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Potential Alkali-Reactivity of Granite Aggregates in the Bukit Lagong Area, Selangor, Peninsular Malaysia

(Potensi Tindak Balas Alkali Batuan Agregat Granit di Kawasan Bukit Lagong, Selangor, Semenanjung Malaysia)

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ABSTRACT

The Bukit Lagong area is the most important aggregate supply centre in Selangor. Geological studies were carried out in four quarries in the Bukit Lagong area and samples were subjected to petrographic examination and accelerated expansion tests to assess the potential alkali-aggregate reactivity of granite aggregates. The granitic rocks comprise mainly of coarse grained megacrystic granite, minor medium grained megacrystic granite and microgranite. Petrographic examination showed that the primary minerals in these undeformed granitic rocks are not alkali reactive. Faulting and related alteration and mineralization have produced potentially alkali reactive minerals including microcrystalline and strained quartz and fine phyllosilicates. Marginally deleterious and deleterious expansion is shown by the accelerated mortar bar tests. Although alkali reactive rocks are present in some quarries in Bukit Lagong, their volume is small. When blended with the undeformed granitic rocks, the aggregates produced are not expected to cause alkali-aggregate reaction in concrete.

Keywords: Alkali-aggregate reaction; cataclasite; granite aggregate

ABSTRAK

Kawasan Bukit Lagong merupakan sumber batuan agregat yang terpenting di Selangor. Kajian geologi telah dijalankan di empat kuari di kawasan Bukit Lagong dan kajian petrografi serta ujian pengembangan terpecut dilakukan untuk menilai potensi tindak balas alkali agregat untuk agregat granit. Granit megahablur berbutir kasar adalah batuan utama di kawasan kajian dan terdapat sedikit granit megahablur berbutir sederhana dan mikrogranit. Kajian petrografi menunjukkan bahawa mineral primer yang ada pada batuan granit yang tidak mengalami canggaan adalah tidak alkali reaktif. Sesar serta perubahan dan pemineralan yang berkaitan telah menghasilkan mineral yang mungkin alkali reaktif seperti kuarza keterikan, kuarza mikrohabluran dan filosilikat halus. Ujian batang lepa terpecut menunjukkan pengembangan pinggiran mudarat dan mudarat. Walaupun batuan alkali reaktif wujud dalam kuari di Bukit Lagong, isi padu batuan tersebut adalah kecil. Selepas dicampur dengan granit yang tidak mengalami canggaan, agregat yang dihasilkan tidak dijangka akan menyebabkan tindak balas alkali-agregat dalam konkrit.

Kata kunci: Agregat granit; kataklasit; tindak balas alkali agregat

INTRODUCTION

Aggregate, sand and gravel are fundamental components of construction and are essential for building construction and infrastructure projects such as highways, bridges and airports. These materials make an essential contribution to the nation's prosperity and quality of life and civilisation could not continue to exist without their exploitation (Anthony 1991). Due to their relatively large bulk, low price at the production site and high haulage cost, economic construction of major engineering projects relies on the optimum utilisation of locally occurring natural construction materials. Thus, it is important to know and understand the characteristics of construction materials, particularly near the urban centres, in order to evaluate and optimise their potential usage.

In Peninsular Malaysia, granite is the most important source of construction aggregates and in the state of Selangor, all construction aggregates are produced from granitic rocks (JMG 2010). Strategically located in central Selangor and within 10 km from Kuala Lumpur and near to the North-South Expressway, the Bukit Lagong area is the most important aggregate supply centre in Selangor. There are six active quarries producing about 8 million tonnes of granite aggregates annually, which constitutes about 40% of all aggregates produced in Selangor (Mustaza et al. 2008).

Granite aggregates are the preferred material used in concrete in Peninsular Malaysia. They are generally considered non alkali-aggregate reactive (Chow & Abdul Majid 1990; Yeap 1992). However, recent studies revealed that some of the granite aggregates are alkali reactive (Ng 2010; Ng & Yeap 2007). It is imperative that potentially alkali reactive rocks are not used for the production of aggregates because deleterious aggregates will affect the soundness of concrete structures and adversely impact the construction industry. The objective of this study was to assess the potential alkali-aggregate reactivity of granite aggregates in the Bukit Lagong area. Geological field studies were carried out in four quarries to identify rocks that are potentially reactive. Potentially reactive minerals were determined through petrographic analysis of rock samples. The potential for deleterious alkali-silica reaction was verified using the accelerated mortar bar test.

BACKGROUND ON ALKALI-AGGREGATE REACTION

Alkali-aggregate reaction (AAR) is a chemical reaction where alkali cations in solution (Na^+, K^+) react with reactive aggregates in the concrete (Ferarris 1995; Hobbs 1990). Through this reaction, amorphous phases are formed, which imbibes water and swells. It causes expansion, cracking and weakening of the concrete structure and potentially leading to a collapse.

