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Petrographic examination of ledge rocks aided by microscopic and X-ray diffraction analyses for alkali-silica reactivity

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ABSTRACT

Presence or absence of deleterious constituents and alkali-silica reactivity are especially important when aggregates are to be used in concrete structures. A ledge rock sample was petrographically analysed for alkali-silica reactivity. In overall, two rock clans (metasiltstone and metasandstone) with nine sub clans were identified from the ledge rock sample. All the rock types were well interlocked, indurated, and cemented extensively by calcite. All the silica grains were low quartz. Except a trace amount of chert containing microquartz in rock type C, reactive silica such as amorphous silica and high-quartz are absent. Instead, illite in many rocks and vermiculite in rock types C and D were deleterious silicate components, which in the whole rock sample were 5% and 2%, respectively. Presence of vermiculite and illite is found to be strongly controlled by the presence or absence of clayey partings in metasiltstones and metasandstones.

INTRODUCTION

The alkali-silica reaction is a reaction which occurs over time in concrete between the highly alkaline cement paste and reactive non-crystalline (amorphous) silica, which is found in many common aggregates (Ichikawa and Miura, 2007). The physical properties and proportion of deleterious materials which bear potential reactivity with the cement are crucial in any projects concerning durability of structures. Physical properties are greatly influenced by composition and texture of aggregates. Proportion of deleterious constituents are influenced by composition of constituent rock types in aggregates and degree of weathering of the constituents. In many instances, petrographic results supports for decision making on requirement of further chemical tests, and on selecting aggregate (Monin et al., 2006).

The samples analysed came from a crusher plant; Mahalaxmi Crusher Industries (P) Ltd., Nallu Khola area (Fig. 1), Lalitpur District, where extensive quarrying for construction material has been going on. Maharjan and Tamrakar (2004) carried out physical and mechanical tests of rock samples from the Nallu Khola area, which is the source of the sample in the present study, and suggested suitability of the rocks for concrete aggregates. The present study is mainly targeted to petrographic examination for alkali-silica reactivity of rock samples for concrete aggregates.

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METHODOLOGY

Sample was obtained from the heaps accumulated after quarrying from the Nallu Khola bank. The Nallu Khola banks have huge outcrops of bedrocks of the Tistung Formation (Stöcklin and Bhattarai, 1977; Stöcklin, 1980; DMG, 1998). The Tistung Formation consists of metasandstone, metasiltstone, shale, phyllite, etc. Samples were taken to lab of the Central Department of Geology for petrographic analysis.

The rock fragments were taken for initial examination and were categorised based on their physical characteristics and rock types. Each category of rock types was thin-sectioned and examined under petrographic microscope. About 200 counts per sub-sample were made for determining composition. The texture indicating alkali-silica reactivity was also examined. To assist for determination of clay minerals and deleterious silica components, X-ray data were

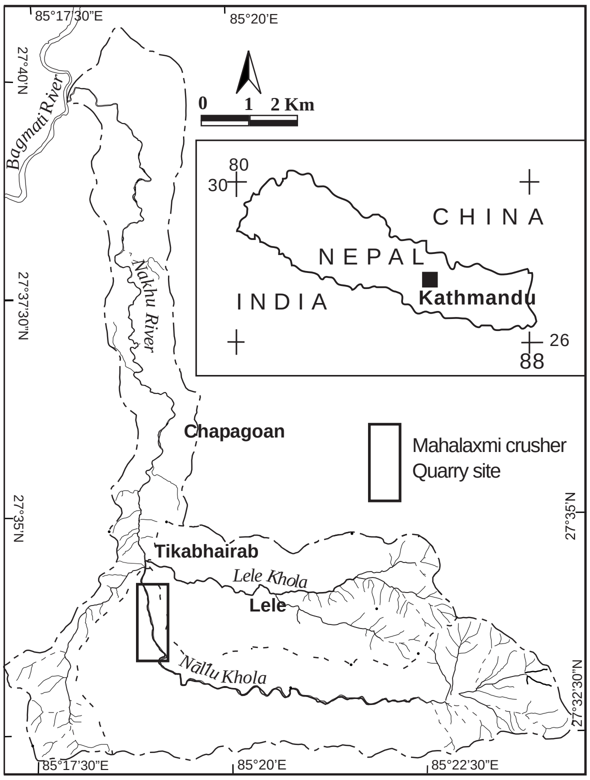

Fig. 1 Location of quarry and crusher plant site.

