Petrography of aggregates in Luzon, Philippines: Identification of components and deleterious materials

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Abstract

Petrography is one of a series of standard tests used to assess an aggregate's components, mechanical qualities, durability, chemical stability, and alkali reactivity. In this study, aggregate materials were collected from rock exposures and/or alluvial deposits from four areas near Metro Manila, Philippines: Bulacan, Rizal, Pampanga, and Zambales. Transmitted light microscopy was conducted to identify rock types and characterise physical and chemical properties that may present potential problems when used as aggregate materials. The results show that the aggregates vary in terms of rock types and alteration type. Samples from Bulacan are mostly porphyritic basalt and fine to coarse-grained sandstone with veinlets of silica and carbonate. The presence of cavities and microfractures caused mainly by vesicles from the volcanic rocks was also observed. Rizal aggregates are composed predominantly of chloritized basalts and andesites with minor clastic rocks and tuffs. The aggregates from Zambales are products of erosion of the Zambales Ophiolite, mixed with the lahar deposits from the Pinatubo eruption. On the other hand, Pampanga aggregates are mostly lahar deposits, containing pumice, a poor choice for aggregate composition due to its low hardness, brittleness and vesiculated texture. Aside from the lithological classification, potentially alkali-reactive constituents were also observed in selected samples from the four sampling areas.

Index Terms: aggregates; Luzon; petrography

1. Introduction

The Philippine government has launched a "Build, build, build", program which aims to enhance the infrastructure of the country, leading to more robust economic development. The key projects under the programme include railways, industrial parts, energy facilities, water resource and flood control projects. These are considered massive construction projects, which will require high quality raw materials, especially aggregates.

Aggregate is any granular material, such as sand, gravel, crushed stone, or iron-blast furnace slag. It is combined with asphalt cement or Portland cement to form asphalt concrete or cement concrete, respectively, and is used in subbases and bases of roadway structure, drainage structures and concrete blocks. The quality of aggregates significantly affects the properties of concrete since it constitutes about 70%-80% of the volume of the concrete[1] and is therefore controlled based on a series of standard tests. Through these tests, the aggregates' compositional, textural and structural characteristics will be assessed to provide data on their mechanical performance, durability, chemical stability, alkali reactivity, and harmful substance content.

One of the standard tests used in the assessment is petrography, or the use of microscopic examination of thin section of rocks, basically for rock identification, description and classification. Petrography provides useful information for understanding the physico-mechanical properties of the rocks being used as aggregates. These properties depend on the degree of alteration and deformation as well as other petrographic characteristics, such as the mineralogical composition, texture, size, shape and arrangement of the mineral grains, the nature of the grains' contacts and the degree of grain interlocking, of the source rock[1]. Knowledge of the relations between petrography and aggregate properties is important to ensure strength and durability of the finished product. As mentioned by Bérubé[2], concrete aggregates must generally satisfy a number of specifications:

a. Mechanical performance: Resistance to fragmentation, abrasion, and polishing
b. Durability: Resistance to environmental conditions, particularly freezing/thawing cycles
c. Chemical stability: Resistance to any deleterious reaction (e.g., dissolution, sulfation)
d. Alkali-aggregate reactivity: Reaction with the highly basic and alkaline concrete pore solution
e. Harmful substances: Soft and friable particles, organic matter, low-density matter
f. Particle shape and surface texture: Sphericity and angularity, toughness and alteration
g. Particle size distribution: Grain size and proportion of fines (% < 80 mm)
h. Other useful (for concrete proportioning) or specified properties (for special uses): surface moisture, water content, absorptivity, specific gravity, bulk density, and percentage of voids

In this paper, petrographic assessment of aggregates collected from four provinces in the Philippines: Bulacan, Rizal, Pampanga, and Zambales will be presented (see ***Figure 1***). These areas are identified as major aggregate suppliers in Metro Manila, where there is substantial demand for aggregates used in the construction of both horizontal and vertical structures.

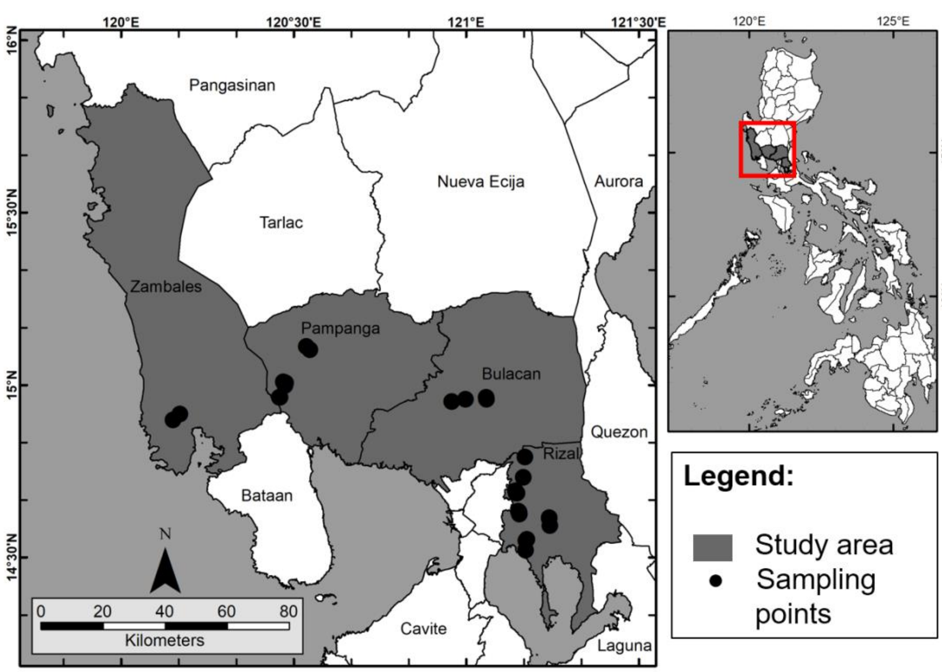

Figure 1. Location map of the study area.
Bulacan, Rizal, Pampanga and Zambales are the main aggregate suppliers for Metro Manila.

2. Aggregate quarries

Fieldwork in various aggregate quarries was conducted, mainly to collect samples. There were two general types of sources for the aggregates used in this study: (1) alluvial deposits and (2) rock exposures.

2.1 Bulacan

In Bulacan, four (4) operating quarries in Dona Remedios Trinidad (DRT) and Angat were sampled (see ***Figure 2***). In the DRT, the quarries are extracted from exposures of the Madlum Formation (Middle Miocene), whereas the Angat River quarries in Marungko and Niugan River are working on alluvial deposits (see ***Figure 3***). The Madlum Formation is a sequence of shale, siltstone, wacke and conglomerate exposed along Madlum River in the vicinity of Barangay Madlum, San Miguel, Bulacan. Included in this formation are the upper metavolcanic member of the Sibul Formation along Madlum River and the upper tuffaceous member of the Quezon Formation in the Angat River area.[4,5] The samples collected in this area are mostly porphyritic basalt with intercalated lamina of very fine to coarse grained sandstone.

On the other hand, in the Marungko and Niugan River Quarries, cobble to boulder samples were randomly selected from the stockpiles. Samples collected vary from igneous to sedimentary rocks, with variations as well within the rock suites. The igneous samples included porphyritic basalt with euhedral plagioclase phenocrysts more than 4mm across, with microphenocrysts of pyroxene and plagioclase laths embedded in volcanic glass.