There are three types of AAR: alkali-silica reaction; alkali-silicate reaction and alkali-carbonate reaction (Gillott 1975). The last reaction is not relevant for granite aggregates. Alkali silica reaction (ASR) results from the reaction of disordered forms of silica minerals in aggregates and the hydroxyl ions (OH^-) in the pore fluid of concrete (Hobbs 1990). The hydroxyl ions usually originate from the sodium and potassium alkalis in the portland cement during hydration. The reaction produces a gel-like material that can be expansive when exposed to water. Reactive silica materials that can cause deleterious expansion listed in decreasing order are: opal, chalcedony, volcanic glass, cristobalite, tridymite and cryptocrystalline quartz (Gaskin et al. 1955; McConnell et al. 1947). Strained and microcrystalline quartz are also potentially reactive. Alkali-silicate reaction is believed to be due to the occurrence of swelling phyllosilicate minerals or reaction involving silicates, particularly phyllosilicates (Gillott 1975; Gillott et al. 1973).

ALKALI REACTIVE MINERALS IN GRANITE

Alkali reactive minerals can occur naturally in granite aggregates in several ways. Primary minerals of the granite and associated rocks found in the quarries are generally devoid of reactive minerals, although minor microcrystalline quartz are present in mymerkite in some granites and as individual grains in some fine-grained microgranite and aplite. Granites near the contact with the country rocks often have metasedimentary xenoliths, which contain phyllosilicates and microcrystalline quartz. Generally, these xenoliths only constitute a very small proportion of the rock mass. However, quartz-mica schist originated from xenoliths constitutes up to 10% of aggregates produced from two quarries in Cheras and Ampang in the 1990s.

Granitic rocks may contain reactive secondary minerals such as opal and chalcedony which infill discontinuities. Field studies of granite quarries show that such mineral veins are rare in Peninsular Malaysia; however, chalcedony has been reported in Selangor by Yeap (1992). Faulting has generated a diverse variety of deformed granites and caused severe straining and grain size reduction of the quartz grains in the granite (Ng 1994). The effect of fault deformation on potential ASR of granites has been discussed in Peninsular Malaysia (Ng & Yeap 2007) and elsewhere (Kerrick & Hooton 1992; Wigum 1995). Lastly, reactive secondary minerals can also form as a result of mineralization and alteration of granites, which are common along faults and veins.

GEOLOGICAL SETTING

The Bukit Lagong area is underlain by granite and metasedimentary rocks belonging to the Kenny Hill Formation (Figure 1). A quartz dyke forms a northwest-southeast trending ridge cutting the metasedimentary rocks, near Taman Matang Jaya. Minor alluvium occurs along the main rivers. All the quarries are within granitic rocks on the foothills of Bukit Lagong. The granite is part of the Kuala Lumpur Pluton described by Cobbing & Mallick (1987) and Cobbing et al. (1992), which is also known as the Beranang Suite by Liew (1983).

Kuala Lumpur Pluton is a large granite body of irregular shape comprising two lobes on the western side of the main range. It has considerable textural and mineralogical variations and mapping of the different lithological variants has been proven to be difficult (Cobbing & Mallick 1987). Both primary texture granite and two-phase variants are present. In the Bukit Lagong area, the main granite unit is coarse grained megacrystic granite (Unit 1), which is a primary texture granite that resembles the Gombak unit of Cobbing and Mallick (1987). It has an overall light grey colour with black specks of biotite (Figure 2(a)). The megacrysts consist of about 10% of very coarse tabular alkali feldspar having similar colour with the groundmass. The coarse grained allotriomorphic and inequigranular groundmass is made up of approximately equal amounts of quartz, alkali feldspar and plagioclase and about 5% of biotite and about 2% of muscovite. The brownish to pinkish grey and transparent quartz mainly occurs in elongated clusters up to 20 mm in size with individual interlocking grains up to 3 mm in diameter.

Groundmass alkali feldspar occurs interstitially between quartz and plagioclase as anhedral to subhedral grains about 2 to 5 mm across. Alkali feldspar forming both megacryst and groundmass is generally microcline and has well developed string perthite and cross hatched twinning (Figure 3(a)). The white to light yellow plagioclase is subhedral with grain size up to 12 mm across. Biotite occurs as single plates up to 5 mm long. The biotite grains are stout euhedral to subhedral and pleochroic from light brown to dark brown. They often contain many inclusions of zircon and apatite and they may be chloritized or altered to muscovite. Muscovite forms single plates and is also intergrown with biotite. Zircon, apatite, sphene, tourmaline, fluorite and ilmenite are common accessories while chlorite, sericite and epidote occur as alteration products.

