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Geoengineering properties of the Sandstones of Upper Murree Formation, Jammu and Kashmir: A case study

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ABSTRACT

Sandstones play a vital role in various geotechnical and civil engineering applications. Understanding the relationship between its petrographic characteristics and geoengineering properties is crucial for reliable design and construction practices. This paper provides a concise overview of the research investigating the relation between the petrographic characteristics and corresponding geoengineering properties of upper Murree sandstone. The Murree Group consists of mudstones and sandstones, which are exposed linearly in the Outer Himalayan belt of Jammu and Kashmir. The sandstones of Murree are the only source of aggregate or building material in this region. The petrographic analysis of the samples revealed that the sandstone is of coarse to fine-grained, stably cemented, unweathered to slightly weathered and having medium strength. These rocks show fractured as well as intergranular porosity whereas, the grains are showing floating contacts, line contacts, point contacts and concavo-convex contacts. Preliminary findings of this study reveal that mineral composition, texture, fabric and the deformation of these sndstones significantly influence their geoengineering behavior. The higher concentration of quartz is an example of such behavior which generally leads to improved strength and lower deformability and on the contrary, higher concentration of clay and mica contribute to decreased strength and increased deformability. In present study, negative correlation between the porosity and compressive strength and positive correlation between cementation and strength of these rocks has been observed.

Keywords: Petrography, Geo-engineering, Upper Murree, Sandstone.

INTRODUCTION

The construction activities in the Lesser and Outer Himalayan zones pose many geological and engineering challenges to the residents living in these areas. Murree belt comprises of fragile sandstones, siltstone and mudstone, having low bearing capacity, low mechanical strength and high deformability and fracturing (Bell and Culshaw, 1998; Belland Lindsay, 1999; DeReuil et al., 2019). The physico-mechanical characteristics of the sandstones, siltstone, mudstone are the most decisive parameters in design and stability assessment of any surface and underground engineering structures (Yasar et al., 2010; Zhang et al., 2017; Sakiz, 2022). Determination of these characteristics is complicated, difficult and time consuming as well as require a great accuracy in sample preparation and testing procedure (Armaghani et al., 2014; Zhang, 2016).

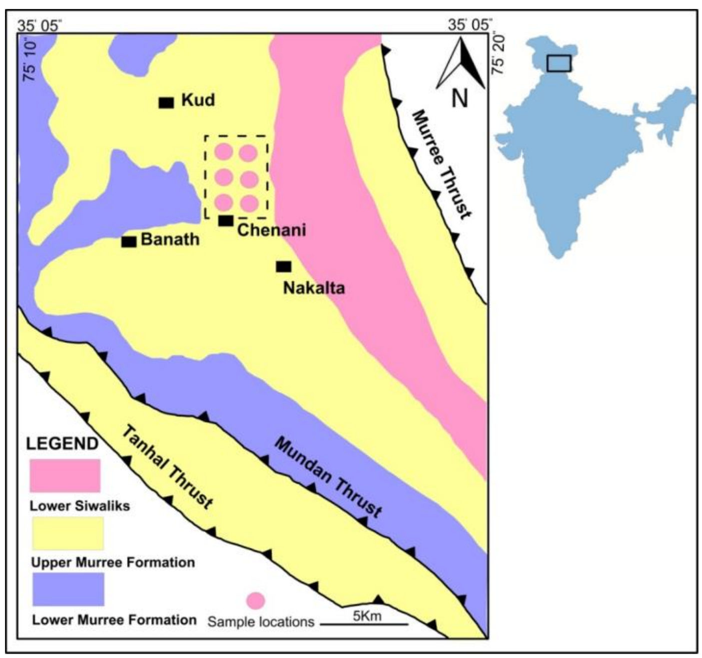

Fig. 1. The geological and structural map of the study area displays the distribution of Murree rocks (after Khan et al., 1971; Karunakaran and Ranga Rao, 1979)

To deduce the strength and class of rocks in a non-destructive and economical manner, the petrographic analysis of rocks can be significant during preliminary studies. Due to different cementation and diagenesis, geomechanical properties of sandstone and siltstone widely vary.