Table 1: Description of physical characteristics of a ledge rock sample

Physical characteristics	Description
1. Particle shape	Angular, flaky and elongate, elongate
2. Surface texture	Rough, some smooth; irregular fractures to even, some with conchoidal fractures
3. Nominal size	Almost between 75 and 150 mm
4. Internal structure	Mostly banded, few poorly banded to massive
5. Colour	Mostly greenish grey, few light grey banded and others are with reddish brown bands and patches
6. Coatings	Calcareous dust coatings on 50% of the fragments, but freshly broken fragments lack coatings
7. Heterogeneity	Low, variable as to internal structures and grain size

considered. Mainly air dried samples were used in XRD analysis (Bruker's D8 advance diffractometer, computer controlled). The scan ranges for bulk mineralogy were 2–40 2θ at a speed 1^{o}/min, and 20–22 2θ at a speed of 0.25^{o}/m for detection of silica, and 4–10^{o} 2θ at a speed of 0.25^{o}/m for the detection of clay minerals.

PETROGRAPHIC ANALYSES

Megascopic features of sample

The results of megascopic examination of rock fragments are given in Tables 1 and 2.

The ledge rock fragments exhibit angular, flaky and elongate (meaning bladed) and elongate (rod) shape (Table 1). They show rough to smooth surface features, of which the former originated by plumose and conchoidal fractures. Most of the samples exhibit banded structures. Colour of the rock fragments varies from greenish grey to reddish brown. Coatings around fragments exist in about 50% of the fragments and in majority of the cases are fine calcareous dust.

Compositionally, the ledge rock fragments are divided into nine sub rock types or rock categories (Table 2). Most of them belong to two rock clans; metasiltstone and metasandstone. Rock categories

Table 2: Composition of a ledge rock sample

Rock category	Description	Weight %
A	Banded, coarse-grained milky white calcareous metasiltstone	1.98
A2	Banded, coarse-grained, white calcareous metasiltstone with a green band	5.30
B	Thickly banded, light grey metasandstone	9.70
B2	Thickly banded, grey calcareous metasandstone	4.85
C	Banded, greenish grey metasiltstone with thinly clayey partings	25.65
D	Banded, greenish grey metasandstone with ferruginous bands	13.11
D2	Banded, grey metasandstone with ferruginous stained spots	4.38
E	Banded, greenish grey metasiltstone	24.02
F	Poorly banded, greenish grey metasiltstone	11.01
	Total	100

Table 3: Percent mineralogical constituents of individual rock category

Rock category		Mineralogical composition (%)													
		Quartz	K-feldspar	Plagioclase	Chert	Muscovite	Chlorite	Illite	Vermiculite	Hematite	Pyrite	Opaque	Other	Calcite	Dolomite
A	Metasiltstone	35	10	13	-	7	-	2	-	-	2	-	-	31	-
A2	Metasiltstone	36	6	11	-	14	5	1	-	2	0.5	-	0.5	30	-
B	Metasandstone	42	10	26	-	7	-	-	-	-	1	-	0.5	-	13.5
B2	Metasandstone	40	6	10	-	10	3	2	-	-	2	3.5	0.5	25	-
C	Metasiltstone	30	10	15	1	6	19	10	5	-	2	2	-	-	-
D	Metasandstone	30	14	6	-	10	9	4	2	8	1	-	1	15	-
D2	Metasandstone	35	12	20	-	4	3	2	-	6	1	-	1	16	-
E	Metasiltstone	25	11	14	-	12	19	4	-	3	1	1	1	9	-
F	Metasiltstone	20	20	5	-	10	22	6	-	3	1	4	1	8	-

A, A2 and B2 are distinctly calcareous, while sub rock type D and D2 show ferruginous bands and patches. Rock categories B, E and F possess more chloritic bands. Rock category C exhibits chloritic bands with other clayey partings.