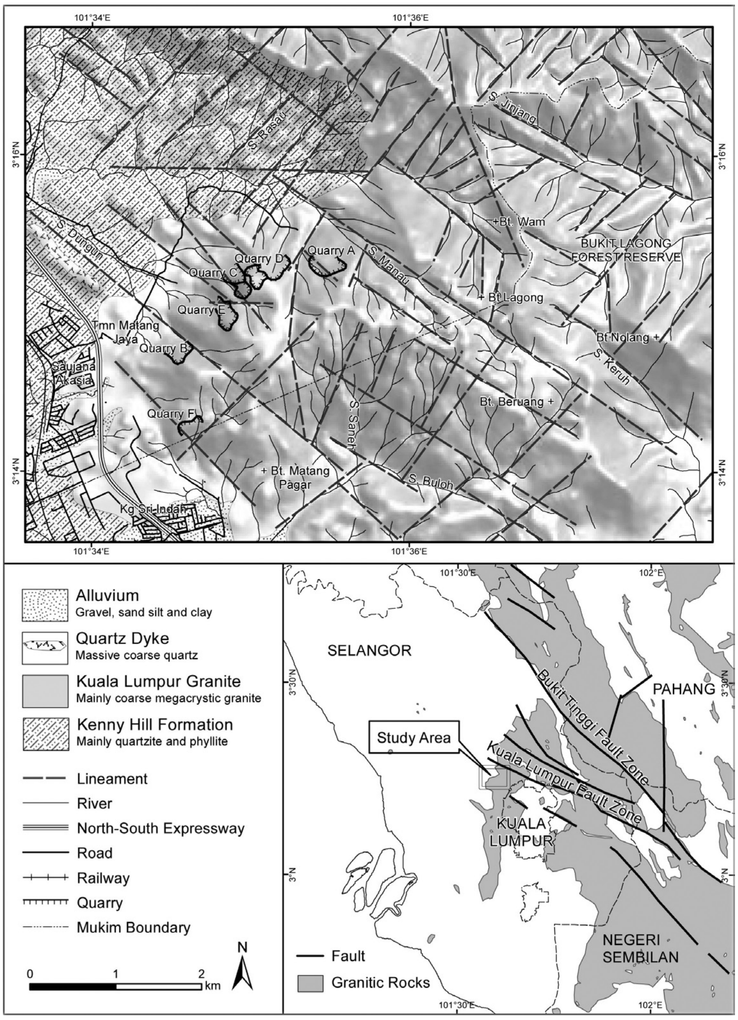

FIGURE 1. Geological map showing the distribution of faults and granitic rocks in the Selangor and adjacent areas (bottom) and the location of granite quarries and lineaments in the Bukit Lagong area (top)

Two-phase variant consisting of medium grained megacrystic granite (Unit 2) is common but volumetrically less than Unit 1. It can be differentiated from the primary texture granite by the presence of megacrysts of coarse rounded quartz and feldspars set in a groundmass of dark grey medium grained equigranular mosaic of quartz and feldspars and fine biotite flakes. The megacrystic texture is prominent due to the colour contrast between the megacrysts and darker groundmass (Figure 2(a)). Other distinctive features are the presence of zonal arrangement of fine quartz grains near the edge of alkali feldspar megacrysts and the common occurrence of mymerkite (Figure 3(b)).

In addition of the two granite units, minor late phase differentiates such as microgranite, aplite and pegmatites are common. They occur as dykes and small lenticular bodies in the granites. Some of these bodies show layered structures, which is also common in other parts of the Kuala Lumpur Pluton (Ng 1997).

The Bukit Lagong area is cut by the northwest-southeast trending Kuala Lumpur Fault Zone (Figure 1). The fault zone is indicated by array of prominent northwest-southeast lineaments observed in aerial photographs and satellite imageries, as well as fault zones observed in the rock outcrops. Northeast-southwest and east-west trending lineaments and faults are also common in the area. Fault rocks including fault breccia and cataclasites are common. However, mylonites such as those found in the Bukit Tinggi Fault Zone are absent. Alteration and mineralization are common along the fault zones.

MATERIALS AND METHODS

Geological studies were carried out on the quarry faces to determine the types of granite present and to locate faults, veins and zones of alteration and mineralization. About 50 rock samples were collected from the 4 quarries. The samples represent typical granites from Units 1 and 2 and microgranites, as well as fault rocks from the fault zones, altered and mineralised granites, quartz veins, quartz-pyrite veins, metasedimentary xenoliths and micaceous enclaves. Twenty samples were selected for petrographic analysis (Table 1) and six samples were selected for accelerated mortar bar test, representing four deformed (cataclastic)

TABLE 1. Summary of the petrographic properties of samples selected for petrographic examination. Note: Slightly: <10% affected, moderately: 10 - 35% affected, highly: 35 - 75% affected, extremely: >75% affected. P:plagioclase, K:alkali feldspar, B:biotite. Sample with asterisk (*) were subjected to accelerated mortar bar expansion test