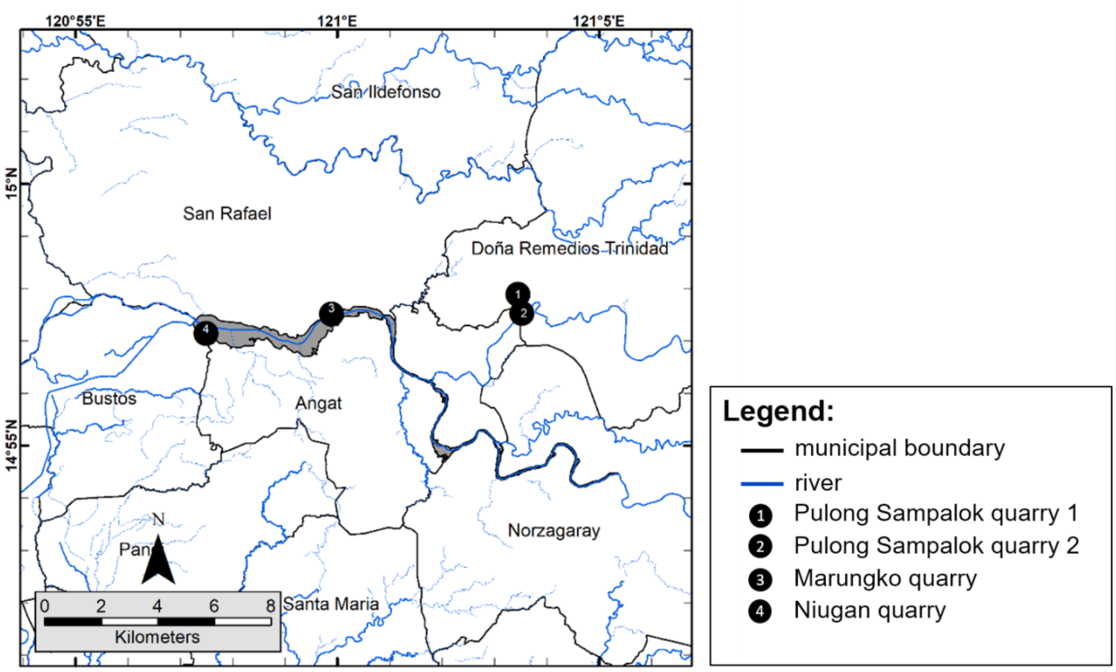

Figure 2. Sample location map in the province of Bulacan Sampling stations 1 and 2 are located in the town of Dona Remedios Trinidad while sampling stations 3 and 4 are situated in the alluvial deposits of Angat River.

2.2 Rizal

Seventeen (17) aggregate quarries were sampled in Antipolo, Angono, San Mateo, and Rodriguez (see ***Figure 4***). Most of the quarries are mining rock exposures belonging to the Montalban Ophiolitic Complex, Madlum Formation and Kinabuan Formation. The Middle Miocene Madlum Formation consists of a thick sequence of sandstone, shale and minor conglomerates as well as andesite flows, pyroclastic breccia, tuff, greywacke and argillite, with massive cavernous limestone with occasional thin beds of crystalline limestone. The Montalban Ophiolitic Complex is the name given by the Mines and Geosciences Bureau[3] to describe the incomplete ophiolitic sequence in the Southern Sierra Madre. It consists of layered and massive gabbro, sheeted diabase dikes, pillow basalts and turbiditic sedimentary rocks. The Late Cretaceous Kinabauan Formation a sequence of sandstone, shale, limestone, calcarenite and calcilutite, is considered the sedimentary cover of the Montalban Ophiolitic Complex[4].

Figure 3. *(left)* Rock exposure in Dona Remedios Trinidad, Bulacan. This is a member of the Madlum Formation, a sequence composed clastics, metavolcanics and tuffs.
(right) Alluvial quarry along the Marungko River in Angat. It is composed of Quaternary alluvium deposits.

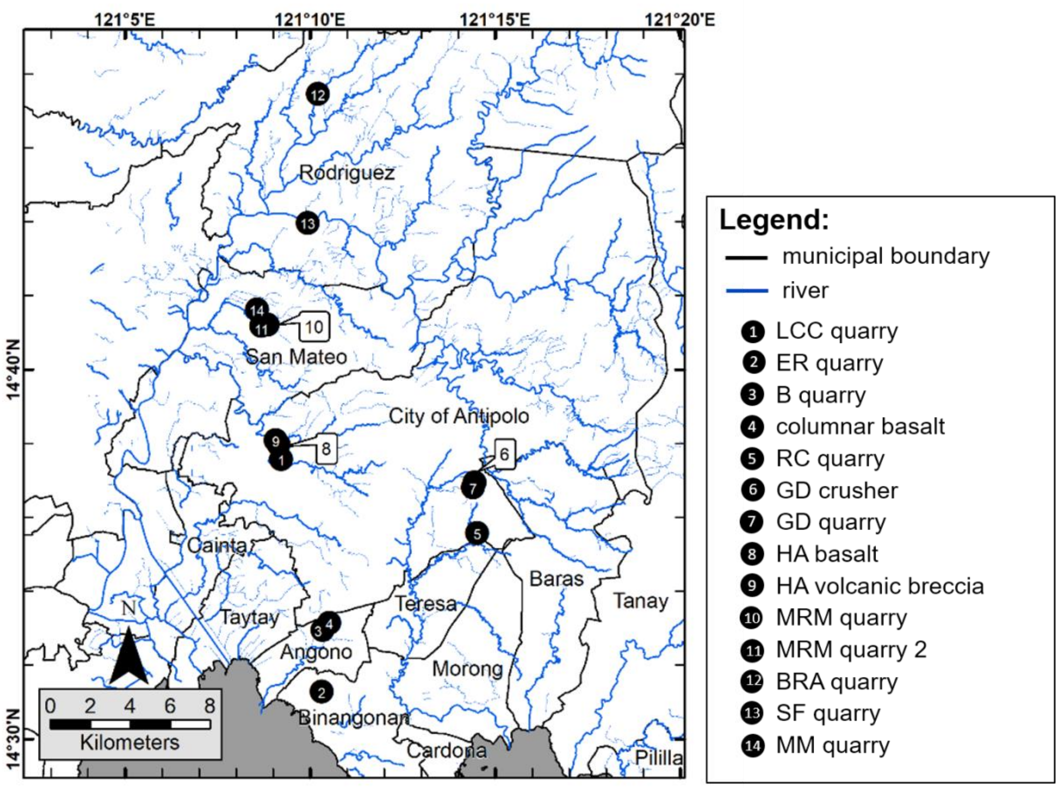

Figure 4. Sample location map of the samples from the towns of Rodriguez, San Mateo, Antipolo and Angono.

2.3 Zambales

In Zambales, aggregate materials were collected from a quarry situated in Barangay Looc, Castillejos, Zambales (***Figure 5***). Samples from this site are mainly products of erosion of the ophiolite from the Zambales Range mixed with the lahar deposits from the Pinatubo eruption. Different kinds of igneous rocks identified here are silicified basalts and serpentinized ultramafics. The company is conducting alluvial quarrying and hauled aggregates are crushed and sized at the crusher near the site. This crusher produces three (3) aggregates products, S -1, 3/4, and G -1, with increasing size respectively.

2.4 Pampanga

Aggregate samples from Pampanga were taken directly from the alluvial source. There were two locations in which these aggregates were collected: from the Floridablanca and Pasig-Protero rivers where the 1991 Pinatubo lahar were deposited (see ***Figure 6***).

The samples were mainly lahar deposits combined with alluvial deposits (microporphyritic andesites, amygdaloidal basalt and pumice). Different kinds of igneous rocks were identified here (see ***Figure 7***).

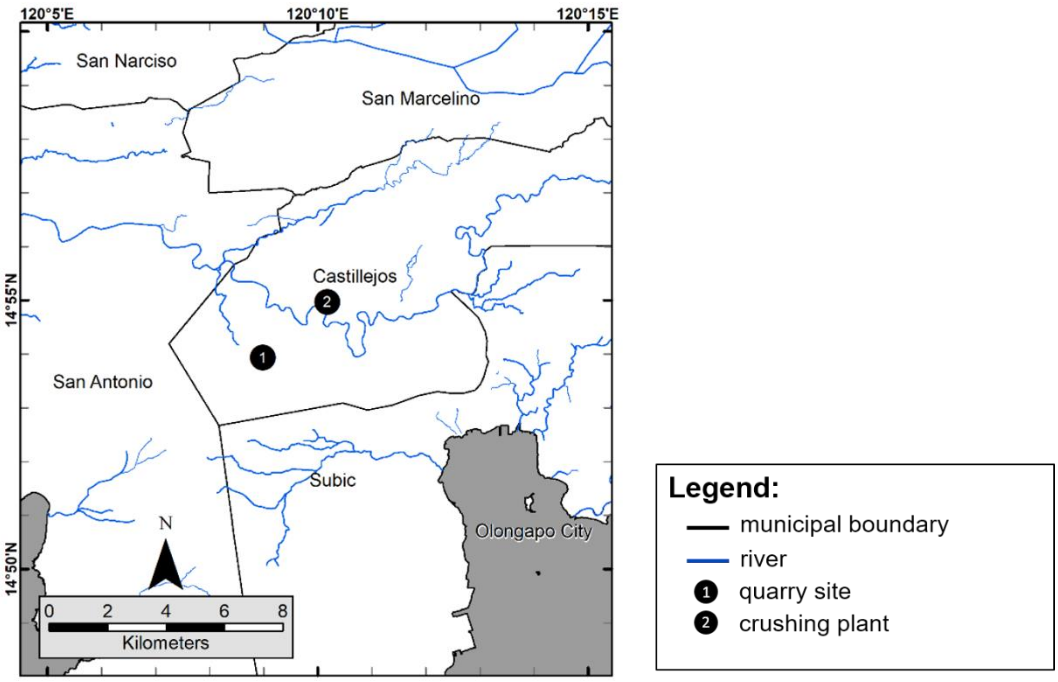

Figure 5. Sample location map of the aggregate samples in Zambales. 1 was collected from the quarry site while 2 was from the crushing plant.