Composition and texture of individual rock types

The results of 200 point counts in each type of rock are shown in Table 3, and individual rock types are described.

Rock category A

Rock category A is a metasiltstone that contains quartz, feldspar and calcitic cement. Quartz grains are mostly of 30–60 μm, and are sutured and well interlocked. Vug-filling quartz grains are commonly 80–90 μm and sometimes reach 200 μm. Fibrous quartz crystals of 60–70 μm are syntaxially grown around few pyrite crystals which are scattered. Calcitic cements are mostly spars (60 μm) occurring extensively replacing quartz and feldspar grains (Fig. 2). Pore- and fracture-filling calcites are also recorded. Muscovite defines a foliation, and some are deformed after their authigenesis and even cross cuts calcite cements.

Rock type A2

Rock ategory A2 is a metasiltstone similar to rock type A1 but differing slightly from A1 by having bands of chlorite. Quartz grains appear distinctly in two dominantly contrasting bands, one with quartz of 40–50 μm and the other with that of 15–30 μm. Quartz grains in both are mega quartz (> 15 μm), equant to elongate and tending to arrange along foliation. Muscovite is richer in bands with finer quartz, and both muscovite and chlorite tend to define one distinct foliation. Calcite occurs as pore-filling and replacing cement, and are <100 μm. Pseudospars (> 100 μm) occurs mostly in veins. Some calcites and/or dolomites alter showing iron oxide stains around them. Calcites also replace and attack feldspar and quartz crystals. Few pores extend along foliation and partially filled veins.

Rock category B

Rock category B is an arkosic metasandstone with distinct light to dark grey bands. It contains quartz and feldspar as dominant constituents. Quartz gains are equant to elongate and dominantly of 100 μm size. Most of them are sutured with interlocking of grains (Fig. 3). Feldspars are 50–150 μm and are often altered. Muscovite although forms a minor constituent defines one set of foliation. Oblique set of muscovite is also detected. Dolomite cement bridges quartz and feldspar grains. Dolospars of 75 μm are frequently observed. Those of 32 μm crystals often replace quartz and feldspars. Some dolospars also occur as void-filling cement.

Rock category B2

Rock category B2 is dark grey to grey in handspecimen. It comprises dominantly quartz and subordinately feldspar, muscovite, calcite and other constituents. Quartz grains are 80–100 μm, equant to elongate having sutured and interlocked contacts. Feldspars are about 100-μm tabular grains. Calcite forms pore-filling and replacing cements often replacing silicate grains. Iron oxide too contributes as a minor cement. The grain size and composition of the rock type B2 suggest it to be very fine-grained, calcareous subarkosic metasandstone.

