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Benom Complex: Evidence of magmatic origin

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Abstract: The study area is underlain predominantly by syenite, monzonite and gabbro. The area lies on the western flank of Benom batholith. Field mapping has proven the intrusive nature of the suite of rocks into the surrounding country rocks. The country rocks were contact metamorphosed into various hornfelses of hornblende hornfels facies. The occurrence of a crystal settling layer within the suite of rocks is particularly convincing of an igneous origin. Moreover, the occurrence of accidental xenoliths in these igneous rocks, which correspond to the aureole rocks, indicate that the xenoliths were incorporated during magma intrusion. The presence of different types of cognate xenoliths ranging from pyroxinite to gabbroic and syenitic in composition, is also widespread in the study area. The occurrence of planar flow structure in the syenite and monzonite defined by megacrystic K-feldspar, is evident of magmatic flow. Petrographic studies reveal that igneous foliation in the suite of rocks is made up of euhedral to subhedral plagioclase and K-feldspar crystals.

Abstrak: Kawasan kajian terdiri daripada batuan syenit, monzonit dan gabro. Kawasan ini terletak di sebelah barat Komplek Benom. Pemetaan lapangan menunjukkan batuan ini menerobos batuan sekelilingnya yang terdiri daripada metamorfisma hornfel daripada fasis hornblende hornfel. Kewujudan lapisan pemendapan hablur di dalam suit batuan ini mencadangkan asalan igneus. Tambahan lagi kewujudan xenolit yang mempunyai ciri-ciri persamaan dengan batuan sekeliling mencadangkan xenolit tersebut telah terjatuh ke dalam magma semasa penerobosan magma tersebut. Kewujudan pelbagai jenis xenolit kognat berjulat daripada piroksinit ke gabroik dan syenitik juga banyak dijumpai di kawasan kajian. Kajian petrografi menunjukkan bahawa foliasi igneus di dalam batuan ini dibentuk oleh plagioklas yang berbentuk euhedral to subhedral plagioclase dan alkali feldspar.

INTRODUCTION

Despite the extensive research project carried out on the Eastern and Western Belts (e.g. Liew 1983, Cobbing *et al.*, 1992), the Central Belt received very little attention from previous workers except for some of the work done by Jaafar Ahmad (1979). Peninsular Malaysia has been divided into three distinct belts i.e. Eastern, Central and Western. The division also conveniently divides the granitic and other igneous rocks. The granitic rocks of the Western Belt are distinctly different from those of the Eastern Belt. The former shows 'S' type characteristics and is predominantly monzogranite to granodiorite, in contrast to the latter which is predominantly 'I' type and has a wider spectrum of rock types from monzogranite to granodiorite to diorite and gabbro. The Central Belt has less published information of their geochemical affinities, however, are comparable to the Eastern Belt (Cobbing *et al.*, 1992). The granitic and other igneous rocks of this belt form a narrow and well defined line of single plutons emplaced into Permo-Triassic rocks. The plutons occur very close to the Bentong-Raub line, which may suggest an underlying structural control for their emplacement. The plutons in the Central Belt are mainly granitic in composition but in some places basic rocks such as gabbro and intermediate rocks such as syenite and monzonite are also present. Two of the main areas which are known to have the basic and intermediate rocks are the Benta and Benom complexes. The western flank of the Benom Complex area (study area) has been studied by several workers and different interpretations have arisen (Scrivenor, 1931; Richardson, 1939; Khoo, 1968 ; Hutchison, 1971; Jaafar, 1979; Khoo & Tan, 1983; Shafari, 1992; Tan & Khoo, 1993; Yong, 1998; Ramesh, 1999; Mohd Rozi Umor & Syed Sheikh Almashoor, 2000). The main controversy is either the rocks in this area represent a migmatite complex or are the product of igneous differentiation. The earliest report of this area was by Scrivenor (1931) who noted the occurrence of hornblende-bearing igneous rocks. Richardson (1939) made the first detailed study mapping the rocks and proposed that the suite of rocks resulted from granitization of earlier basic and ultrabasic rocks by the later Benom granitic magma. Khoo (1968), however interpreted that all rocks in this region have been metamorphosed and suggested a low grade facies series but still maintained the term syenite. Hutchison (1971), based on two localities in the Benta area (northern part of the study area), suggested the whole series of rocks represents a migmatite complex (Benta Migmatite Complex) that is unrelated to the Benom granite. This paper will discuss the new data which show that the intermediate and basic rocks from the study area is magmatic and not migmatite or metamorphic as suggested by some of the previous authors. The evidence will be divided into field and petrographic evidence and will be discussed in a separate section.