Sample	Location Rock Type	Colour	Dominant Grain Size	Texture	State of Weathering	Alteration	Potential deleterious mineral
QA001	Quarry A Quartz Vein	White	Medium grained	Granular	Slightly discoloured	None	Minor microcrystalline quartz
QA002	Quarry A Microgranite	Light grey	Fine	Hypiodio-morphic inequigranular	Fresh	P - Slightly sericitised, K - Slightly kaolinised, B - Slightly chloritised	Minor microcrystalline quartz
QA003	Quarry A Granite Unit 1	Light grey	Coarse	Megacrystic, allotriomorphic	Slightly discoloured	P - Moderately sericitised, B - Moderately chloritised	None
QA004	Quarry A Granite Unit 2	Grey	Medium	Megacrystic, mortar texture	Slightly discoloured	P - Moderately sericitised, B - Moderately chloritised	Minor microcrystalline and strained quartz
QA005	Quarry A Proto-cataclasite	Greenish grey	Fine to medium	Fragmental texture	Moderately discoloured	P - Highly sericitised B - Extremely chloritised	Microcrystalline and strained quartz
QA006	Quarry A Proto-cataclasite	Dark grey	Fine to medium	Fragmental texture	Moderately discoloured	P - Moderately sericitised, B - Extremely chloritised Sericite veinlets in P & K	Microcrystalline and strained quartz
QA007*	Quarry A Meso-cataclasite	Light grey to greenish grey	Fine	Fragmental and granular	Highly discoloured	P & K - Extremely silicified B - Extremely chloritised 2° quartz & calcite in matrix & quartz veinlets	Microcrystalline and strained quartz, ?chlorite
QA008*	Quarry A Granite Unit 1	Greenish grey	Fine to medium	Megacrystic, allotriomorphic	Slightly discoloured	P & K - completely altered to sericite, chlorite and quartz	Microcrystalline quartz, ?sericite & chlorite
QA009	Quarry A Proto-cataclasite	Dark grey	Fine to medium	Fragmental texture	Slightly discoloured	P - Moderately sericitised, B - Completely chloritised 2° chlorite in matrix	Microcrystalline and strained quartz, ?chlorite
QA010*	Quarry A Granite Unit 2	Grey	Medium	Megacrystic, mortar texture	Slightly discoloured	P - Slightly sericitised, B - Moderately chloritised	Minor microcrystalline and strained quartz
QA011	Quarry A Xenolith, meta-sedimentary	Dark grey	Fine	Weakly foliated granular mosaic	Slightly discoloured	None	Microcrystalline quartz
QB001	Quarry B Granite Unit 1	Light grey	Coarse	Megacrystic, allotriomorphic	Slightly discoloured	P - Moderately sericitised, B - Moderately chloritised	None
QB002	Quarry B Meso-cataclasite	Dark greenish grey	Fine	Fragmental texture	Moderately discoloured	P - Highly sericitised B - Extremely chloritised 2° quartz in matrix, calcite veinlets	Microcrystalline and strained quartz, ?chlorite
QB003	Quarry B Granite Unit 2	Grey	Medium grained	Megacrystic, hypidiomorphic	Slightly discoloured	P - Moderately sericitised, B - Moderately chloritised	Strained quartz
QB004*	Quarry B Meso-cataclasite	Dark grey to black	Fine	Fragmental texture	Highly discoloured	P - Highly sericitised B - Extremely chloritised 2° chlorite in matrix, quartz-pyrite veins	Microcrystalline and strained quartz, ?chlorite & pyrite
QB005*	Quarry B Proto-cataclasite	Dark grey	Fine to medium	Fragmental texture	Moderately discoloured	P - Highly sericitised B - Extremely chloritised 2° sericite in matrix, calcite veinlets	Microcrystalline and strained quartz, ?sericite
QB006	Quarry B Microgranite, layered	Light grey to grey	Fine	Hypidiomorphic, inequigranular	Fresh	P - Moderately sericitised, B - Moderately chloritised	Microcrystalline quartz
QB007	Quarry B Enclave, micaceous	Black	Fine to medium	Hypidiomorphic	Slightly discoloured	None	None

(continue)

Continued (TABLE 1)

Sample	Location Rock Type	Colour	Dominant Grain Size	Texture	State of Weathering	Alteration	Potential deleterious mineral
QC001*	Quarry C Meso-cataclasite	Dark grey to black	Fine to medium	Fragmental texture	Highly discoloured	P - Highly sericitised B - completely chloritised 2° quartz, chlorite, sericite & pyrite in matrix	Microcrystalline and strained quartz, ?chlorite & pyrite
QC002	Quarry C Proto-cataclasite	Dark grey	Fine to medium	Fragmental texture	Moderately discoloured	P - Highly sericitised B - Extremely chloritised 2° chlorite in matrix	Microcrystalline and strained quartz, ?chlorite

granites, one altered (completely sericitized) granite and one normal (undeformed and weakly sericitized) granite.

Petrographic examination was carried out on thin sections to determine the grain size, texture, microstructure and mineralogy, particularly potentially reactive minerals. Terminology for fault rocks recommended by IUGS (Brodie et al. 2007) is used in this report. The accelerated mortar bar expansion test was performed on samples following the method in ASTM C1260 (ASTM 2004) by an accredited commercial laboratory. This 16-day test adopted from procedures by Oberholster and Davies (1986) is an accelerated version of the original mortar-bar test (ASTM C227; ASTM 1990) which requires at least 6 months to complete. Three bars (25 mm × 25 mm × 250 mm) were prepared for each sample. The proportion of the materials for the test mortar by mass was 1 part cement to 2.25 parts of graded aggregate to 0.47 part of water. The mortar bars were demoulded after 24 h, immersed in water in a sealed container and placed in an oven at 80°C for 24 h. The length of the mortar bars was measured using a comparator with a dial micrometer graduated to read 0.002 mm. The mortar bars were immersed in 1N NaOH at 80°C in a sealed container and returned to the oven. Their length change was monitored after 1, 5, 8, 11 and 14 days of immersion in NaOH. The average expansion of the three bars was calculated to the nearest 0.01%.