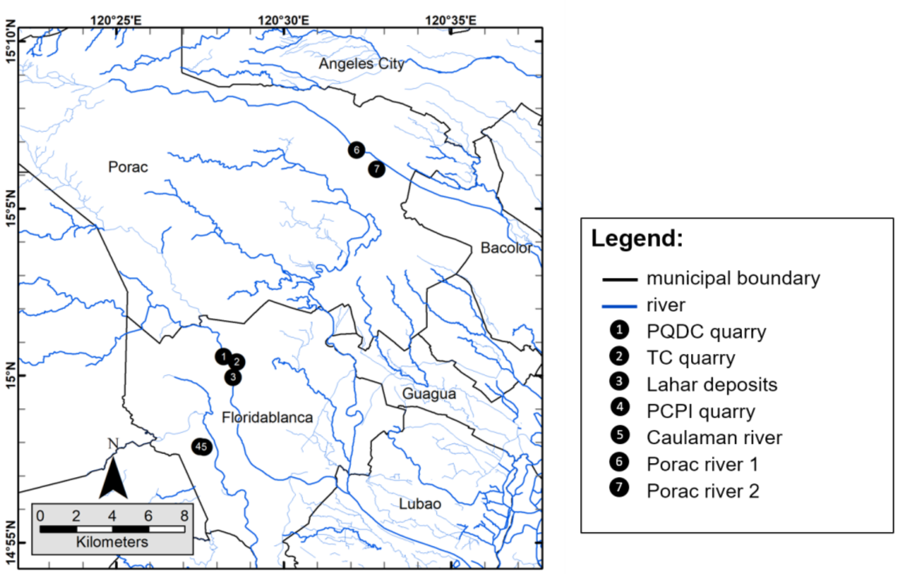

Figure 6. Sample location map of the samples collected from the province of Pampanga. Most of them are lahar deposits along the rivers of Caulaman and Floridablanca.

Figure 7. Lahar deposit quarry at Gumain River.
Aggregates ranges from boulder to clay size and are mostly andesites and pumice.

3. Results: Petrography of the aggregates

Transmitted light microscopy of the aggregate samples showed variations in the rock types from the different sites. Focused petrographic examinations were performed on the mounted thin section slides such as:

1) Identification of components (primary and secondary)
2) Identification of potentially deleterious features and components
   a) Textural: presence of microfaults and other possible failure features such as cavities; presence of alteration minerals such as clay.
   b) Compositional: identification of constituents that may be potential to reactions such as alkali-silica and alkali-carbonate reactions in concrete and other components that may affect the strength of the concrete.

3.1 Bulacan aggregates

Table 1 lists the sample name and petrographic identification of the samples. The dominant rock types in the DRT samples were porphyritic basalt and fine to coarse grained sandstone of the Madlum Formation (see ***Figure 8***).

Samples BUL 10-01, -02, -05, -06, -13, -28, and -35 comprise vitrophyric to porphyritic basalts containing clusters of phenocrysts of clinopyroxenes, euhedral laths and twinned plagioclases and opaque minerals embedded in a groundmass of volcanic glass with plagioclase laths. Chlorite replaced some of the primary minerals. Some amygdaloidal basalts (samples BUL 10-18, -21, -23, -24 and -25) contain irregularly shaped vesicles filled with silica. Subhedral to euhedral microphenocrysts of plagioclases (1 mm across) were observed in microcrystalline groundmass. The vitroporphyritic basalt contains clustered phenocrysts of euhedral clinopyroxene (30%) crystals up to 5mm across with some crystals twinned; euhedral laths, twinned plagioclase (15%) which are altered to clay minerals; and opaque minerals (15%) embedded in a groundmass (40%) of volcanic glass with feldspar microlaths. Some samples collected are amygdaloidal with irregularly shaped vesicles lined with silica minerals.

Sandstones and wackestones of the Madlum Formation were also quarried as aggregates (BUL 10-03, -04, -07, -08, -09, -10, -11 and -12). Angular lithic fragments of volcanic porphyritic rocks and mudstone are present. Crystal fragments of pyroxenes, plagioclases and quartz, with the rare occurrence of foraminifera, can be observed in the wackestones. The matrix ranges from sandy, with sparry calcite cement, to clayey.

Cobbles to boulders of fine-grained diorites were collected from the Angat alluvial quarry. They contain anhedral twinned plagioclases and green hornblende and clinopyroxenes altered to chlorite and epidote.

Table 1. Samples collected in Bulacan Province, with petrographic identification and potentially deleterious features and components.

Dona Remedios Trinidad		Marungko, Angat		Niugan, Angat	
BUL 10-01 BUL 10-02 BUL 10-05	Porphyritic basalt	BUL10-13	Porphyritic basalt	BUL 10-21 BUL 10-23 BUL 10-24 BUL 10-25	Amygdaloidal basalt
BUL 10-03 BUL 10-09 BUL 10-10	Wacke	BUL 10-14 BUL 10-17 BUL 10-19 BUL 10-20 BUL 10-22	Diorite	BUL 10-22 BUL 10-26 BUL 10-27 BUL 10-28 BUL 10-33 BUL 10-34	Diorite
BUL 10-04 BUL 10-08	Siltstone	BUL 10-15 BUL 10-16	Dacite	BUL 10-29	Andesite
BUL 10-06 BUL 10-11 BUL 10-12	Sandstone	BUL 10-18	Amygdaloidal basalt	BUL 10-30	Quartz vein cobble
				BUL 10-31 BUL 10-36	Very altered rock
				BUL 10-35	Chloritized basalt

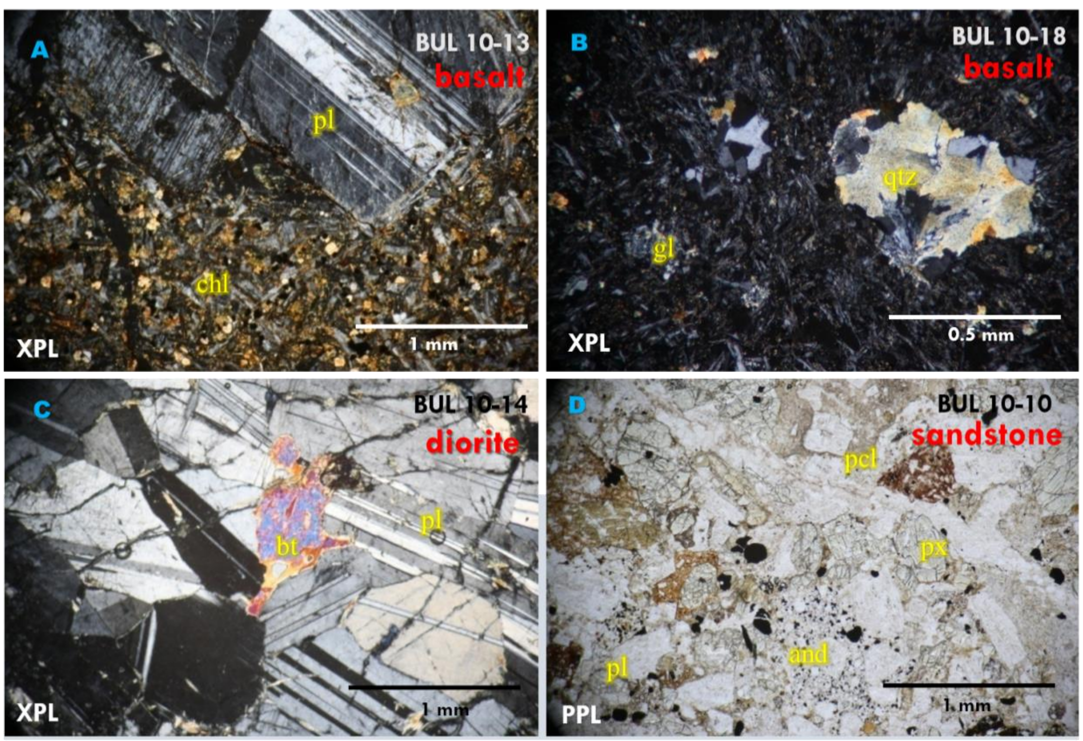

Figure 8. (**A**) Sample BUL 10-13. 50x. XPL. Porphyritic basalt showing plagioclase (pl) grains in chloritized (chl) groundmass. (**B**) Sample BUL 10-18. 100x. XPL. Amygdaloidal basalt showing quartz amygdales and volcanic glass (gl) groundmass. (**C**) Sample BUL 10-14. 50x. XPL. Diorite showing biotite (bt) grain surrounded (pl). (**D**) Sample BUL 10-10. 50x. Sandstone in PPL showing lithic fragments of andesite (and) and pyroclastics (pcl) with crystal fragments of pyroxenes (px) and plagioclases (pl).

