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Review Paper

A geotechnical study on properties and uses of Shales of the Dharwar system, Karnataka, India

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Abstract

The Dharwar system of rocks in Karnataka comprises of shales which are basically sedimentary rocks having high content of clay and silt. They generally exhibit laminated structure and possess low strength, low permeability and high water sensitivity. Apart from several uses, the shales are considered to be prominent source of oil and natural gas including their use as seals in the petroleum traps and reservoirs. In the present paper, it is attempted to present the properties and uses of shales of the Dharwar system which is 4–1 billion years old and has special distinction of being the first and oldest metamorphosised sedimentary rock system in India. Due to its unpredictable behaviour, shales are found to be difficult rocks to classify, sample and obtain reliable test results for their use in engineering works. The origin, distribution, classification, properties and the possible uses of shales of Dharwar system are briefly discussed and their engineering evaluation for construction also has been presented.

Keywords: Shales, Classification, Dharwar system, Composition, Oil and natural gas.

Introduction

Shale is a fine-grained sedimentary rock formed by the compaction of silt and clay-size mineral particles which makes it fissile and laminated. Shale can be considered as boundary material between soil and rock; which makes it typical for characterising its engineering properties. Hence Shales are considered to be problematic for their use as construction material in engineering applications[1]. In general, the shale is composed of quartz, feldspar and minerals. Illite, kaolinite and semectite are generally the major minerals found in shale. Other minor constituents normally found are organic carbon, carbonate minerals, iron oxide minerals, sulfide minerals, and heavy minerals. Shales are the most abundant of all sedimentary rocks constituting about 60%.Shales occur in various colours ranging from white or green to grey and brown to black depending on their composition and environment prevailed over the deposition[2].

In this paper, the composition, classification, properties and uses of shales are presented with emphasis on their engineering evaluation. The shales of Dharwar system are considered in particular while illustrating the importance of this rock class.

Origin and composition of shales: Shales may form in any environmental condition in which sediment is abundant and the water energy is sufficiently low to allow settling of suspended fine silt and clay[3]. Silts and clays when newly deposited from suspension in water undergo compaction due to continuous accumulation of other sediments above them. The silt and clay percentage in the shales may vary but however at least 50% of their material is finer than fine sand. The transformation of soil into shale rock and the subsequent formation of metamorphic rocks depending on the mineral composition of the shale and degree of metamorphism is schematically indicated in Figur-1.

Classification of Shales: Shales are fissile sedimentary rocks formed from transportation, deposition of debris or fragments of disintegrated materials of silt and clay. Fissility of the clay is the main characteristic of the shales which distinguish them from other sedimentary rocks. Shales can thus be classified based on the observable features and environment of deposition such as texture, mineralogical composition, type of cementation/ cementing materials, depositional environment, organic matter content and strength[4]. Brief discussion on the classification of shales is presented below.

Texture: The texture of shales is generally featured by the presence of silt and clay particles. Based on the percentage of silt or clay content of the rock, the shales are classified as silty shales or clayey shales, which are commonly known as argillaceous shales.

Mineralogical composition: On the basis of predominance of minerals viz. feldspar, quartz or mica present in the rock, the shales may be classified as feldspathic, quartzose or micaceous shales[5].