The variation in geomechanical properties like compressive strength, elastic modulus, shear modulus, bulk modulus and poisson's ratio have great impact on the petrographic characteristics (Bell,1978; Shakoor and Bonelli, 1991; Shahsavari and Shakiba, 2022). The petrographic characteristics of a rock are not only controlled by internal factors like environment of deposition, burial conditions, mineralogical composition, microstructure, texture, nature of grain contacts and diagenesis but also impacted by external factors like surrounding geological conditions and regional tectonic setting (Meng et al., 2006; Ulmer et al., 2014). The impact of mechanical properties on petrographic parameters of sandstone suggest a bivariant relation between strength characteristics and packing density (PD) which has no significant relationship with mineralogical composition (Bell, 1978; Tamrakar et al., 2007). Howarth and Rowlands (1986) suggested packing density in sandstone has been found to have moderate relation with several mechanical properties. Fahy and Guccione (1979) revealed that in case of calcareous sandstone, as the mean and median of grains as well as quartz content increases, the value of unconfined compressive strength (UCS) decreases. On the other hand, with increase in carbonate content and straight grain contact the value of UCS increases significantly (Fahy and Guccione, 1979). The study carried out by Doberenier and De Freitas (1986) concluded that usually the weak sandstones have low packing density and with decrease in the grain size and increase in grain contacts, the mechanical strength increases. Shakoor and Bonelli (1991) revealed that the sandstones with grain to void ratio, straight contact and grain to matrix ratio have low mechanical strength whereas, those with high density low absorption and higher values for suture contact have higher strength and Young's modulus values. Nevertheless, the textural parameters i.e. grain contacts are decisive than mineralogical composition in determining engineering parameters of sandstone (Ulusay et al., 1994). Sandstones with high percentage of angular grains and sutured contacts have relatively high strength whereas, the sandstones with significant grain to grain contacts and higher value of packing proximity, display low poisson's ratio and high young's modulus (Ulusay et al., 1994). On the contrary, point, straight, and concavo-convex grain contacts are not significant to decipher mechanical properties of sandstones (Ulusay et al., 1994). The objective of this study is to analyze the sandstones of the Upper Murree Formation to observe the relationship between petrographic characteristics and physical engineering index properties.

STUDY AREA

The Murree Formation represents Miocene molasse deposits consists of alternating beds of sandstone, siltstone, conglomerate and calcrete, deposited in tidal-fluvial dominated microtidal estuarine environment in the foredeep basin (Gansser, 1964; Singh and Singh, 1995; Singh, 2000). In the north-south traverse, these sediments are exposed for about 50 km along the Jammu-Srinagar national highway (NH-44) and for hundreds of kilometres in the southeast-northwest direction. The sandstones in the Murree Group are planar bedded, cross bedded, cross laminated and rippled, the siltstone is laminated and the conglomerates comprises of muddy pebbles (Singh, 2000). The Murree Group is sub-divided into Lower Murree and Upper Murree Formations (Wynn, 1874). Generally, lithology of Lower Murree is argillaceous whereas, the Upper Murree Formation is of arenaceous nature (Wadia, 1926, 1931). The rock sequence in the Upper Murree Formation consists of light gray, fine to medium grained, thick sandstones and brick red claystone whereas, the Lower Murrees are composed of cross-laminated, cross bedded and rippled sandstone, siltstone, conglomerate and calcrete (Karunakaran and Rao, 1979). A preliminary investigation has been carried out in Upper Murree Formation to understand the relationship among mineral composition, petrography characteristics and petrophysical properties for which six sandstone samples were collected from the study area.

MATERIAL AND METHODS

The fresh samples were collected from Upper Murree Formation (Fig. 1). Two thin sections (one horizontal and one vertical) were prepared and studied under Leica high power petrological microscope. Framework grains varying from 300 to 350 per thin section were counted. Point-counting was carried out to identify individual grains using the Gazzi-Dickinson method (Dickinson, 1970; Ingersoll *et al.*, 1984). The photomicrographs of each thin section were taken under 5X and 10X magnifications. The geomechanical properties of individual samples have been discussed following the standard methods of engineering classifications of rocks by Goodman's engineering classification (1989), classification of mineral size by Core Logging Committee (1978), classification of weathering/alteration of rocks by