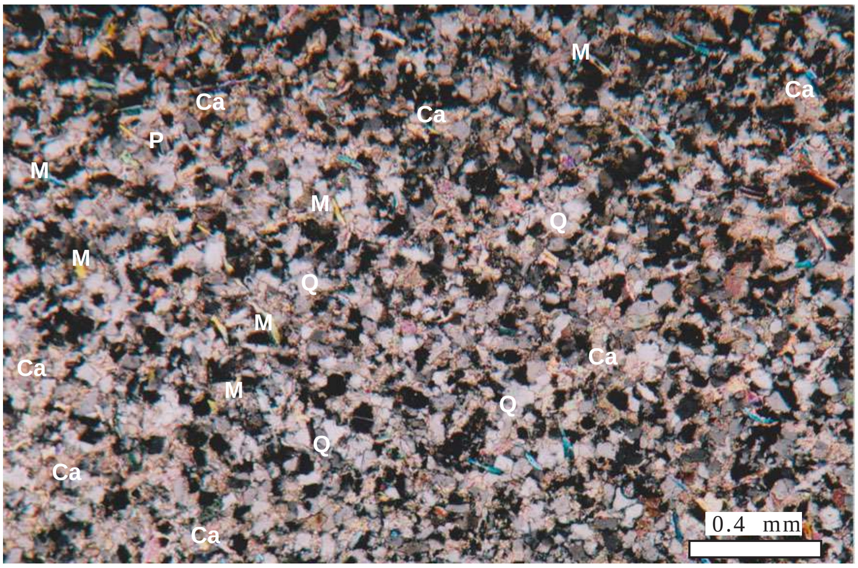

Fig. 2 Photomicrograph of rock category A. Calcite occurs as replacing and void-filling cements (M = muscovite; Q = quartz; P = plagioclase; Ca = calcite).

Fig. 3 Photomicrograph of rock category B showing interlocking grains of quartz and feldspars (O = orthoclase; M = muscovite; Q = quartz; P = plagioclase; D = dolomite).

Rock category C

Rock category C is metasiltstone with a distinct chlorite bands. The major constituents are quartz, plagioclase and k-feldspar. Remarkably clay minerals constitute around 34% of which chlorite is dominant. Quartz grains are equant to elongate and with sutured grain boundaries. They are 15–30 µm in silty band, 40–µm in sand-grade mineral bands, and <15 µm in clayey bands. Few chert grains (200 µm) comprising microquartz occur in sand-grade bands. In silty bands, chlorite and muscovite tend to form one set of distinct foliation. Both muscovite and chlorite replace quartz and feldspars. Illite occurs as a cementing mineral (Fig. 4). Clayey bands are rich in illite, chlorite and vermiculite.

Rock category D

Rock category D is a micaceous arkosic metasandstone with ferrugineous patches. Quartz and feldspars form dominant framework constituents. Quartz grains range from 15–120 µm and are dominantly mega quartz. Laths of k-feldspars alter to clay minerals. Elongate quartz grains and feldspars extend along with chlorite and muscovite. Illite and vermiculite are also remarkable. Calcite and hematite produce pore-filling cements. Calcite frequently replaces feldspars and quartz grains. Hematites occur in scattered small patches and are widely associated with calcite.

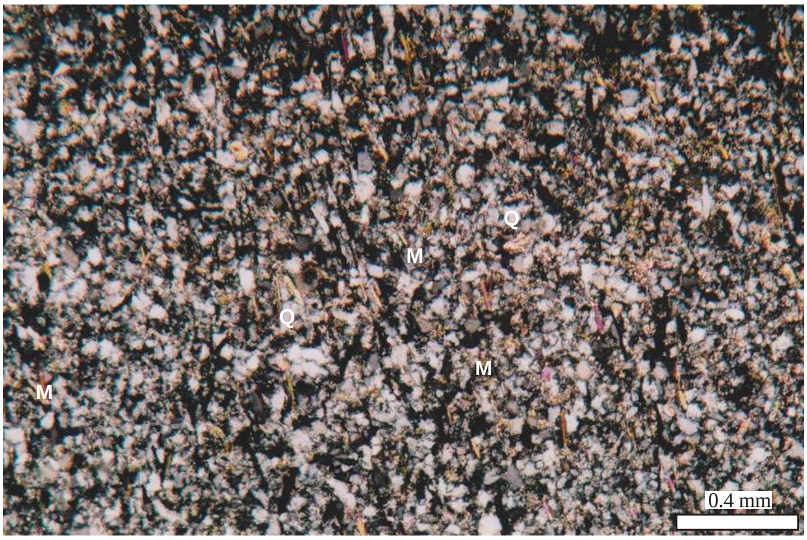

Fig. 4 Photomicrograph of rock category C showing preferred arrangement of muscovites, and clayey cement between quartz grains (M = muscovite; Q = quartz).