TECTONIC SETTING AND FIELD ASPECTS

The study area lies within the Central Belt, flanking the western part of the Benom granite. The rocks are found intruding into Middle to Upper Triassic sediments of the Semantan Formation and also have thermally metamorphosed the sediments. The various types of metasedimentary rocks are calc-silicate pelitic hornfels with lesser amount of quartzites. The rocks are invariably folded possibly implying a folding phase before the igneous intrusion. The general strikes of the metasediments are north-south with high dip angle ranging from 40° to 70° which is not parallel to the igneous contact (Figure 1). implying the latter are intrusive. The igneous rocks found in the study area are mainly gabbro, syenite, monzonite, with lesser amounts of doleritic dykes and mafic microgranular enclaves. The gabbro outcrops in the western part of the study area forming a north-south trending belt which is parallel to the general trend of the regional strike. Good outcrops of gabbro can be seen in the lower part of Sungai Kasai where it is in contact with metasedimentary rocks. The intermediate rocks are mainly syenite and monzonite and occupy the eastern part of the area.

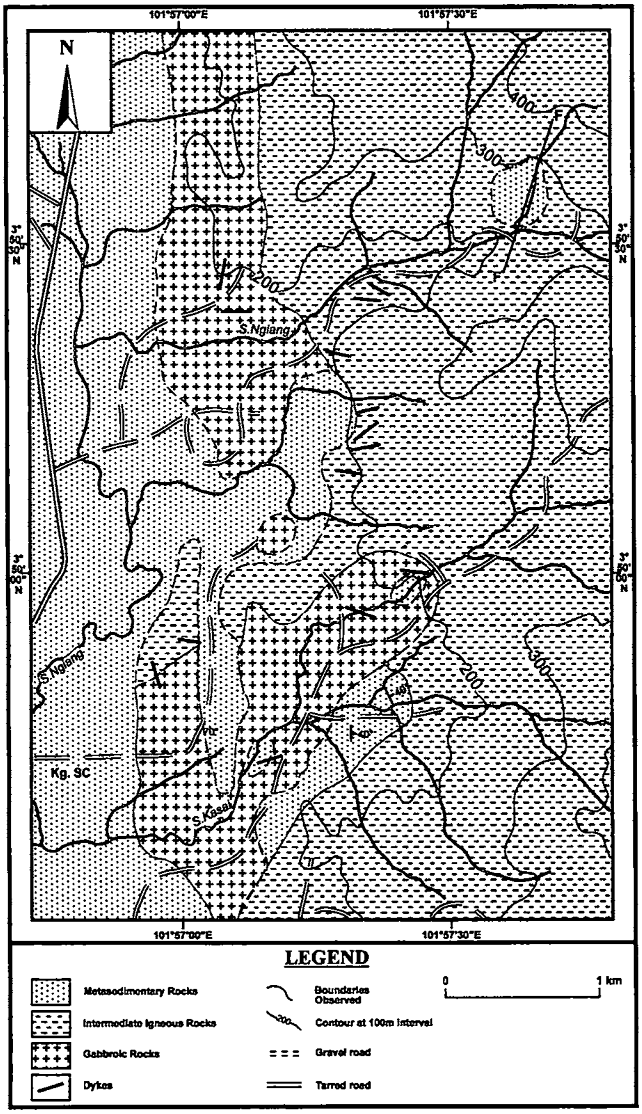

Figure 1. Simplified geological map of the western part of the Benom Complex.