RESULTS

PETROGRAPHIC AND PETROPHYSICAL ANALYSIS

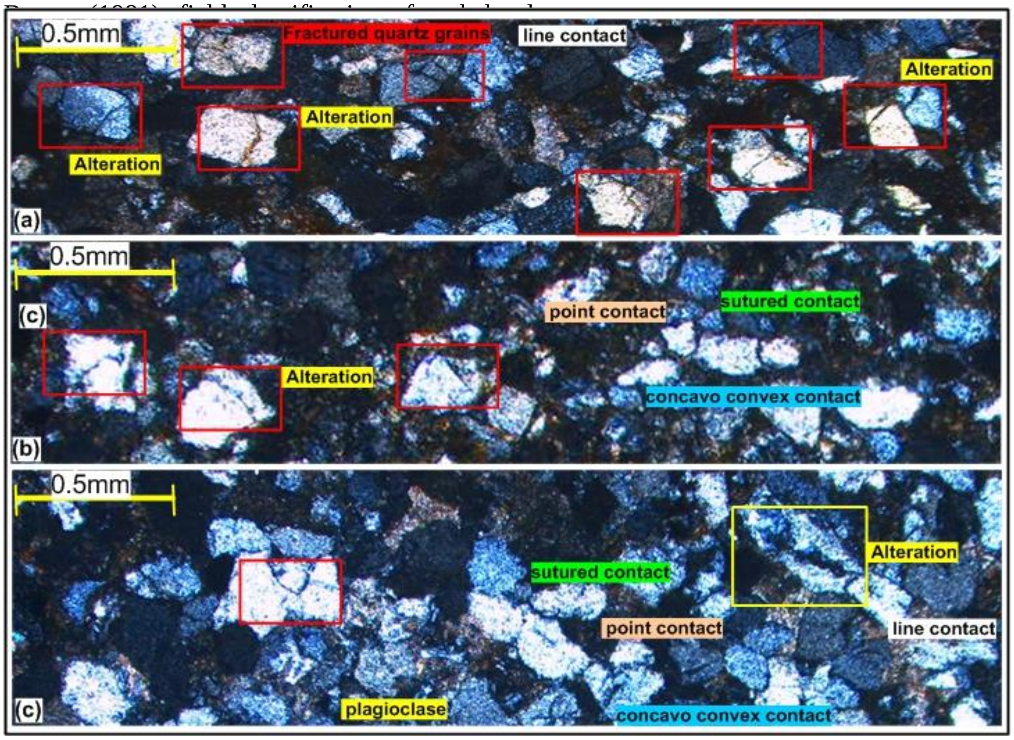

Fig. 2. Photomicrographs of the thin sections showing mineral components, microstructures, grain contacts and secondary alteration/ filling in the fractures (a) UM1 (b) UM2 (c) UM3.