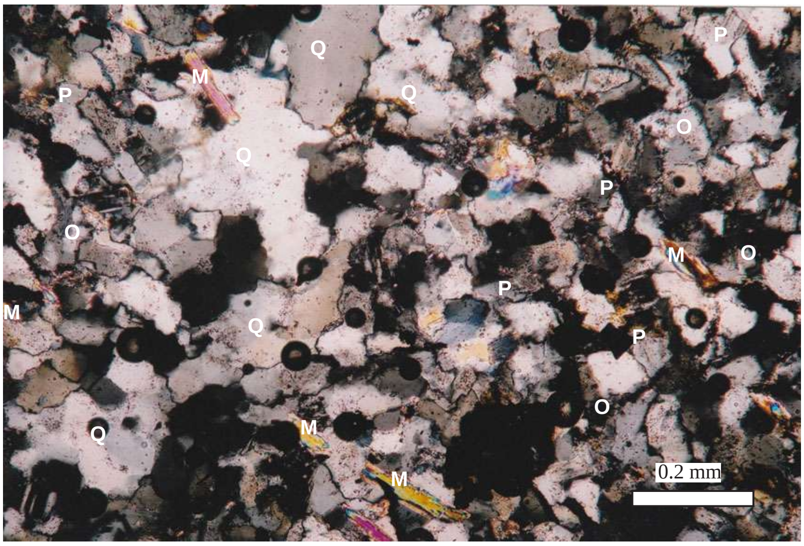

Fig. 5 Photomicrograph of rock category D2 showing alteration of feldspar, interlocking of quartz and feldspars, and extension of muscovite through quartz and feldspar (O = orthoclase; M = muscovite; Q = quartz; P = plagioclase).

Rock category D2

Rock category D2 belongs to arkosic metasandstone which is characteristically light grey with reddish brown ferrugineous patches. Quartz and feldspars predominate the framework constituents (Fig. 5). Quartz and feldspars are 60–90 μm. Vein-filling quartz grains are 200–300 μm. Muscovite and chlorite occur in minor amount. Muscovites often extend through other silicate grains. Hematite and calcite are cementing materials. Calcite replaces feldspar and quartz of rock and of veins. Localised replacement of silicate grains is remarkable. Some iron oxides are related to leaching of calcites.

Rock category E

The rock category E is a banded greenish grey metasiltstone. Quartz and feldspars dominate muscovite and chlorite. Chlorite as authigenic clays contributes substantially, and along with muscovite form a well defined foliation (Fig. 6). Bands of chlorite and muscovite alternate with that of quartz (50–60 μm) and feldspar. The chlorite and muscovite rich band incorporates quartz and feldspar grains of 15–30 μm. Besides, calcite, hematite, illite and chlorite occur within intergranular spaces as cementing material. Sometimes crystals of calcite grow into distinct euhedral crystals. Illite occurs minorly between quartz and feldspar grain boundaries. Pyrite crystals are scattered mostly in the chlorite-muscovite bands.

Rock category F

The rock category F is greenish grey and poorly banded medium-grained arkosic metasiltstone. It consists mainly of quartz and K-feldspars, muscovite and chlorite, and subordinately of plagioclase, illite,