Under a polarizing microscope, the Bulacan aggregates show cavities and microfractures (see ***Figure 9***). The amygdaloidal basalt contains irregular- to spherical-shaped cavities which are filled with secondary minerals like chlorite, silica and/or carbonates (see ***Table 1***). Fractures filled up with silica and carbonate minerals are also observed (BUL 10-02, -04, -05, -27 and -29). The presence of clay minerals in the aggregates may also weaken the aggregates as these are soft materials in a flaky habit. Clay minerals occur mainly as alteration products of the original rocks. Some of the samples taken from the Marungko and Niugan alluvial quarries include altered samples with clay minerals.

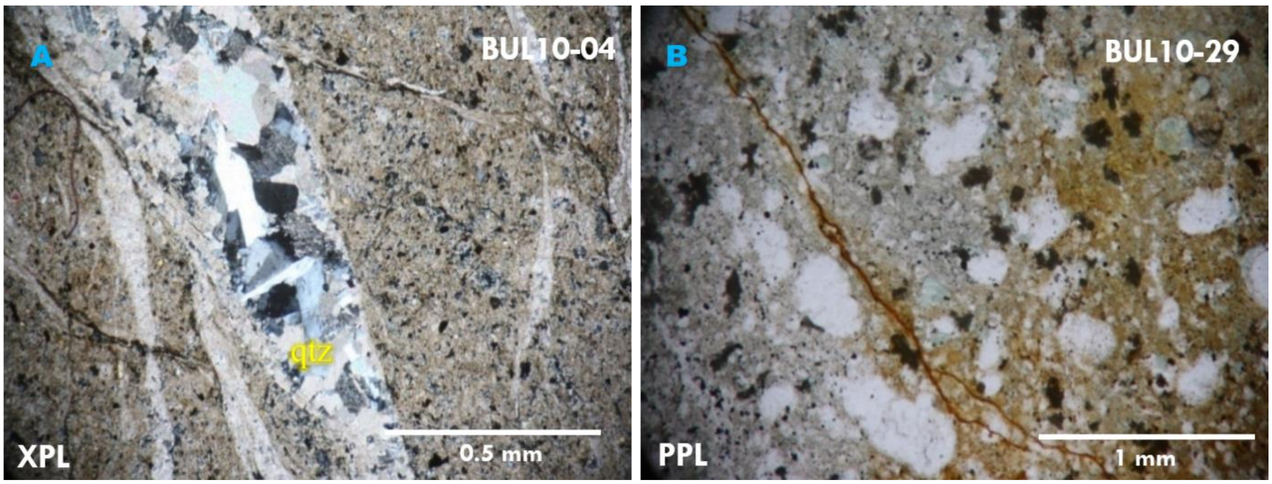

Figure 9. (**A**) Sample BUL 10-04. 100x. XPL. Sample showing a fracture filled in with quartz (qtz) vein. (**B**) Sample BUL 10-29. 100x. PPL. Altered sandstone with microcracks (brown).

3.2 Rizal aggregates

Rizal is one of the main sources of aggregates for the construction industry in Metropolitan Manila. The aggregate quarries work mainly on rock outcrops of the Kinabuan Formation (Late Cretaceous). ***Table 2*** gives the information on the Rizal aggregates.

The Antipolo basalts are vitrophyric and porphyritic hypocrystalline, with phenocrysts (0.5-4mm across) composed of subhedral to euhedral twinned plagioclase, euhedral polygonal olivine and euhedral twinned clinopyroxene. Microphenocrysts (0.1 mm across) include plagioclase, clinopyroxene and olivine and trace amounts of thin laths of potassium feldspar. Some of them are also amygdaloidal with irregular to spherical amygdules of clay and chlorite (see ***Figure 10***). Moderate alteration occurs with clay minerals, quartz, calcite and chlorite as secondary phases. Other rocks sampled include laminated claystone and fine-grained wacke. Angular crystal fragments of quartz and feldspars less than 0.1 mm across are embedded in a clayey matrix.

An amygdaloidal microporphyritic basalt with fine grained twinned plagioclase microphenocrysts in a volcanic glass groundmass was collected from a non-operating quarry in Angono. The amygdules contain chlorite. A potential aggregate quarry site in Angono was also visited for this study. The studied outcrops show intercalations of amygdaloidal porphyritic basalt and lithic tuff.

Aggregates from the San Mateo quarries consist mainly of aphyric porphyritic basalt. Samples CON-01, -02, and -03 are fine-grained hypocrystalline with subhedral laths of twinned slender plagioclase (65%) laths as phenocrysts, with anhedral quartz in a vitric groundmass. MON-10-01 is glomeroporphyritic andesite with phenocrysts of subhedral laths (up to 4mm), with the characteristic twinning and sieve texture plagioclase and subhedral to euhedral prismatic crystals of clinopyroxene in a devitrified groundmass.

The OXF aggregate samples from Rodriguez include mainly aphyric to porphyritic basalt with subhedral to euhedral plagioclase and pyroxenes. Plagioclase (45%) up to 0.5 mm across occurs as thin laths in the groundmass. Clinopyroxenes (10%) occur as subhedral to euhedral crystals 0.5 mm across. Smaller olivine, up to 1 mm occurs as subhedral to euhedral crystals. VUL samples exhibit crystalline, porphyritic texture with twinned subhedral plagioclase (< 0.1 mm across), subhedral prismatic pyroxene (< 0.1 mm across), and relict olivine phenocrysts in a feldspathic groundmass, while one of the samples is amygdaloidal porphyritic with microlaths of feldspars in a glassy groundmass. The PAC sample is a pyroclastic rock with lithic clasts (0.5 to 4 mm) in a crystal tuff matrix. Lithic clasts (20%) are subangular to angular fragments of porphyritic and amygdaloidal basalts. Crystal fragments (10%) of pyroxenes are also present. The SUP samples are amygdaloidal porphyritic aphyric basalts, with anhedral to subhedral crystals phenocrysts of subheral thin plagioclase laths, anhedral olivine and clinopyroxene. The groundmass includes microlaths of plagioclase and clinopyroxene crystals with volcanic glass. Amydules contain chlorite + quartz + calcite.

Table 2. List of samples collected from Rizal.