FIELD EVIDENCE OF MAGMATIC ORIGIN

Evidence of intrusive contact

Detailed mapping by the second author has delineated the contact between metasedimentary and igneous rocks in the study area. The various types of metasedimentary rocks found are calc silicate hornfels, amphibolite, pelitic hornfels with lesser amount of quartzite. These rocks were contact metamorphosed during emplacement of the igneous rocks. The metasedimentary rocks were invariably folded in a few outcrops especially in the lower part of Sungai Kasai, implying a folding phase before the igneous intrusion.

Evidence of crystal settling layers

Boulders of layered rock made up of layered syenite and melagabbro, characterised by K- feldspar rich layers separating the darker units, can be seen in the lower part of Sungai Kasai (Figure 2). The more resistant K-feldspar-rich layer displays rugged surfaces on these boulders through the process of weathering. K-feldspar occurs as whitish, unoriented crystal grains, giving the conspicuous layering. The layers of K-feldspar-rich syenitic units are not equally spaced. Some layers occur closely together whereas others are more widely spaced.

Accidental xenoliths

Accidental xenoliths refer to pieces of host rock (country rock) which are incorporated in the syenitic or gabbroic magma. They are the real xenoliths in the sense that they represent foreign rock. The occurrence of accidental xenoliths in the suite of rocks ranging from gabbro to syenite suggests an igneous intrusion since these xenoliths represent pieces of country rock that had fallen into the intruding magma. The types of accidental xenoliths found in the igneous rock correspond to those in the aureole. The accidental xenoliths are contact metamorphosed by the host magma into various hornfelses of hornblende-hornfelses facies

Occurrence of cognate xenoliths

Cognate xenoliths are defined as xenoliths that are derived from its own stock e.g. gabbro that is derived from a differentiating syenite. They occur when pieces of an early product of differentiation from the same source are brought up by the convecting magma. There is a whole range of cognate xenoliths in the study area, ranging from pyroxinite to syenite. Based on the common occurrence, three types are recognized i.e. pyroxenite, gabbro and syenite.

Cognate xenoliths of pyroxinite composition can include up to 10% of other minerals such as biotite and hornblende. It is usually greenish dark in colour and their size ranges from a few cm to a few meters. They occur as blocks with sharp contact with their host and can be found in both syenite and gabbro. Cumulate horizons of pyroxinitic cognate xenoliths have been noted by Tan and Khoo (1993) in the southern part of the study area.

Cognate xenoliths of gabbroic composition (Figure 3) range from biotite-rich melagabbro to dioritic rock. The occurrence of gabbroic rock is usually interfingering with the host syenite. The contact is sharp but can be diffuse. The cognate xenoliths of gabbroic composition can be found abundantly in the upper part of Sungai Ngiang and Sg. Kasai. Their size ranges from a few cm to a few meters. Some probably occur as giant blocks which are not easily recognized in the field. Cognate xenolith of syenitic composition are found in the gabbroic rock. They occur as angular to elongated bodies with sharp to gradational contacts. Some show 'digested' margin. in the host rock. The size ranges from a few cm to a few meters. They are also common and easy to recognize due to their whitish K-feldspar giving a colour contrast with their darkish host gabbro.

Occurrence of synplutonic dykes and associated enclaves

A synplutonic dyke is a dyke that intrudes into solidifying host magma. It may be broken up and disrupted to become inclusion trails which, on further disintegration, become isolated enclaves. The occurrence of synplutonic dykes and their associated enclaves is conspicuous in the field. They occur in various shapes, colours and sizes. The shape of enclaves range from rounded to highly angular. Morphologically four common types of enclaves are recognized (cf. Barbarin & Didier, 1992). They are:

(1) Whole dyke - usually has irregular dyke width, the length of the dyke is still maintained but some are folded by the solidifying host (Figure 4),

(2) Slightly broken dyke - Some dykes are pillowed and slightly broken up by the host rock. The dyke is irregularly oriented but can be traced over distance,

(3) Enclave trail - Some dykes are disassociated to become enclave trails. The individual enclave defining the enclave trail varies in shape and size. The trails are sometimes folded and irregularly oriented (Figure 5),

(4) The isolated enclave - The enclaves occur singly with no inclusion trails. They have a variety of shapes and sizes and the contacts are always sharp.