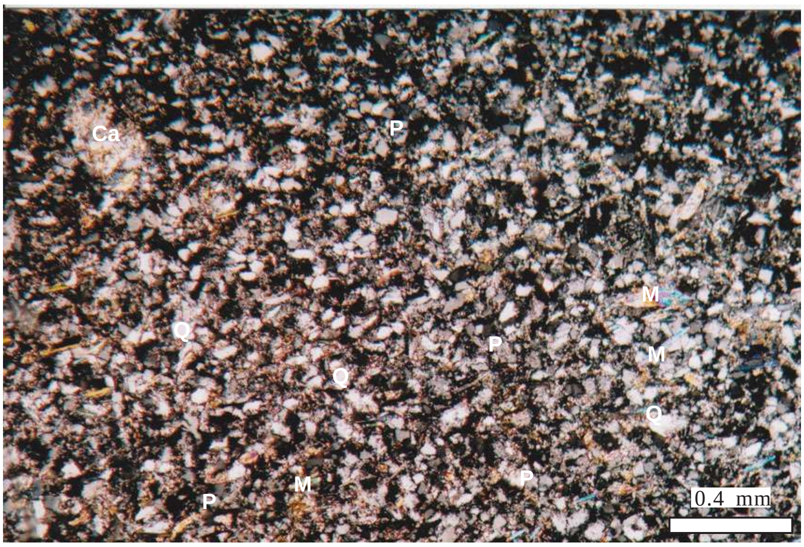

Fig. 6 Photomicrograph of rock category E showing dominant quartz and feldspar constitutents with intergranular cement of clay minerals, and authigenic micas forming foliation (O = orthoclase; M = muscovite; Q = quartz; P = plagioclase; Ca = calcite).

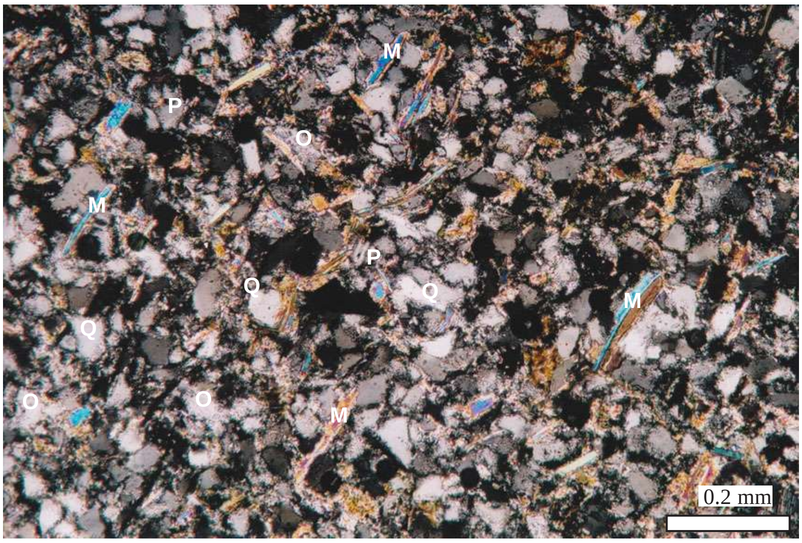

Fig. 7 Photomicrograph of rock category F showing dominant quartz and feldspar grains, crossed foliation of muscovite, and cements of fine micas and clay minerals (O = orthoclase; M = muscovite; Q = quartz; P = plagioclase).

hematite, calcite and opaques. Quartz and feldspars are dominantly of 30-45 μm, but they vary from 15-75 μm. Quartz grains are equant to slightly elongate and tend to lie along the foliation defined by muscovite and chlorite (Fig. 7). K-feldspars are dominantly linked by argillaceous cements of chlorite and illite present in grain boundaries (Fig. 7). Calcites contribute little in bridging the framework silicate grains in this rock, and hence argillaceous component is the dominant cementing material.

WEIGHTED COMPOSITION

Table 4 represents the overall weighted composition of individual rock categories and the total weighted composition of the ledge rock sample. The sample dominantly constitutes quartz (30%) and feldspar (25%). Chlorite (14%), muscovite (9%) calcite (9%) and illite (5%) are remarkable constituents. Other components which occur minorly are hematite, vermiculite, pyrite, dolomite, opaques, etc., and a trace amount of chert.