Antipolo		**Angono**		**Rodriguez**		**San Mateo**	
ANTJ10-01	Porphyritic basalt	ANGJ10-01	Amygdaloidal basalt	PAC 10-01	Lithic tuff	CON 10-01	Basalt
ANTJ10-02	Amygdaloidal basalt	ANGJ10-02	Porphyritic basalt	OXF 10-01	Altered rock	CON 10-02	Basalt
ANTJ10-04	Amygdaloidal basalt	ANGJ10-07	Amygdaloidal basalt	OXF 10-02	Porphyritic basalt	CON 10-03	Porphyritic andesite
ANTJ10-05	Porphyritic andesite	ANGJ10-08	Amygdaloidal basalt	OXF 10-03	Basalt	MON 10-01	Andesite porphyry
ANTJ10-08	Amygdaloidal basalt	ANGJ10-10	Amygdaloidal basalt	OXF 10-06	Basalt		
ANTJ10-13	Laminated claystone and sandstone	ANGJ10-12	Amygdaloidal basalt	OXF 10-07	Basalt		
ANTJ10-14	Sandstone	TERJ10-01	Amygdaloidal basalt	VUL 10-01	basalt		
ANTJ10-24	Claystone	TERJ10-02	Amygdaloidal basalt	VUL 10-02	Basalt		
GOZ 10-01	Crystal tuff			VUL 10-03	Amygdaloidal basalt		
GDS 10-01	sandstone			VUL 10-04	Basalt		
ACE 10-01	Amygdaloidal basalt			VUL 10-05	basalt		
				VUL 10-06	Porphyritic basalt		
				SUP 10-01	Amygdaloidal basalt		
				SUP 10-02	Amygdaloidal basalt		
				SUP 10-03	Amygdaloidal basalt		
				SUP 10-04	Basalt		
				SUP 10-05	Amygdaloidal basalt		
				SUP 10-06	Amygdaloidal basalt		
				RODJ 10-11	Amygdaloidal basalt		
				RODJ 10-12	Amygdaloidal basalt		

Cavities are in the form of vesicles in the basalts. Some are filled up with secondary minerals such as chlorite, silica and carbonates forming amygdules. The shapes vary from irregular to spherical. Some of the aggregates have fractures which run through the samples. Some of these fractures are already filled with silica and carbonate minerals forming veins, veinlets and stringers. Microstructures such as microfractures and cavities occur, too (see ***Figure 11)***.

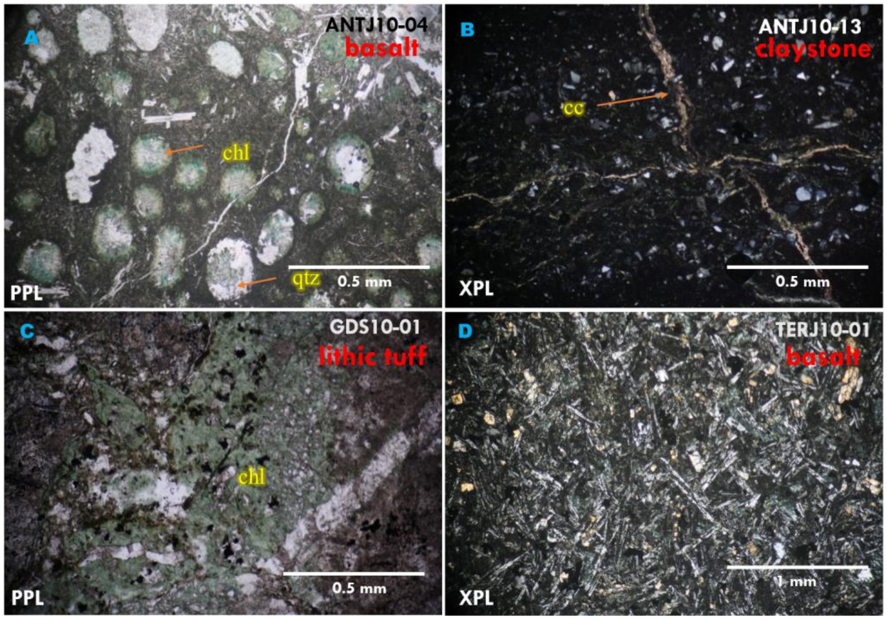

Figure 10. (**A**) Sample ANTJ10-04. 100x. PPL. Amygdaloidal basalt showing rounded cavities filled with quartz (qtz) and chlorite (chl). These amygdales are surrounded by volcanic glass groundmass. (**B**) Sample ANTJ10-13. 100x. XPL. Claystone sample with criss-crossing calcite (cc) veins. (**C**) Sample GDS10-01. 100x. PPL. Chloritized (chl) lithic tuff with quartz veins. (**D**) Sample TERJ10-01. 50x. XPL. Porphyritic basalt showing the twinned, euhedral plagioclase laths and some chlorite grains.

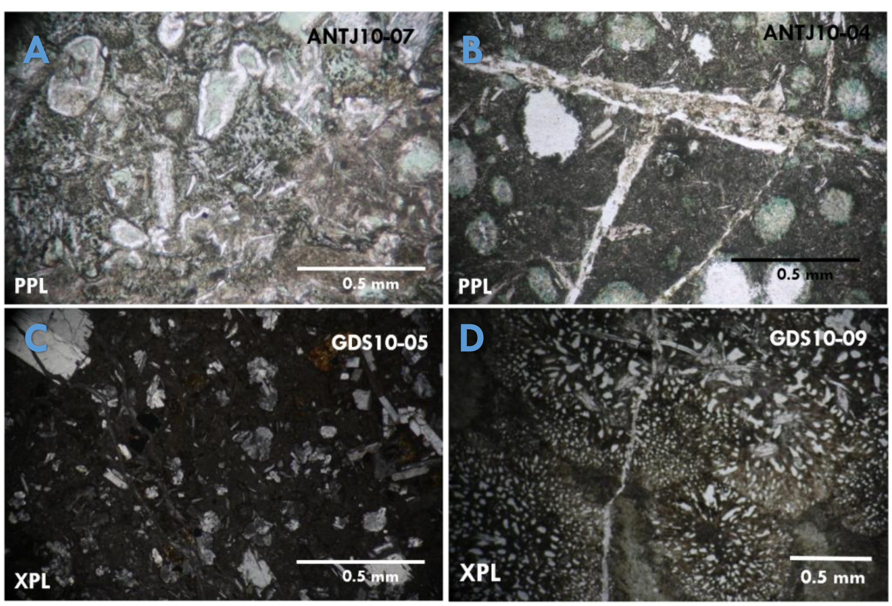

Figure 11. (**A**) Sample ANTJ10-07. 100x. PPL. Chloritized porphyritic basalt. Cavities are filled with silica and feldspars and the matrix is altered to clay. (**B**) Sample ANTJ10-04. 100x. PPL. Amygdaloidal with amygdules filled with chlorite and quartz. It also contains cracks and microfractures. (**C**) Sample GDS10-05. 100x. XPL. Porphyritic basalt with plagioclase crystals. (**D**) Sample GDS10-09. 100x. XPL. Porphyritic basalt showing myrmekitic texture of silica.

3.3 Zambales aggregates

The aggregates were collected mainly from a rock quarry and crushing plant. ***Table 3*** summarizes the properties of the rocks found in the Zambales quarry.

The basalts (CAS-01, -04, -06) are mostly silicified aphanitic to porphyritic hypocrystalline with subhedral to anhedral pyroxene (augite) crystals as phenocrysts where some of the crystals are chloritized. Rare fine-grained plagioclases occur in the devitrified volcanic glass groundmass.

Variably serpentinized ultramafic and altered mafic rocks are observed (CAS-02 -03 and -07) in the same quarry (see ***Figure 12B***), including harzburgite and gabbro, respectively (see ***Figure 12C***), where the feldspars and anhedral pyroxene crystals are observed to be disseminated. CAS - 08 is a harzburgite composed of orthopyroxene and olivine altered to serpentine and chlorite. Chlorite is found in the cracks of the crystals while serpentine forms the mesh texture. Drusy quartz veins are also observed (see ***Figure 12A***).

Samples from the crushing plants are composed of several fragments of serpentinized harzburgite. Serpentine is identified by its low relief, low birefringence and a typical serpentine appearance (see ***Figure 12B***).

The aggregates from the Unirock quarry exhibit features which may affect their strength and durability. The physical features that were identified include cavities and microfractures, which are observed in almost all the samples. The fractures are filled with silica and carbonate minerals forming veins and veinlets that run through the samples (see ***Figure 13***).

The samples are also intensely altered to clay and serpentine minerals. This could affect the chemical property of aggregates as they are easier materials to weather.

Table 3. Samples collected in Zambales Province with petrographic identification.

Quarry Site		**Crushing plant**		
CAS-01 CAS-04 CAS-06	Basalt	S-1	Several rock fragments	Serpentinized ultramafic with several pyroxene crystals (85%) Disaggregated pyroxene crystals (5%) Very altered rock (10%)
CAS-02	Serpentinite	3/8	Several rock fragments	Heavily serpentinized ultramafics
CAS-03 CAS-07	Serpentinized peridotite	3/4	Several rock fragments	Peridotite
CAS-05	Gabbro	G-1		Chloritized rock, some parts are silicified, remnants of plagioclases and pyroxenes were observed
CAS-08	Harzburgite			

3.4 Pampanga aggregates

There are two aggregate sources in Pampanga: the municipalities of Floridablanca and Porac. In Floridablanca, samples were collected from the Gumain and Caulaman River quarries. Gumain aggregates are mostly alluvial and lahar deposits, with different igneous rocks as cobbles and boulders and some minerals fragments of quartz and magnetite. These igneous rocks are identified as microporphyritic andesites, amygdaloidal basalts and pumice. The Caulaman River aggregates are mostly fresh andesites and basalts.