RESULTS

GEOLOGY OF THE QUARRIES

Four quarries in the Bukit Lagong area were studied and these quarries are named arbitrary as Quarry A to Quarry D, respectively. In Quarry A, coarse grained megacrystic granite (Unit 1) dominates and there are minor occurrences of medium grained megacrystic granite (Unit 2) and microgranite. The granitic rocks are cut by several fault zones, the most prominent fault forms a 1 to 3 m thick, 020° trending zone of chloritised and silicified cataclasites. There are several smaller northwest-southeast trending fault zones with centimeter to decimeter thick sub-parallel to anastomosing zones of cataclasites (Figure 2(b)). A zone of northwest-southeast trending strongly sericitised granite up to 5 m thick is also observed. Quartz veins, quartz-tourmaline veins, chlorite veins, metasedimentary xenolith and micaceous enclaves are present.

Quarry B is underlain by about 75% granite from Unit 1, 20% Unit 2 and 5% microgranite. The rocks are cut by several faults, but no broad zones of fault rocks are produced. Two cataclasite zones associated with northwest-southeast faults are present, one of them is silicified (Figure 2(c)), while the other is chloritised and cut by several quartz-pyrite veins that are sub-parallel to the fault. There are also quartz veins, quartz-tourmaline-muscovite veins, chlorite veins and metasedimentary xenoliths.

Apart from the presence of layered microgranite, the rocks in Quarry C are similar to Quarry B. Quarry C is cut by a prominent northwest-southeast fault zone, forming a 5 to 10 m thick zone of cataclasite and fault breccia. The incohesive fault breccia causes poor fragmentation during blasting where huge blocks that require secondary fragmentation were produced (Figure 2(d)). The cataclasite is silicified, chloritised and pyritized. There are also several smaller northwest-southeast trending fault zones with silicified and chloritised cataclasites. Quartz veins, quartz-tourmaline veins and chlorite veins are also present.

Quarry D is underlain by granites of Units 1 and 2 with lesser microgranite. No broad fault zones are observed during the brief site visit.

PETROGRAPHIC EXAMINATION

Faulting has resulted in the formation of a wide variety of fault rocks in the granite, ranging from fault gouge and breccias to cataclasites. The main potentially deleterious minerals in cataclastic granites are strained quartz and microcrystalline quartz. Quartz with undulatory extinction is common in all undeformed and deformed granite samples. However, not all quartz with undulatory extinction is indicative of deleterious behaviour (West 1991). It is generally accepted that quartz with undulatory extinction angle larger than 15°, and quartz with deformation bands and lamellae is considered as strained quartz. Quartz in the undeformed granite samples is generally not strained and shows only patchy wavy extinction. However, quartz with sweeping undulatory extinction is common in granite Unit 2 and some quartz veins. All quartz clasts in the cataclasites are strained with sweeping undulatory extinction (Figure 4). Quartz clasts with deformation bands and lamellae