Though the contacts between the phases are sharp on the broad outcrop scale, they are commonly lobate to crenulate in detail. Pillowing of the more mafic phase in the more felsic phase adjacent to their contact is common (Figure 6). Some enclaves show a few cm wide finer grained chilled margins. Some are seen to align in an inclusion trail, defining an enclave dyke. The concentration of enclaves also varies from place to place. The highest concentration is observed across the gabbro-syenitic rock boundary. They usually occur as single enclaves, an enclave dyke or as swarms. The presence of dykes of all stages of disintegration indicates that these dykes were intruded synplutonically into a still mobile magma. Folding of synplutonic dykes is mainly caused by magmatic flow in the host rock during their intrusions. This is particularly evident when the fold hinge is parallel to the magmatic foliation. Necking and back veining is another interesting feature of these dykes. The back veining is caused by superheating of the host magma by the intruding dykes thus lowering the viscosity of the host magma and causing necking and back veining of the host magma into the dykes.

PETROGRAPHIC EVIDENCE OF MAGMATIC ORIGIN

Igneous foliation

It has been noted microscopically that the suite of rocks under study is made up of igneous minerals. This is obvious especially when minerals show euhedral to subhedral grains e.g. biotite, pyroxene, K-feldspar and plagioclase. It is observed that the oriented K-feldspar and plagioclase, which define the igneous foliation are highly euhedral implying that they have crystallized from a melt since feldspars generally do not grow as euhedral crystal in

Figure 2. Crystal settling layers in the igneous rocks near Sungai Kasai. The layering is madeup of K-feldspar in melagabbro.

Figure 3. Cognate xenolith of gabbroic composition in the syenite and vice versa.

unmelted metamorphic rocks (Vernon, 1968, 1976, 1986; Shelly, 1992). Furthermore the feldspar crystals show igneous microstructure such as synneusis and oscillatory zoning, and are unbroken. Interstitial minerals in these rocks also show no sign of plastic deformation or recrystallisation. This is particularly evident in quartz syenite because interstitial quartz is anhedral, non-deformed and non-aligned. These anhedral aggregates support an igneous origin because quartz and quartz aggregates do not have strong shape preferred orientation in a non deformed pluton. The fact that quartz undergoes plastic deformation and consequent elongation more readily (for any given P,T, fluid etc.) than other minerals can be used as a criterion to argue that solid state deformation has not occurred. If a metamorphic origin is suggested for this suite of rocks one would expect to see lensoid and elongated minerals, resulted from recrystallised aggregates. However microscopic studies have shown that those features are absent, thus ruling out a metamorphic origin. Moreover, other minerals such as hornblende and pyroxene, which also exhibit igneous microstructures (twinning, zoning, corona texture etc), further substantiate an igneous origin for these rocks.

Apatite

Detailed petrographic study revealed that the occurrence of apatite is ubiquitous in all types of rock in the study area. The occurrence of apatite can be divided into 2 groups depending on their relative size and shape. The first group belongs to relatively big and equant crystals. They are observable even under low magnification and appear to be abundantly disseminated inside other minerals e.g. pyroxene, biotite and K-feldspar. This apatites exhibit euhedral six-sided basal outline while elongate crystals are highly euhedral with transverse fractures. The second group of apatite is relatively smaller and acicular which is only discernible under high magnification. The apatite needles are also found disseminated in other minerals and appears in clusters. It is observed that the first group of apatite is confined to gabbro, syenite and monzonite though the second group of apatite is also present in lesser amount in these rocks. Enclaves and synplutonic dykes however are devoid of the first group apatite. They only contain an abundance of acicular apatite. The implication of the presence of these two different groups of apatite appears to reflect on their crystallization history. This is mirrored in the occurrence of this mineral in two groups of rocks namely the gabbro-syenite-monzonite and the enclave – dyke group. The former group of apatite represents the normal slow cooling product below the liquidus temperature. The latter appears to be the product of quenching process as has been shown experimentally by Wyllie *et al.* (1962). From the present studies, it is inferred that the gabbro, syenite and monzonite underwent a slow cooling process while the enclaves and dykes are rapidly cooled. However the presence of acicular apatite together with the equant and bigger apatite could mean that the earlier crystallization at depth would have crystallized out the equant and big apatites while magma that crystallized at higher levels rapidly cooled, thus producing acicular apatite. Nevertheless the occurrence of apatite is strongly suggestive of the former existence of a liquid phase in this suite of rocks and the different types of apatite may prove to be of value in interpretating their crystallsation history.