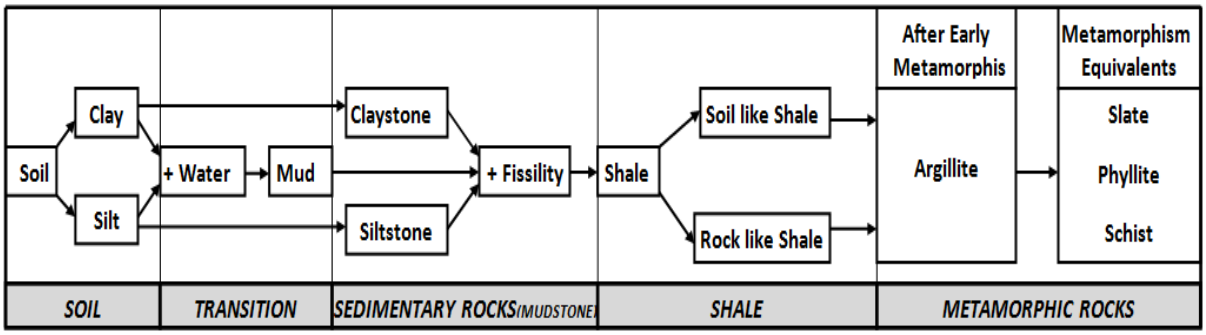

Figure-1: Transformation of soil into shale and subsequent metamorphic rocks.

Cementation / cementing materials: Cementation being the basic process in the formation of shales, the cementation process and the type of cementing materials are also considered as a prominent criterion for their classification. Since the cementing material has considerable effect on the rock properties, this classification is quite useful particularly for assessing the performance of shales when required to be used for construction purpose. Shales are thus classified as calcareous, siliceous or ferruginous depending upon the predominance of the presence of cementing materials viz. lime, silica or iron oxide respectively.

Environment of deposition: The environment in which sediments are accumulated and later get transformed into rock is a natural geographical process which can be considered as another valid base for classifying the shales[6]. Three sedimentary environments of deposition namely, continental, transitional or marginal and marine are prominently observed. Shales are classified as marine, deltaic and lacustrine shales depending upon the prevailing environment of deposition during the sedimentation. Shales of marine deposits are non-paralic and exhibit predominant presence of clay minerals viz. illite and montmorillonite. These shales are found in great depths and normally have dark colour, considerable presence of marine fossils. The deltaic shales are found to have paralic patterns with shale and sand stone layers deposited in sequential manner. Composites of clay, silt, sand, organic matter and various plant deposits.

Organic matter content: Presence of organic matter content in shales is another criterion forming the base for their classification[7]. Based on the predominance of bitumen or carbon, the shales are classified as bituminous or carbonaceous. The bituminous and carbonaceous shales generally contain more than 10% of organic matter which in fact induces black or grey colour to the shales. High percentage of organic matter originated from animal fragments like fossils give rise to bituminous shales. Likewise, the presence of plant stems, leaves or pollen grains in large percentage lead to the category of carbonaceous shales.

In addition to the above criterion, the rock strength may be considered for classifying the shales, which can be fairly useful in evaluation of strength of shales. Likewise, colour of the shales, which in fact may be quite useful in understanding the composition of the materials forming the shales and suggesting its usefulness, may also form a base for classifying the shales. The summary of the classification of shales is presented at Table-1.

Table-1: Criterion wise classification of shales.

Criterion	Classification
Texture	Silty shales, Clayey shales, Sandy shales
Colour	Black and Grey shales, Red, Brown, Yellow shales
Mineralogical composition	Feldspathic shales, Quartzose shales, Micaceous shales
Cementing materials	Calcareous shales, Ferruginous shales, Siliceous shales
Organic matter content	Carbonaceous shales, Bituminous shales
Depositional environment	Lacustrine shales, Deltaic shales, Marine shales
Strength characteristics	Soil-like or rock-like shales, Weak or Strong shales, Low strength or High strength shales, Low/ High modulus ratio shales, Soft/Plastic or Hard/Brittle shales

The Dharwar System shales – Lithology and Distribution

Lithology: The shales of Dharwar system were discovered in the erstwhile Dharwar district of Karnataka state, the present name of which has now been changed as Dharwad. The geological name for the crystalline schist near Dharwad is known as 'Dharwar System', the name being given by Robert B.F. who identified them way back in 1886. The Dharwar system is formed by lava, dust and other particles of volcanic origin and is made up of sedimentary rocks. Over a period of time on their formation, these rocks appear to have undergone considerable deformations such as folding, faulting, tilting etc; which is predominantly due to the forces within earth causing movements of the crust. As such these shales are observed not to have horizontal layers in their occurrence.