The basalts from both sources are vitrophyric with subhedral to euhedral plagioclases and pyroxenes phenocrysts embedded in an altered volcanic glass (see ***Figure 14A***). The andesites are hypocrystalline and porphyritic with clays, calcite and epidote replacing some of the pyroxene, and plagioclase phenocrysts and the chlorite filling up the cavities in between crystals (see ***Figure 14B***). Crystal tuffs contain crystal fragments of iron oxides and clay minerals which replace amphiboles and plagioclases, respectively (see ***Figure 14C***). ***Table 4*** summarizes the samples collected from Pampanga.

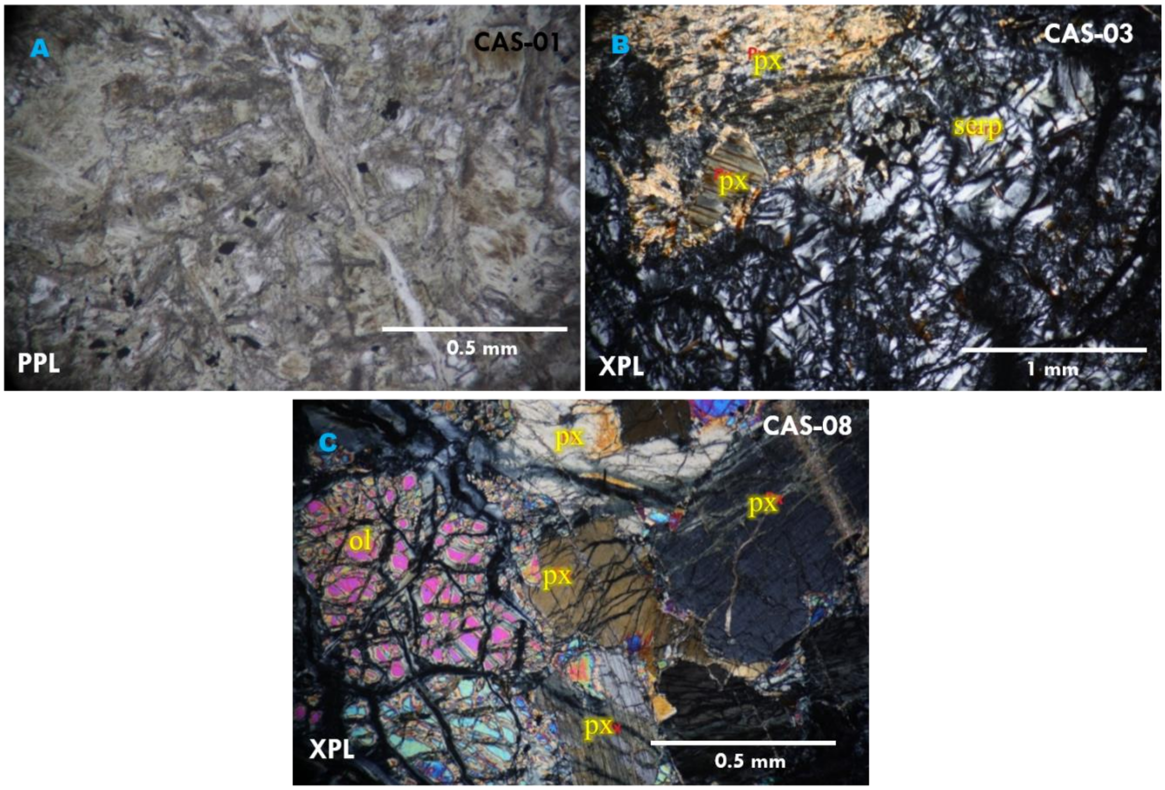

Figure 12. (**A**) Sample CAS-01. 100x. PPL. Section of basalt characterized by anhedral to subhedral pyroxenes and anhedral plagioclases. (**B**) Sample CAS-03. 50x. XPL. Heavily altered rock with serpentine (serp) as the main component. Several heavily altered pyroxenes (px) can also be observed. (**C**) Sample CAS-08. 100x. XPL. Slightly weathered harzburgite characterized by the presence of olivine (ol) and pyroxene (px) crystals. Serpentine can also be observed surrounding the mafic minerals and along mineral fractures.

In Porac, the aggregates are pyroclastic rocks, with gabbro, andesite, amygdaloidal basalt and pumice clasts. The andesitic fragments found are porphyritic with large zoned plagioclase and twinned amphibole grains. "White sand" was also collected from the quarry, which is basically lahar deposit with abundant pumice (see ***Figure 15***).

The Pampanga aggregates contain cavities which may be due to the vesicles in the pumice and basalts. These are filled with secondary minerals like silica, chlorite and carbonates. Most of the samples are also intensely altered to clay minerals.

4. Discussion: Assessment of potentially deleterious materials

A thorough petrographic examination of the constituents and textural characteristics can give indications of the quality, condition, and chemical stability of the aggregates. The mineral composition plays a significant role in the physical characteristics and engineering properties. A prior knowledge of the aggregate mineral properties would be helpful in the selection of aggregate sources.

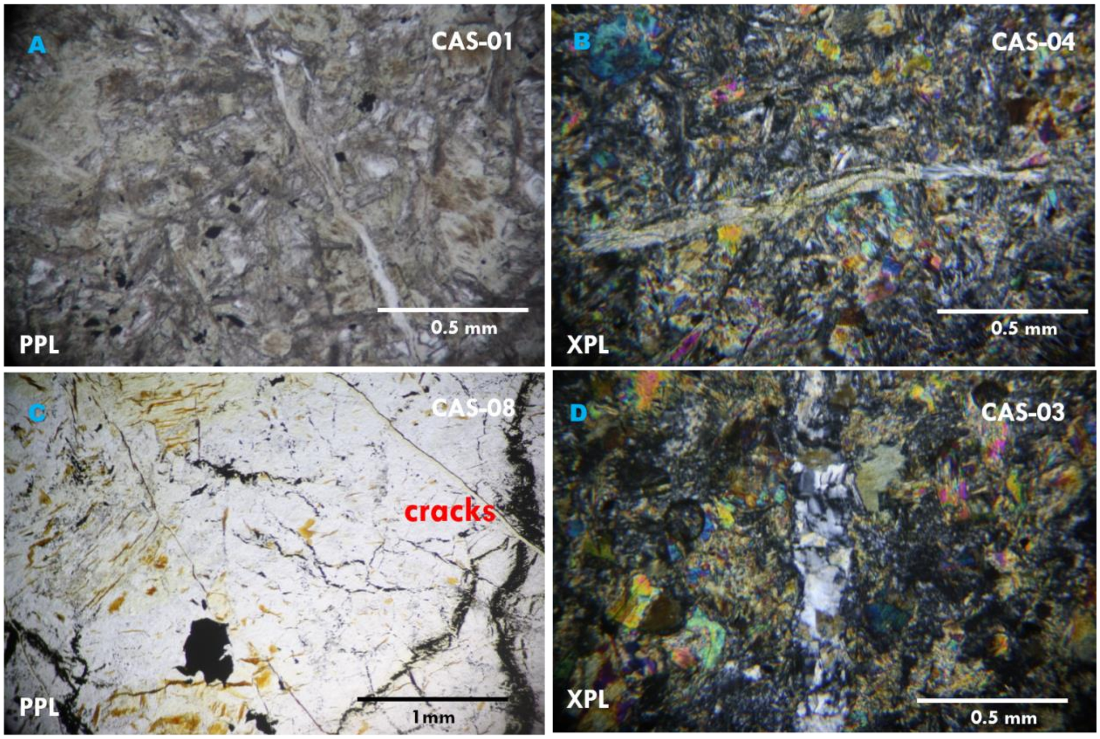

Figure 13. (**A**) Sample CAS-01. 100x. PPL. Chloritized basalt cut across by silica veins. (**B**) Sample CAS-04. 100x. XPL. Heavily altered rock also cut by carbonate vein. (**C**) Sample CAS-08. 50x. PPL. Rock with several cracks and microfractures. (**D**) Sample CAS-03. 100x. PPL. Heavily altered rock cut by a silica vein.