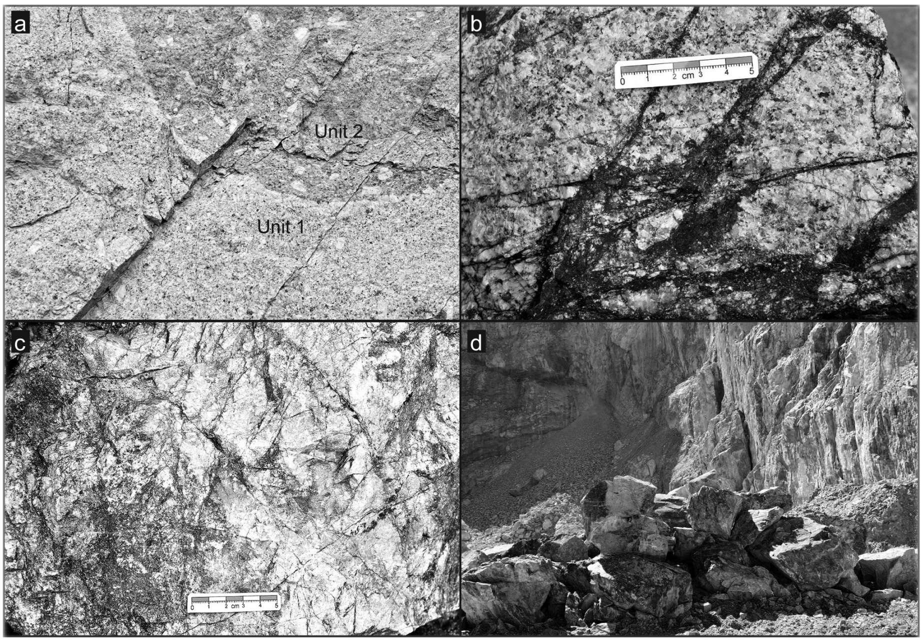

FIGURE 2. Field photographs (a) Contact between the coarse grained megacrystic granite (Unit 1) and the medium grained megacrystic granite (Unit 2, two phase variant) in Quarry B. Unit 2 has a darker medium grained groundmass and megacrysts of rounded alkali feldspar, plagioclase and quartz, (b) A northwest-southeast trending fault zone in Quarry A with centimeter thick sub-parallel to bifurcating bands of cataclasites, which are cut by thin north-south trending chlorite veins, (c) Silicified cataclasite in Quarry B. The rock is fine grained and very hard due to silicification. Fragmental texture can be seen. Lesser chloritisation is also present and (d) A broad northwest-southeast trending shear zone in Quarry C comprises fault breccia that cuts silicified, chloritised and pyritised cataclasites. The presence of incohesive fault breccia along the shear zone causes poor fragmentation during blasting. The large block of cataclasites can be seen in the foreground and fine breccia fragments can be seen at the toe of the quarry face in the background

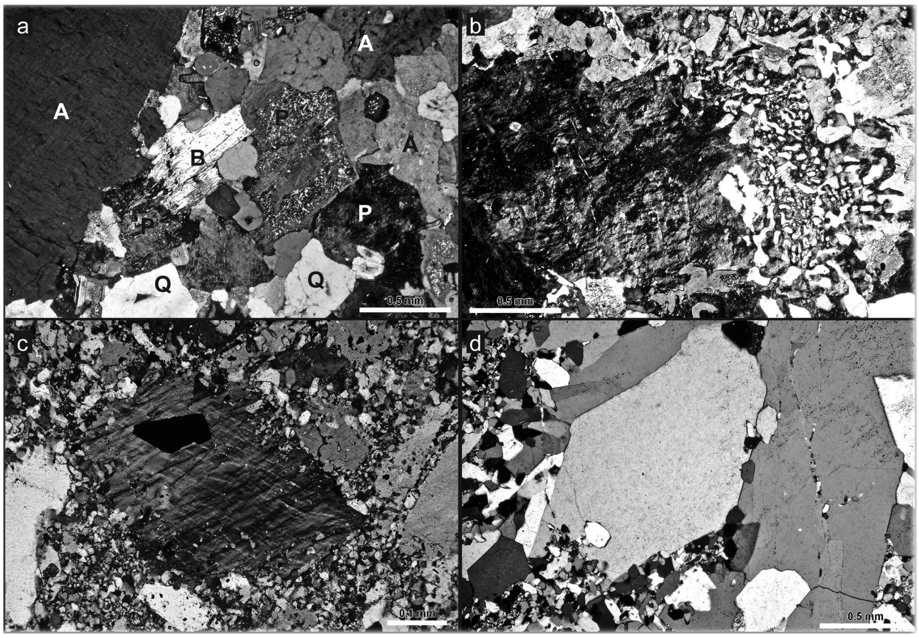

FIGURE 3. Photomicrographs taken under crossed nicols. (a) Coarse grained megacrystic granite (Unit 1, sample QA003) with alkali feldspar (A), plagioclase (P), quartz (Q) and biotite (B). The alkali feldspar occurs as megacryst and groundmass and has perthite structure. Plagioclase is partially sericitised, (b) Microcrystalline quartz occurs as vermicular grains in myrmekite at the edge of an alkali feldspar in the medium grained megacrystic granite (Unit 2, sample QA004), (c) Sample QC001, a mesocataclasite occuring in a broad fault zone in Quarry C shown in Figure 2(d). It is silicified and variably sericitised and pyritised. The quartz clast in the centre shows two sets of deformation lamella and a pyrite grain. Microcrystalline quartz grains are present in the matrix and (d) Quartz grains in a quartz vein have variable grain size, which range from coarse to microcrystalline (sample QA001)