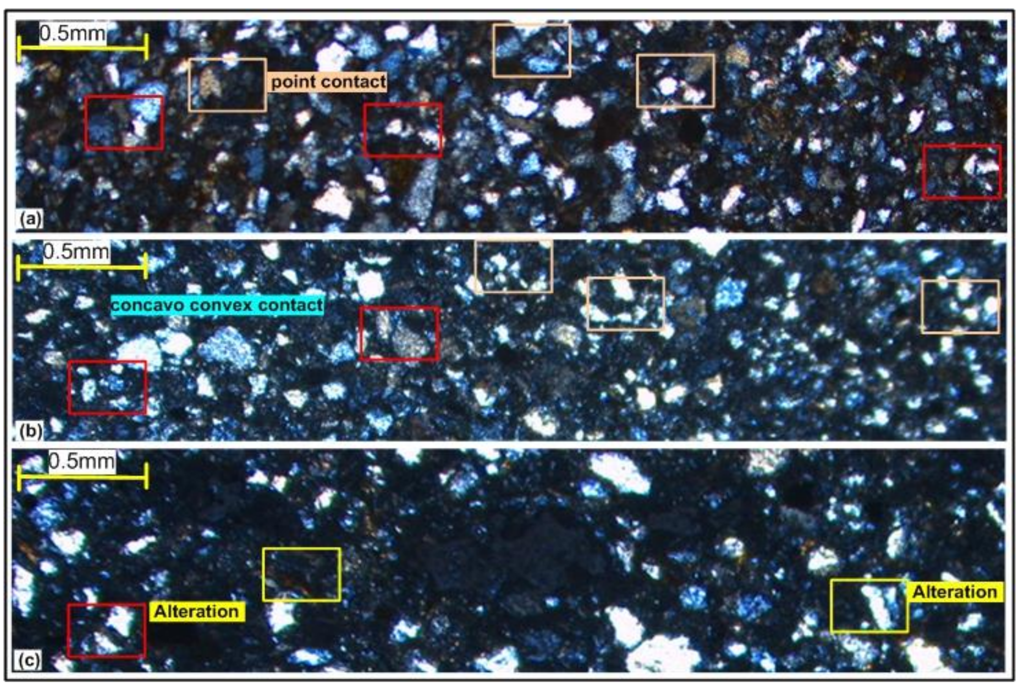

Fig. 3. Photomicrographs of the thin sections showing mineral constituents, microstructures, grain contacts and secondary alteration/ filling in the fractures (a) UM4 (b) UM5, and (c) UM6.

The modal composition and textural properties are the most important parameters that determine the maturity of sandstones. The petrographic analysis of the sandstone samples collected from the Upper Murree Formation has been carried out to estimate the model composition, textural properties, nature of matrix, fractures in the grains, and alteration or filling in the fractured grains. Thin sections of six fresh sandstone samples labelled as UM1, UM2, UM3, UM4, UM5, UM6 were analysed. The examination of thin sections revealed that the sandstones examined range in grain size from fine (UM5) to medium (UM4, UM6) and coarse grain (UM1, UM2, UM3) comprising of sub-rounded, angular to sub-angular in nature (Figs. 2 & 3). The major mineralogical constituents of all of the samples include quartz, feldspar and lithic fragments embedded

Table 1. The percentages of individual minerals identified in thin sections

Sample Constituents/Mineralogy	UM1	UM2	UM3	UM4	UM5	UM6
Quartz	65	55	70	50	62	60
Feldspar	05	04	04	05	04	05
Mica	06	06	07	07	06	08
Matrix + Cement +Clay Minerals (Smectite)	12	15	10	18	12	10
Heavy Minerals	02	02	-	-	01	-
Rock Fragments/Detrital grains	05	06	05	15	08	05
Calcite	-	-	-	-	-	-
Opaque minerals	05	12	09	05	07	12

in matrix constitutes significant proportion of the samples (10-18%). The matrix comprises of dominantly the clay minerals which are altered to montmorillonite and smectite. Mica, opaque and heavy minerals constitute the minor fraction of all the samples (Figs. 2 & 3). Quartz grains in the studied samples are monocrystalline, having undulose extinction as well polycrystalline (Figs. 2 & 3). The monocrystalline quartz grains are fractured and are filled with secondary minerals (Fig. 2a-c). The samples dominantly show aggrading neomorphism into large crystals (Fig. 3a-c). Matrix consists of very fine material, which is present within interstitial spaces between the framework grains showing variability in the packing density and packing proximity (Fig. 3c). The rock forming minerals include quartz, feldspar and rock fragments which are angular, sub-angular to sub-rounded (Fig. 2a-c). In addition, clay minerals and accessory minerals including minor amount of mica, chlorite and heavy minerals are also present (Figs. 2 & 3). The detrital fraction of the studied samples contains 40-65% quartz, 4-5% feldspars (microcline and plagioclase), lithic fragments vary between 5-10%, matrix between 10-18%, 6-8% mica and 5-12% opaque minerals (pyrite, magnetite) (Table 1). The samples show alteration of feldspar to kaolinite and fractures in quartz gains are filled with clay minerals (Fig. 2a-c). The mineralogical maturity of sandstones is determined by their quartz to feldspar ratios (Pettijohn et al., 1987). According to Prothero et al. (2004), sandstone is texturally immature if the proportion of clay size material (matrix) exceeds 50%, irrespective of the degree of sorting and roundness. Although the abundance of quartz is generally greater than other framework elements, the presence of appreciable amounts of feldspars and considerable quantity of rock fragments makes these rocks mineralogically sub mature (Table 1). Mineralogical and tectonic classifications of sandstone of Murrees were described following Folk (1974) and Dickinson, & Suczek (1979) as litharenites to sub-litharenites (Singh, 2000; Jamwal et al., 2020). The rock fragments are mostly clasts of carbonate; siltstones and shale constitute 5-10% of the samples. Quartz grains in Murree sandstone have the origin from plutonic rock (felsic in origin), older sandstones that have been recycled and also from metamorphic rocks (Saleem et al., 2018; Jamwal et al., 2020).