Figure 4. A folded synplutonic dyke in the syenite. Note that K-feldspar phenocrysts are truncated by the dyke.

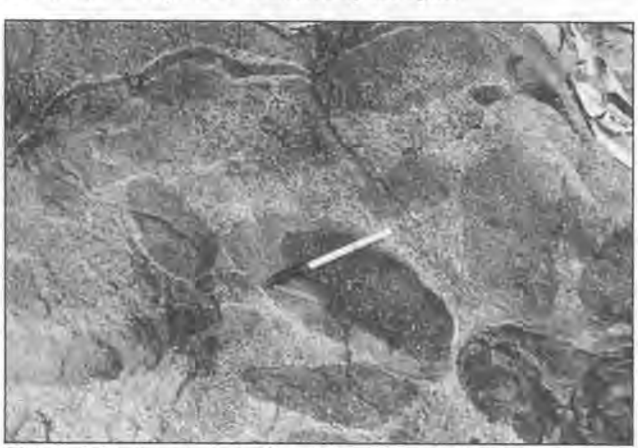

Figure 5. Enclave trails in the gabbro. Note the hybridized margin of some of the enclaves.

Composition convergence between enclave and host

Most enclaves contain more or less the same mineral composition as their host but in different proportions. The major minerals present are poikilitic K-feldspar, hornblende, pyroxene, biotite with abundant apatite needles. The close mineralogical affinity which is observed between enclaves and the surrounding host, leads us to infer that equilibrium condition (T, PH_2O, PO_2) were achieved between the two magmas during the mixing episode. The fact that both enclave magma and host magma is very fluid at the time enhanced the process of mixing. The mixing process has enabled chemical and mineralogical equilibrium to be achieved by means of chemical and physical interchange. Kouchi & Sunagawa (1985) have shown that basaltic and dacitic magma can mix easily to form andesitic melt during laminar flow assisted by convection in the mafic melt. From field and microscopic study, the magmatic flow is great as mirrored by K-feldspar foliation and elongated enclaves. This coupled with the occurrence of local turbulence during the injection of mafic globules into the phenocrysts-rich magma would enhance mixing between these two magmas. Moreover the rounded shape of enclaves probably increases the liquid-liquid interface for further and quicker chemical and mineralogical equilibrium.

DISCUSSION AND CONCLUSIONS

The occurrence of accidental xenoliths in the suite of rocks ranging from gabbro to syenite strongly suggest an igneous origin since these xenoliths represent pieces of country rock that had fallen into the intruding magma. Other evidence of igneous origin is the wrapping round of feldspar due to rotation of xenolith in a flowing magma and the occurrence of cognate xenoliths parallel to the flow direction of K-feldspar.

The presence of dykes of all stages of disintegration suggests that these dykes were intruded synplutonically into a still mobile magmatic rock. This alone is a strong evidence that the suite of rocks is igneous and not metamorphic. The rounded shapes of some of the enclaves, with lobate to seriated boundaries and wispy protrusions suggest magma mingling (Vernon 1986). The finer grained dykes suggest that the enclave magma was strongly intercooled so the the nucleation rate of mineral participation at that temperature increased and a relative finer grain size was produced. The enclaves that are elongated parallel to the rock foliation suggest magmatic flow. Folding of synplutonic dykes were also caused by magmatic flow in the host rock during the intrusion. This is particularly evident when the fold hinge is parallel to the magmatic foliation. Necking and back veining is another interesting feature of the synplutonic dykes. The back veining of these dykes is caused by superheating of the host magma by the intruding dykes thus lowering the viscosity of the host magma causing necking and back-veining of the host magma into the dykes.