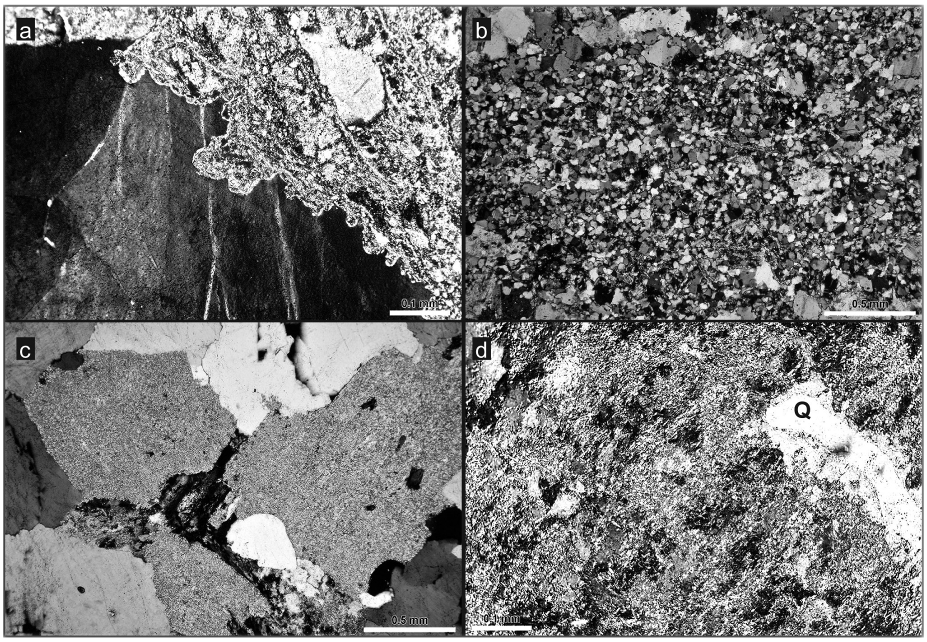

FIGURE 4. Photomicrographs taken under crossed nicols. (a) Sample QB002, a silicified and sericitised mesocataclasite. The coarse quartz clasts shows sweeping undulatory extinction and few deformation bands. The jagged grain boundary indicates pressure solution of quartz. There are abundant fine sericite veinlets and microcrystalline quartz grains in the matrix, (b) The metasedimentary xenolith in the granite of Quarry B contains abundant microcrystalline quartz (sample QB007), (c) Plagioclase in the sericitised granite is completely altered but the relict outlines are still intact (sample QA008) and (d) A magnified view of the completely altered plagioclase in (c). There are many fine grained irregular quartz grains in the altered plagioclase, in addition to sericite and some chlorite. Note the overgrowth of secondary quartz around an elongated quartz inclusion (Q)

occur subordinately in the cataclasites but are common in the mesocataclasite from Quarry C (sample QC001, Figure 3(c)). Fine quartz neocrysts in the silicified cataclasites are generally undeformed. Quartz in the metasedimentary xenolith also shows negligible deformation.

Small amounts of microcrystalline (<63 μm) quartz grains occur in the microgranite, in some quartz veins (Figure 3(d)) and in the granite Unit 2 as myrmekite (Figure 3(b)). Microcrystalline quartz is common in the cataclasites (Figures 3(c) and 4(a)) and the metasedimentary xenolith (Figure 4(b)). Deformation of granites resulted in grain size reduction. In the cataclasites, microcrystalline quartz is produced by abrasive wear and it is consisting of angular quartz clasts in the matrix. In the silicified granite and silicified cataclasite, the microcrystalline quartz neocrysts are precipitated from hydrothermal solution and is relatively strain-free. Not all quartz grains in the silicified samples are microcrystalline, some of the quartz form coarse subhedral grains in vienlets. Although, quartz can occupy up to 75% of the silicified rocks, generally the microcrystalline fraction is only about 25%.

Microcrystalline quartz is also found in strongly sericitised granite (sample QA008), where all the plagioclase has been completely altered (Figure 4(c)). In some of the sericitised plagioclase, very fine irregularly-shaped quartz grains are observed (Figure 4(d)), probably formed from the excess silica produced during the alteration process.

The significant amount of fine phyllosilicates (sericite and chlorite) occurred in some altered cataclasites and sericitised granite (Figure 4(c) and 4(d)). The potential of these fine phyllosilicates to cause alkali-silicate reaction cannot be ruled out. Up to 5% of pyrite is found in the cataclasite. The pyrite occurs in clusters in the matrix of the cataclasites (sample QC001) and in quartz veins cutting the cataclasite (sample QB004).

MORTAR-BAR TEST

The expansion of the mortar-bars based on an average of three bars is plotted in Figure 5. According to the ASTM C-1260 (ASTM 2004), the expansions of less than 0.10% at 14 days under the NaOH immersion are indicative of innocuous behaviour. Expansions of more than 0.20% at 16 days after casting are indicative of potentially deleterious expansion. Mortar bars with expansions between 0.10% and 0.20% have marginal behaviour that includes both innocuous and deleterious aggregates.

The highest expansion is recorded in sample QC001 (0.25%), a mesocataclasite with silicification, chloritization, sericitization and pyritization found in the broad fault zone in Quarry C. Sample QA008, a granite with all feldspars altered to sericite and microcrystalline quartz, also has potentially deleterious expansion (0.21%). The other deformed granite samples (QB004, a chloritised mesocataclasite with quartz-pyrite veins; QB005, a chloritised and weakly sericitised mesocataclasite and