Five types of grain to grain contacts were observed in the thin sections. These are floating, concavo-convex, suture contact, point contact and long contact (Figs. 2 & 3). The long contact is dominating followed by concavo-convex, point contacts and suture contacts (Figs. 2 & 3). The point contacts and floating contacts of grains can be attributed to the packing during depositional process, the line contact is due to diagenesis whereas, the concavo-convex and sutured contacts may be due to notable confining and directed stresses as well as the growth of cement (Taylor, 1950). The quartz grains are fractured suggesting confining stress as well as directed stress due to the post depositional tectonic deformation as a consequence of continued India-Asia plate convergence process. The petrophysical properties of the sandstone analyzed include types and condition of porosity. The rock strength is a petrophysical property that can be deduced from the mineral composition, type of porosity and presence

Table 2: Classification of rocks samples on the basis of Petrography

Classification of mineral size (from Core Logging Committee (1978)	Fine grained (0.06 - 0.2 mm)	Medium grained (0.2 – 0.6mm)	Coarse grained (0.6 – 2.0mm)	Very Coarse Grained >2.0mm			
	UM5	UM2, UM6	UM1, UM2, and UM3				
Goodman's engineering classification of rocks (from Goodman, 1989)	Stably cemented	With slightly soluble cement	With highly soluble cement	Incompletely or weakly cemented	Un cemented		
	UM1, UM2, UM3, UM4, UM5, and UM6	-	-	-	-		
Classification of weathering/alteration is as follows: Brown (1981)	Unweathered /unaltered	Slightly weathered /altered	Medium weathered/altered	Highly weathered/ altered	Completely weathered/altered		
	UM4, UM5, and UM6	UM1, UM2, and UM3	-	-	-		
Field classification of rock hardness (Singh and Elkington, 1983)	Very soft rock (1-3 MPa)	Soft rock (3 - 10 MPa)	Medium hard rock (10 - 25 MPa)	Hard rock (25-70 MPa)	Very soft rock (1-3 MPa)	Soft rock (3 - 10 MPa)	
			UM2, UM5, and UM6,	UM1, UM3, UM4			
Classification of rock strength used by Bieniawski (1989) Intact rock strength (MPa)	extremely low (<1)	very low (1-5)	low (5-25)	moderate (25-50)	medium (50-100)	High (100-250)	Very High >250
Point load strength	-	-	-	1 - 2	2 - 4	4 - 10	> 10
	-				UM1, UM2, UM3, UM4, UM5, and UM6	-	-

of fractures in the grains. The average values of porosity of the Murree sandstone is 9.6% (Existing Optical Porosity) and 32.6% (Minus Cement Porosity) (Jamwal et al., 2020). The analysed samples show intergranular i.e. primary porosity, secondary porosity and fractured porosity (Fig. 2a-c). In all of the thin sections, the void space between the quartz grains constitutes primary porosity and is attributed to depositional processes which are having least effective porosity. The fracture porosity is dominant in the samples UM1, UM2 and UM3 and least in the sample UM6. Porosity and compressive strength are interrelated due to the fact that the strongly compact sandstone shows least porosity whereas, the weakly compact sandstone shows the highest porosity. Thus, the weakly cemented rock samples are showing low compaction and thus low porosity.