ALKALI-SILICA REACTIVE POTENTIAL

Rock categories of the sample exhibit banded to poorly banded internal structures. Bands exhibit compositional difference. Fine-grained bands are often rich in micas, chlorites and other clay minerals. Coarser bands are light coloured bands with tectosilicates. Oblique to bands are patchy and fracture-filling occurrences of calcite and in some cases hematite. Metasiltstones are medium-to coarse-grained and constitute quartz, felspars and chlorite as major minerals. Muscovite and calcite are intermediate and other constituents are minor. Quartz

Table 4: Weighted composition of constituents of individual rock category for the whole rock sample

Minerals	Weighted composition of constituents of individual rock category									Weighted composition
	A	A2	B	B2	C	D	D2	E	F	
Quartz	0.69	1.91	4.07	1.94	7.70	3.93	1.53	6.01	2.20	30.0
K-feldspar	0.20	0.32	0.97	0.29	2.57	1.84	0.53	2.64	1.20	10.6
Albite	0.26	0.58	2.52	0.49	3.85	0.79	0.88	3.36	0.55	13.3
Chert	-	-	-	-	0.26	-	-	-	-	0.3 (trace)
Muscovite	0.14	0.74	0.68	0.49	1.54	1.31	0.18	2.88	1.10	9.1
Chlorite	-	0.27	-	0.15	4.87	1.18	0.13	4.56	2.42	13.6
Illite	0.04	0.05	-	0.1	2.57	0.52	0.09	0.96	0.66	5.0
Vermiculite	-	-	-	-	1.28	0.26	-	-	-	1.5
Hematite	-	0.11	-	-	-	1.05	0.26	0.72	0.33	2.5
Pyrite	0.04	0.03	0.10	-	0.51	0.13	0.04	0.24	0.11	1.2
Opaques	-	-	-	0.17	0.51	-	-	0.24	0.44	1.4
Others	-	0.03	0.05	-	-	0.13	0.04	0.24	0.11	0.6
Calcite	0.61	1.60	-	1.21	0.61	1.97	0.70	2.16	0.88	9.7
Dolomite	-	-	1.31	-	-	-	-	-	-	1.3
Total	1.98	5.30	9.70	4.85	25.65	13.11	4.38	24.02	11.01	100.0

grains are low-quartz (Fig. 8) and almost megaquartz (size >15 microns). Silica scanning by XRD indicates that all the intense and peaks of the diffractograms belong to low quartz (2 theta = 20.9 degrees and d-spacing = 4.25) (Fig. 8). There is no single pattern indicating intense curve matched with opal (amorphous silica; reactive silica). There is also no other reactive high-quartz in the sample as silica scanning does not reveal such. Reactive silica is therefore absent from the rock categories, except the trace amount of chert which occurs in the rock category C (as detected from microscopic study), i.e., metasiltstone with thin clay partings. The amount of chert is negligible in the bulk composition. Vermiculite which is one of the varieties of swelling clay is low in amount in two of the rock categories, i.e., C and D (Table 4). In totality, vermiculite contributes 2%. Illite, the other non-swelling clay mineral is in noticeable amount in the rock category C and in overall sample of the ledge rock.

CONCLUSIONS

Fundamentally, two rock clans, metasiltstone and metasandstone have been identified. Presence of distinct clayey banding and constituents further distinguishes metasiltstones and metasandstones. In overall, nine categories have been identified. All these rock categories are well interlocked and cemented extensively by calcite. They are also well indurated. Some fragments of ledge rock sample although possess clayey coatings, the latter may be removed during processing in the crusher plant. Rocks do not contain remarkable amount of reactive silica. All the silica are low quartz except a trace amount of chert consisting of microquartz in the rock category C. Shattered grains are rare. Considering these features, the alkali-silica reactive potential is negligible.

Illite in many rocks and vermiculite in rock types C and D are considered to be deleterious silicate components, which may expand in the presence of water. But they are not as deleterious as smectite. The overall contents of illite and vermiculite in the whole rock sample are 5% and 2%, respectively. These minerals do not involve themselves in alkali-silica reaction, but they expand under the presence of moisture. Furthermore, illite is not as swellable as vermiculite. The presence of vermiculite and illite are strongly controlled by the presence or absence of clayey partings. If the quality of the aggregate has to be enhanced, these clayey constituents will have to be removed from the aggregates during processing.