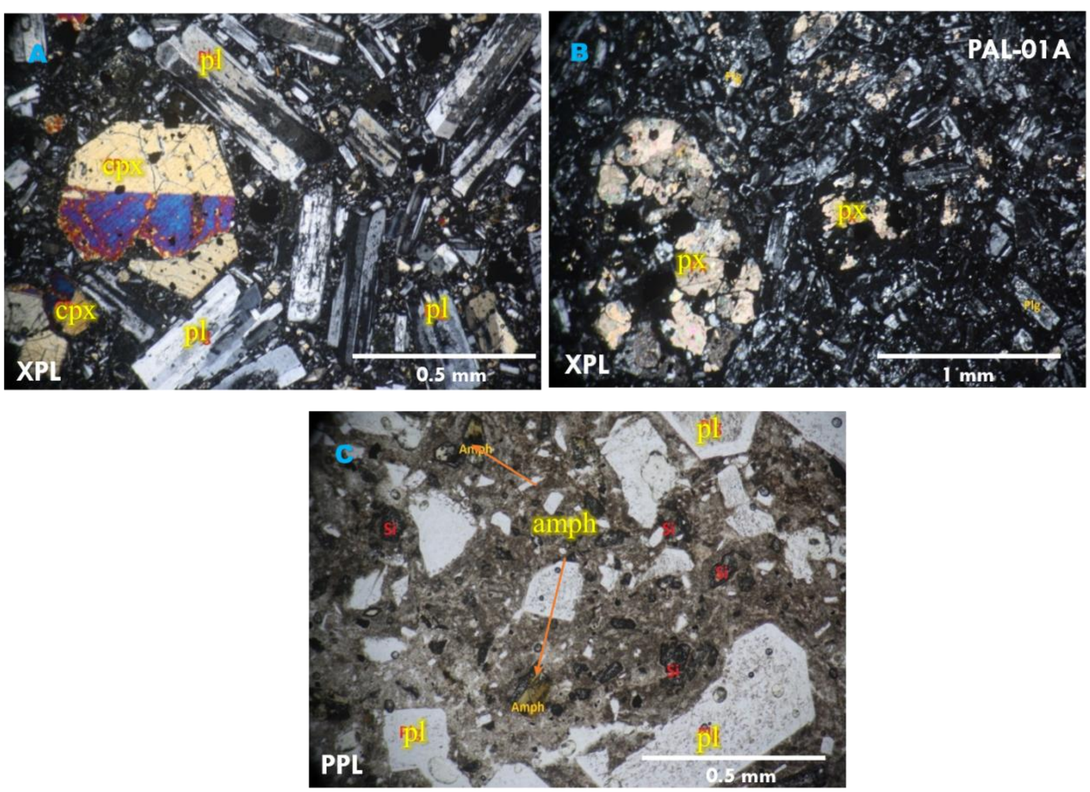

Figure 14. (**A**) Vitroporphyritic basalt from the Pacific Concrete Products, Inc. XPL, FOV 2.2mm, 100x. (**B**) Highly weathered andesite porphyry with plagioclase as phenocryst. Taken from sample PAL-01A, one of the aggregates from Palakol Quarry Dev't Corp. XPL, FOV: 4.4mm, 50x. (**C**) Picture of a porphyritic hypohyaline rock with plagioclase and amphibole as phenocrysts. Some fragments are silicified. PPL, FOV: 2.2mm, 100x.

As a cheaper and quicker way of roadbuilding, asphalt is commonly used in the Philippines. This results in a huge demand for aggregates for the construction of infrastructure like roads to transport local products to market. Roberts *et al.*[6] provide some general guidelines for aggregate used in Hot Mix Asphalt (HMA). Aggregate surface chemistry is used to determine how well an asphalt cement binder will adhere to an aggregate surface. Poor adherence or stripping can cause premature structural failure. However, some aggregate chemical properties can change over time, especially after the aggregate is crushed. A newly crushed aggregate may display a different affinity for water than the same aggregate that has been crushed and left in a stockpile for a year. ***Table 5*** summarizes the desirable properties of rocks for HMA.

Table 4. List of samples collected from the Pampanga province.

Floridablanca			**Porac**		
Gumain River			*Pasig-Protero River*		
PAL-01A	Source	Andesite porphyry	GS-01	Source	Andesite and pumice
PAL-01B	Source	Amygdaloidal basalt	GS-02A	Source	pumice
S-1 Gumain	Crusher	Several rock fragments (porphyritic andesite, silica, pyroclastic materials)	GS-02B	Source	Porphyritic andesite
¾ Gumain	Crusher	Several rock fragments (pyroxenite, gabbro, lithic sandstone)	4mm	Crusher	Porphyritic basalt and andesite
¾ B red Gumain	Crusher	Oxidized porphyritic andesite	3/8 GS	Crusher	Pumice and amygdaloidal basalt
G-1 Gumain	Crusher	Basalt	Lahar WS	Crusher	Pumice, andesite, basalt
NS-1	Crusher	Pyroclastic materials (magnetite, white ash, plagioclase and amphibole fragments)			
NS-2	Crusher	Composed of pyroclastic materials with relatively more magnetite sand than NS-1			
LAH-01	Crusher	Reworked pumice			
Caulaman River					
NS-3	Source	Porphyritic andesite			
S-1 Caulaman	Crusher	Fragments of magnetite, pumice, quartz, and lithic fragments			
3/8 Caulaman	Crusher	Andesite and pumice			
¾ Caulaman	Crusher	Several rock fragments (andesite, conglomerate, magnetite)			
G-1 Caulaman	Crusher	Gabbro and andesite			
TRE-01	Source	basalt			

On the other hand, when used in concrete, aside from the dominant constituents of the aggregates, it is equally important to identify potentially alkali-silica reactive and alkali-carbonate reactive constituents. These reactive components produce hygroscopic gel which, when moisture is present, absorbs water and expands[7]. The gel expansion causes cracking in the concrete. ASTM C295 identified the possible alkali-silica and alkali-carbonate reactive constituents. These reactants include: opal, chalcedony, cristobalite, tridymite, highly strained quartz, microcrystalline quartz, volcanic glass, and synthetic siliceous glass which are commonly found in glassy to cryptocrystalline intermediate to acidic volcanic rocks, some argillites, phyllites, greywacke, gneiss, schist, gneissic granite, vein quartz, quartzite, sandstone, and chert. Potentially deleterious alkali-carbonate reactive rocks are usually calcareous dolomites or dolomitic limestones with clayey insoluble residues[8]. Furthermore, the mineral composition of aggregates may also give vital indicators of the stability of the components to local weathering conditions. The aggregates also need to be assessed texturally for microfractures and other possible failure features that could compromise the overall strength of the aggregates.

The aggregates collected from Bulacan are mostly basalts and diorites. Though basalt is considered a good rock type for mixture with HMA because of its toughness, resistance to stripping, and good crushed shape[4], the basalts in Bulacan are mostly amygdaloidal which means that there are cavities present and most are filled with silica, a potential alkali-silica reactive constituent. The diorites have good hardness and have a fair resistance to stripping which make them a fair component of aggregates. Sandstones are also good constituents of aggregates in Bulacan because of their fair hardness and good resistance to stripping, surface texture, and crushed shape. The presence of clay minerals as alteration products in the aggregates may also weaken the aggregates due to their soft nature and flaky habit[1]. Furthermore, feldspars, silica and carbonates, which occur in some samples, are considered potential alkali reactive minerals to concrete.