GEO-MECHANICAL PROPERTIES

The geomechanical properties of the rocks depend on the modal composition, texture, density, porosity, porewater, confining pressure, weathering and alteration, bedding plane, and joint properties (Vutukuri et al., 1978). The process of weathering is by means of either mechanical, chemical or biological action or combination of these which drastically affects the engineering properties of both the rock material and the rock mass. Some of the very important effects of weathering/alteration on rocks are the decrease in strength, density and volumetric stability and increase in deformability, porosity and weatherability. Since the rock or soil responds to different stimuli like loading-unloading, temperature disturbance, and flow of fluid, therefore, the geoengineers are mostly interested to know how beneficially the response of these materials can be controlled or modified. It is evident that in each case of construction, the geoengineer needs to know different properties of material like strength properties, volume change, fluid and gas conductivity and interaction of materials with external factors. The geotechnical property of materials also varies with depositional environment of clastic rocks. The impact of depositional environment on the mechanical properties of clastic rocks can be determined by examining the detrital quartz content (Meng et al., 2006). The textural characteristics of the sandstone/siltstone are more significant than mineralogical composition due to the fact that the mineralogical composition is independent of porosity (Heidari et al., 2013).

The increase in the quartz content and decrease in the matrix content attributed to increase in strength i.e., Uniaxial Compressive Strength (UCS) and point load index parameters (Ktena and Sabatakakis, 2013). The packing among detrital grains of sandstone can be assessed in terms of grain to grain contacts or packing proximity. The floating of detritus through cement and matrix and different types of contacts like grain to grain contact (Point, straight, concavo-convex, and sutured contact) have significant impact on the engineering properties of rocks. The nature of contact is an important parameter to determine the conditions during or post deposition. The uniaxial compressive strength of a rock material constitutes the highest strength limit of the rock mass of which it forms a part. It is determined in accordance with the standard laboratory procedures. For the purpose of rock mass classification, the use of well-known point load strength index can be useful as the index that can be determined in the field on rock core retrieved from borings and the core does not require any specimen preparation. Knowing the rock type and rock material hardness, it is possible for the experienced engineer or engineering geologist to make fairly accurate estimates on rock material strength. These can be readily verified by uniaxial compressive strength or point load tests. The samples from Upper Murree Formation show point load strength index values ranging between 2-4 MPa.

DISCUSSION AND CONCLUSIONS

Petrographic analysis of the sandstone samples of the Upper Murree Formation was carried out to know the relationship between petrographic characteristics of the samples with the geoengineering properties. The study was conducted to decipher the preliminary geomechanical properties of sandstones using petrographic analysis. This type of study is being carried out during the initial stage of any major construction project like tunnels, underground excavations, building material, road construction, railway track, etc. The thin sections were studied to know the mineral composition in terms of volume percentage, texture, fabrics and microstructures particularly focussing on the contacts of grains, fractures in the grains, infilling of fractures, alteration and matrix. The results show a wide range of textures covering fine-medium-coarse fractions (UM5-fine grained; UM4 & UM6-medium grained; UM1, UM2 & UM3-coarse grained), stably cemented (UM1, UM2, UM3, UM4, UM5, and UM6), unweathered (UM1, UM2, UM3, UM4, UM5, and UM6), two types rock hardness: medium hard rock (UM2, UM5, and UM6) and hard rock (UM1, UM3, and UM4) and having medium intact rock strength (UM1, UM2, UM3, UM4, UM5, and UM6).

The quartz grains in the studied samples are monocrystalline and polycrystalline displaying undulose extinction. The monocrystalline quartz grains are fractured and are filled with secondary minerals. The detrital fraction of the studied samples includes 40-65% quartz, 4-5% feldspars (microcline and plagioclase), lithic fragments between 5 and 10%, matrix between 10 and 18%, 6-8% mica and 5-12% opaque minerals (pyrite, magnetite). The samples show alteration of feldspar and clay minerals filled in the fractures of quartz grains but no significant relationship exists between the alteration and strength of rock. The samples of the Upper Murree sandstone have almost similar characteristics due to similar source, depositional environment, provenance, texture, weathering index, diagenetic characteristics regional and local stress conditions. This study reveals significant relationship that exist between the textures of rocks (syndepositional, diagenetic and post diagenetic) and engineering properties of the rocks (point load, strength, rock hardness and rock class). The petrographic analysis of samples from different litho-units of the Upper Murree i.e. mudstone, sandstone, siltstone can be useful to establish the relationship with geomechanical properties.

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