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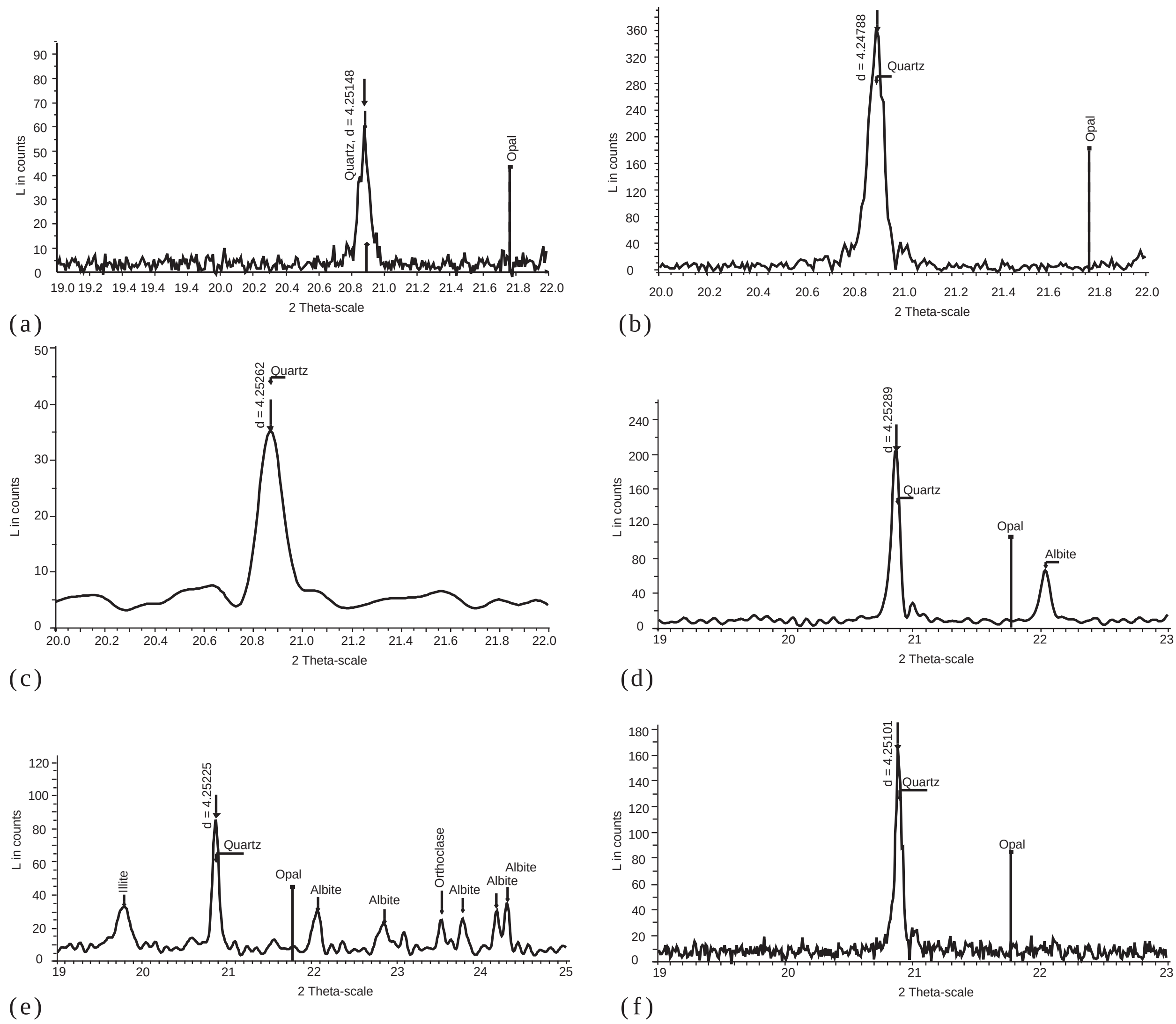

Fig. 8 Diffractograms of ledge rocks after silica-scanning for identifying reactive silica: (a) Sample A, (b) Sample B, (c) Sample C, (d) Sample d, (e) Sample E, and (f) Sample F.

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