely.

(ix) The size of megacrysts against grain size of groundmass: Another feature of K-feldspar megacrysts of the UG is that their size changes/varies with the size of the groundmass grains. That is, outcrops with fine-grains tend to have smaller sizes of megacrysts than coarse-grained outcrops. This occurrence has also been noted in other places (in England: [24]; in Montana: [50] and it suggests an igneous origin [49].

(x) Simple twinning of the K-feldspar megacrysts: The K-feldspar megacrysts of the UG in the thin section show simple twining characteristics. This appears to be a common characteristic of K-feldspar megacrysts in granitoids [28; 51; 18; 25; 31; 52, 44] and suggest a magmatic origin for the megacrysts.

CONCLUSION

From the discussion thus far, it would suffice to arrive at the following conclusion: that the K-feldspar megacrysts of the Uwet granodiorite are phenocrysts of magmatic origin, and they are definitely not "late-stage" crystals as suggested by [1], nor formed at solidus temperature, but must have been formed at the early stage of the magma crystallization and in the presence of enough liquid (liquidus temperature) to allow the megacrysts flow in the magma. K-feldspar megacrysts are known to grow to large grains in the presence of enough liquid (between 50-80%) [14]; [53]; [54]; [55]. The K-feldspar phenocrysts of Uwet granodiorite are similar to the alkali feldspar megacrysts from the porphyritic Karkonoze granite (western Sudetes-Poland) which is products of magma mixing.

The most likely suggested source of K for the formation of K-feldspar are the deformed biotite-rich Precambrian rocks (igneous and meta-sedimentary) which existed before the intrusion of the Pan African Uwet granodiorites. It is believed that during emplacement, the uprising magma assimilated the country rocks (the UG were emplaced by magmatic stoping) and K^+ dissociated from the biotite-rich country rocks and enriched the magma. This accumulation led to crystallization of K-feldspar megacrysts.

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