The alignment of K-feldspar crystals in the intermediate rocks is conspicuous. The K-feldspar occurs as euhedral, rectangular crystals, measuring up to 8 cm in length and 2 cm in width (Figure 7). The foliation sometimes is deflected around enclaves and is cut by flow drag which resulted from early faulting. The foliation in the studied rocks was once interpreted as metamorphic foliation, implying a regional metamorphism. The fact that the K-feldspar occurs as euhedral crystals would rule out such a possibility. The occurrence of enclaves interpreted as incompletely solidified magma globules is strongly suggestive of a magmatic origin. The preferred alignment of elongated enclaves parallel to the foliation indicates a magmatic flow process during their injection. The deflection of foliation around enclaves also indicates that enough melt was present and the flow was unaffected except deflected by ongoing velocity gradients around a magma globule. Foliation in igneous rocks can form by different processes and mechanisms. Generally foliation can form by magmatic flow, submagmatic flow, high temperature solid state deformation and moderate to low temperature deformation (Paterson *et al.*, 1989). A magmatic origin is particularly favoured for foliation defined by the igneous commonly euhedral minerals, especially where the foliation is parallel to external and internal pluton contacts. Based on the field and petrographic evidence, the foliation in the suite of rocks is interpreted to be formed by magmatic flow which is defined as deformation by displacement of melt with consequent rigid body rotation of crystals without significant interference between crystals to cause deformation, i.e. suspension like behaviour (Paterson *et al.*, 1989).

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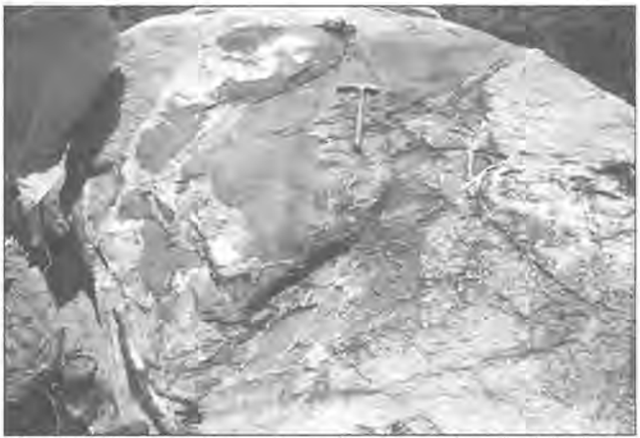

Figure 6. The detached enclaves from a synplutonic dyke in the syenite. Note the lobate to crenulate contact of the dyke.

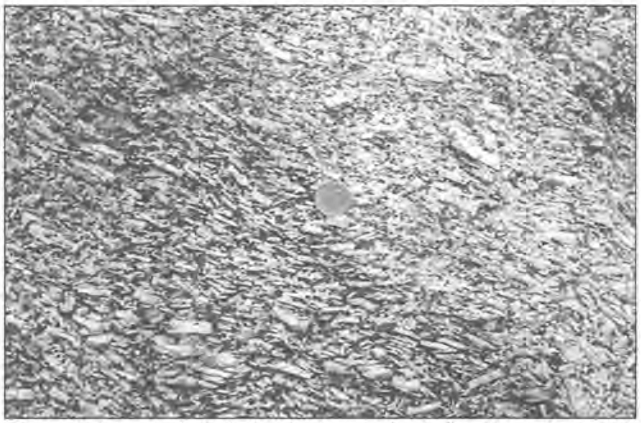

Figure 7. Magmatic foliation in the syenite defined by euhedral K-feldspar megacrysts. The megacrysts measure up to 8 cm in length in some places.

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