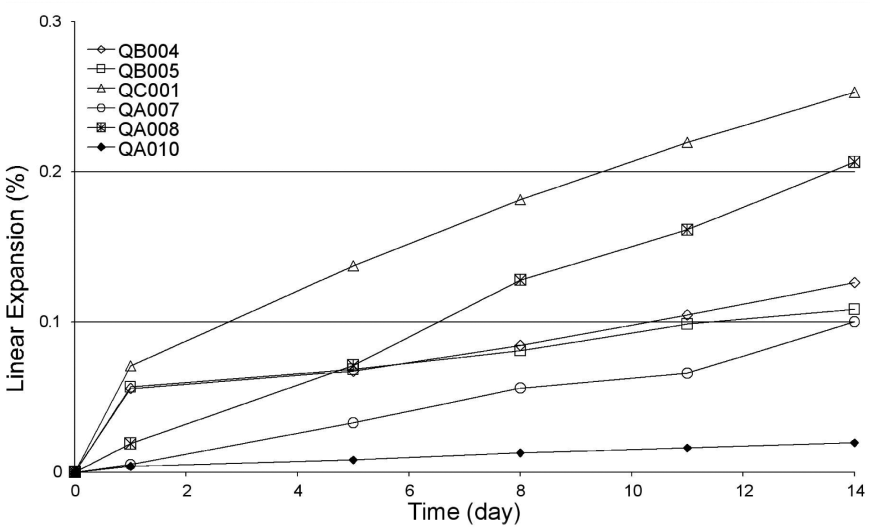

FIGURE 5. Results of the ASTM C1260 mortar-bar test. Linear expansion values are averaged from three bars, time is days of immersion in NaOH

QA007, a silicified mesocataclasite with quartz veins) have expansion between 0.1% and 0.2%. The undeformed granite (sample QA010) showed innocuous behaviour in the mortar bar test.

DISCUSSION

Undeformed and unaltered granite and related rocks in the Bukit Lagong area are not alkali reactive due to the scarcity of deleterious mineral constituents in these rocks. This is shown by the petrographic examination and accelerated mortar bar test on one sample (sample QA010).

The metasedimentary xenoliths contain abundant microcrystalline quartz and are potentially alkali-reactive. Although xenoliths are common in two quarries, they constitute an insignificant proportion (<1%) of the rocks extracted for aggregates and thus are not expected to pose any serious problem in terms of AAR.

Quartz, quartz-tourmaline, quartz-muscovite-tourmaline, calcite, quartz-pyrite and chlorite veins are found cutting the granites, the last two types are often associated with fault zones. Apart from pyrite and chlorite, which may be deleterious, the other minerals in the veins are largely innocuous and these veins are also volumetrically insignificant. Oxidation of pyrite at or near the surface of concrete can cause surface defects and staining but it is unlikely to cause any structural damage.

The most likely source of deleterious minerals are related to fault deformation and hydrothermal alteration. All protocataclasite and mesocataclasite samples contain strained and microcrystalline quartz, however, the proportion of these minerals cannot be easily determined due to the heterogeneous nature of these fault rocks. Fine phyllosilicates (sericite and chlorite) are common in the deformed and altered granites.

The sample having the highest expansion (QC001, 0.25%) contains highly strained quartz clasts and microcrystalline quartz, as well as fine chlorite and sericite. However, it is not possible to determine whether the expansion was caused by ASR or alkali-silicate reaction of phyllosilicates. This potentially deleterious rock also forms the thickest observed fault zone. The mesocataclasite in this fault zone is dark grey to black in colour and thus can easily be differentiated from the undeformed granite. According to the operator of Quarry C, discoloured rocks, including weathered granites and dark coloured fault rocks, normally are only used for the production of crusher run.

The potential deleterious expansion of the sericitised granite (sample QA008, 0.21%) is probably due to the presence of both microcrystalline quartz and fine phyllosilicates. Unlike the mesocataclasite described above, the sericitised granite cannot be easily identified by untrained personnel. The altered zone is about 5 m wide and is cutting the quarry face at high angle. Thus, at any batch of aggregate production, the sericitised granite is not likely to constitute more than 10% of the final product.

The other deformed granite samples only have marginal expansion (0.10% - 0.13%) although potentially deleterious minerals are common in the thin sections. Deformed rocks along the fault zones are inhomogeneous in terms of mineral content, intensity of deformation and thickness. Thin sections are generally made from the more deformed part of the fault zone, while the samples used for expansion test contains mixtures of fault rocks with various degrees of deformation. Samples may also contain some undeformed clasts and wall rock, particularly for anastomosing fault zones. The samples used for expansion test may contain less deleterious minerals than that observed in the thin sections. In practice, deformed rocks from thin fault zones cannot be easily separated during the quarrying process and due to their small volume, when mixed with undeformed granites, the final blended aggregates are unlikely to cause deleterious expansion in concrete.

Conclusion

The granitic rocks in the Bukit Lagong area are cut by the Kuala Lumpur Fault Zone and several other faults. Deformation caused by faulting and the associated alteration and mineralization have produced potentially alkali-reactive minerals, which are identified in the petrographic examination and verified by limited accelerated mortar bar tests. Although, alkali reactive rocks are present in some quarries in Bukit Lagong, generally these rocks will not pose serious problems in the production of concrete aggregates as they constitute only a small proportion of the extracted rocks.

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