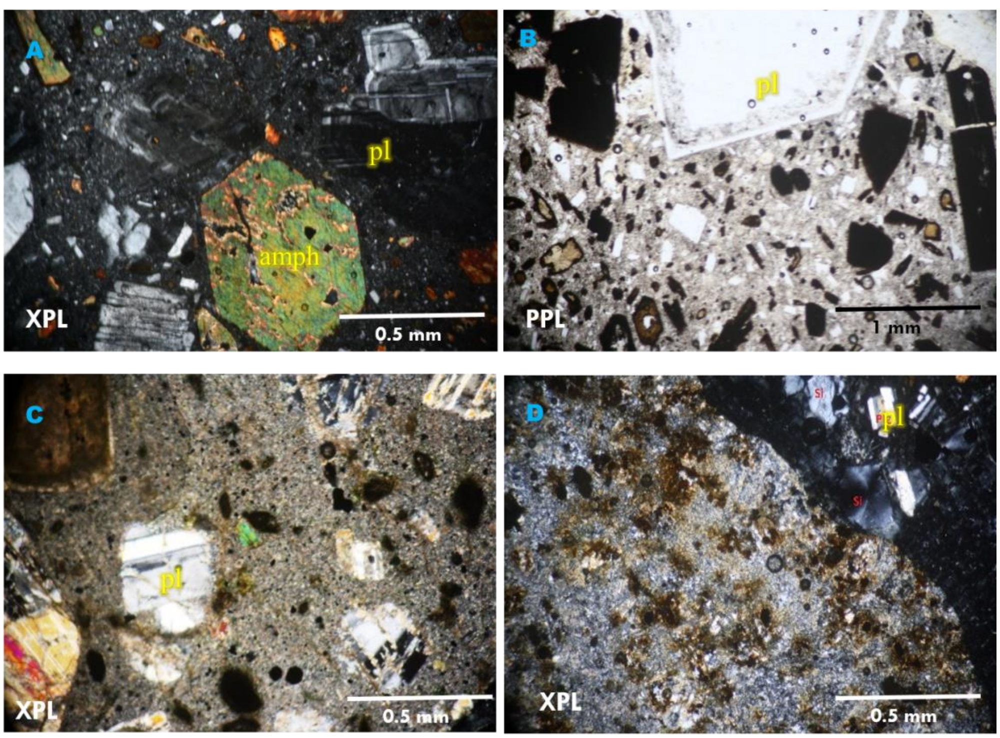

Figure 15. (**A**) Sample GS02B. 50x. XPL. Porphyritic andesite with large plagioclase (pl) and amphibole (amph) grains. The groundmass is contains of volcanic glass. (**B**) Sample LAHAR. 50x. PPL. This sample was taken from the "white sand". This photo only shows one of the components of the lahar deposit. This one is oxidizes porphyritic andesite, with large plagioclase (pl) grains and opaque minerals. (**C**) Sample Caulaman 3/8. 50x. XPL. Porphyritic volcanic rock fragment with plagioclase (pl) as phenocrysts and the groundmass is altered to sericite. (**D**) Sample S-1 Gumain. 50x. XPL. Heavily altered rock with silica and plagioclase (pl) crystals.

Aggregates from Rizal are also composed of amygdaloidal and porphyritic basalts, as well as porphyritic andesites. Some of the samples are already heavily altered to chlorite and clay minerals which may affect the toughness of the rocks. The volcanic glass groundmass is also a source of silica that is an alkali-silica reactive constituent. Aside from that, the presence of criss-crossing veins of calcite and quartz in the studied basalts, andesites and some claystones may be considered as adverse factors.

Table 5. Desirable Properties of Rocks for HMA (from Cordon, 1979 as referenced in Roberts *et al.*[5])
Notes: 1. Aggregates that are hydrophilic (water-loving) tend to strip more readily since water more easily replaces the asphalt film over each particle. 2. Freshly crushed aggregates with many broken ionic bonds tend to strip more easily.

Rock Type	Hardness, Toughness	Resistance to Stripping[1,2]	Surface Texture	Crushed Shape
Igneous				
Granite	Fair	Fair	Fair	Fair
Syenite	Good	Fair	Fair	Fair
Diorite	Good	Fair	Fair	Good
Basalt (trap rock)	Good	Good	Good	Good
Diabase (trap rock)	Good	Good	Good	Good
Gabbro (trap rock)	Good	Good	Good	Good
Sedimentary				
Limestone	Poor	Good	Good	Fair
Sandstone	Fair	Good	Good	Good
Chert	Good	Fair	Poor	Good
Shale	Poor	Poor	Fair	Fair
Metamorphic				
Gneiss	Fair	Fair	Good	Good
Schist	Fair	Fair	Good	Fair
Slate	Good	Fair	Fair	Fair
Quartzite	Good	Fair	Good	Good
Marble	Poor	Good	Fair	Fair
Serpentine	Good	Fair	Fair	Fair

Basalts and gabbros are the dominant rock-types in the Zambales samples. These, according to Roberts *et al.*[6], are good components for aggregates. However, the basalts and gabbros contain serpentine, a secondary mineral which plays a critical role in determining the moisture content in a rock. Its phyllosilicate structure allows more water to be captured, which can create surfaces of weakness and as a result lowers the rock strength[9]. The physical features that were identified include cavities and microfractures, while the chemical features are mostly alterations of primary minerals to serpentine and clays. The fractures are filled with silica and carbonate minerals, forming veins and veinlets cross-cutting the samples. The silica and carbonate contents may be the source of alkali-silica and alkali-carbonate reactive components when mixed with concrete.

In the aggregates from Pampanga, the dominant rocks are basalts and andesites. They may be good components of aggregates; however, they are mixed with pumice, which is known for its low hardness, brittleness and vesicular texture, which make it a poor choice for aggregates. The lahar deposits also contain abundant quartz grains, which is an alkali-silica reactive component. Cavities from the vesicles of pumice and basalts are mostly filled up with secondary minerals like silica, chlorite and carbonates, which are potential ASR components.

5. Conclusions

Variable rock-types with different degrees and patterns of alteration occur in the four provinces of Philippines, which include the major aggregate quarries. Potential alkali reactive constituents were observed in some samples such as silica (including quartz) from devitrification of groundmass, veins, and amygdules. Potential durability of the aggregates may be influenced by the presence of microfractures, cavities and clay minerals. Further testing of the aggregates for durability and strength is suggested as per use of the aggregates. The employment of X-ray diffractometry and other analyses to test the compositions can also be used to confirm the presence of potential deleterious materials. Petrographic examination can also be directed specifically at the possible presence of contaminants in aggregates, such as synthetic glass, cinders, clinker, or coal ash, magnesium oxide, calcium oxide, or both, gypsum, soil, hydrocarbon, chemicals that may affect the setting behaviour of concrete or the properties of aggregate, animal excrement, plants or rotten vegetation, and any other contaminant that may be undesirable in concrete.

References

[1] P. Petrounias, P. P. Giannakopoulou, A. Rogkala, P. M. Stamatis, P. Lampropoulou, B. Tsikouras and K. Hatzipanagiotou, "The effect of petrographic characteristics and physico-mechanical properties of aggregates on the quality of concrete," *Minerals*, 8(12), 2018.

[2] M. A. Bérubé, "The mineralogical and petrographic analysis of concrete aggregates," *JOM*, 53(12), 45-47, 2001.

[3] Mines and Geosciences Bureau (MGB), *Geology of the Philippines*, Mines and Geosciences Bureau – Department of Environment and Natural Resources (MGB–DENR), Quezon City, Philippines, 2004.

[4] R. Pena, *Lexicon of Philippine Stratigraphy*, Mines and Geosciences Bureau – Department of Environment and Natural Resources (MGB–DENR). Quezon City, Philippines, 2004.

[5] G.W. Corby, R. M. Kleinpell, W.P. Popenoe, R. Merchant, H. William, J. Teves, R. Grey, B. Daleon, F. Mamaclay, A. Villongco, M. Herrera, J. Guillen, J. S. Hollister, H. N. Johnson, M. H. Billings, E. M. Fryxell, E. F. Taylor, C. N. Nelson, D. C. Birch, R. W. Reed, and R. Marquez, "Geology and Oil Possibilities of the Philippines". *Technical Bulletin* 21, Bureau of Mines, DANR, 1951.

[6] F. L. Roberts, P. S. Kandhal, E. Ray Brown, D. Lee and T. W. Kennedy, *Hot Mix Asphalt Materials, Mixture Design and Construction*, NAPA Research and Education Foundation, Lanham, MD, 1996.

[7] Corps of Engineers Washington D.C., "Engineering and Design. Standard Practice for Concrete for Civil Works Structures." *Engineer Manual*, 1994. http://www.dtic.mil/dtic/tr/fulltext/u2/a402916.pdf

[8] ASTM Committee D-30 on Composite Materials, *Standard test method for tensile properties of polymer matrix composite materials*, ASTM International, 2008.

[9] P. P. Giannakopoulou, P. Petrounias, A. Rogkala, B. Tsikouras, P. M. Stamatis, P. Pomonis, and K. Hatzipanagiotou, "The influence of the mineralogical composition of ultramafic rocks on their engineering performance: A case study from the Veria-Naousa and Gerania ophiolite complexes (Greece)," *Geosciences*, 8(7), 2018.