The Dharwar system is known to be the oldest sedimentary rocks resulted from the earliest sediments formed due to the weathering of schists and gneisses[8]. There are four types of rock system in this rock formation viz. (a) Igneous rocks, (b) Crystalline sedimentary rocks (c) Disfigured sedimentary rocks and (d) Incrusted Igneous rocks. The rocks of Dharwad schists are spread in north south direction as bands in different sizes. Surrounding this are found granite and gneiss rocks.

The shales of Dharwar system of rocks have thus been subjected to considerable metamorphosis. The prominent rock types of these are slates, schists and phyllites. They are rich in minerals and the occurrence of these rocks is found to be in the form of outcrops with narrow and elongated formations. No layering formation is observed in the structure of these rocks and they are found to occur mostly in tabular forms.

Distribution: Shales of Dharwar system are found in scattered patches of rocks occur in scattered areas in: i. The Himalayan region, ii. North- western parts of India iii. Eastern and Central regions of the Peninsula and iv. Southern Deccan region. The distribution of the Dharwar system shales in India is shown at Figure-2[8].

Southern Deccan includes the Dharwar region (presently called as Dharwad) of Karnataka state where these rocks have been were found in abundance. Nearly about 15,540sq.km of area in the districts of Dharwad and Ballari of Karnataka state is occupied by these rocks. Five prominent areas of occurrence of shales of Dharwar system have been identified[9]. The Central and Eastern Peninsula comprises of large area spread over the parts of the country in the states viz. Madhya Pradesh, Maharashtra, Jharkhand, Orissa and West Bengal. North-Western Region of Dharwar system rocks are found to occupy a wide surface area in Rajasthan and Gujarat states. The outcrops of the Dharwar system rocks are also found in the Himalaya regions plateau of Meghalaya of North East region.

Properties of Shales of Dharwar system and their evaluation for construction: The mechanical properties of shales are of great concern and their evaluation becomes quite essential to consider them for the construction[10,11] Shear strength and settlement properties of the shale and its derived soils are critical in analysing the stability of structures built on them. Horsrud noted that due to the typical properties of shales it is difficult to make their assessment and evaluate their suitability from engineering point of view[12]. The critical characteristics which make the shales problematic are low strength, high clay content, low hydraulic conductivity and sensitivity to water or fluids.

Due to the varied nature of shales, the properties also vary for different shales. The index and geotechnical properties which are useful in the evaluation of shales as engineering material for construction have been determined. Table-2 gives typical range of values of these properties.

The desirable range of values of these parameters for the shales of Dharwar system are also given in the table along with their engineering evaluation[13]. The values indicated are based on the respective tests conducted as per the relevant IS codes for these tests. The evaluation offers further scope as well, for conducting few more tests viz. slake index test, slake durability index test, jar slake index test, point load test etc. and considering the values of these indices also for the evaluation.

Figure-2: Distribution of the Dharwar system shales over India[8].

Shales of Dharwar system and the soils derived from them are considerably problematic materials from the point of view of construction upon them. Due to the high content of clay particles they exhibit swelling characteristics thereby exerting considerable swelling pressure on the structures constructed over them. As can be seen from the Table-2, the shales of Dharwar system exhibit moderate to poor geotechnical characteristics to be considered as engineering material for construction. Presence of montmorillonite, a clay mineral, makes these shales more prone to the volume changes with the entry of moisture into them and subsequent exit. This is due to the structure of the clay minerals which make the shales and the soils derived from them behave and exhibit the nature of expansive soils. With the onset of monsoon and the entry of water, the shales increase their volume thereby causing a pressure called 'swell pressure' which may be up to the order of 6 t/m^2. With the exit of water during summer and steep reduction in the moisture content, the soils tend to shrink due to the reduction in volume.

As a result, the structures happen to lose the support beneath them and undergo upward and downward movement. This kind of frequent movements with the seasons and changing moisture content result in the detrimental effect on the stability of the structures viz. buildings, roads, canal sides/embankments, sewer lines etc. Owing to the poor shear strength of shales, subsidence and land slides are commonly observed in these rocks and their soil derivatives. As can be noted from the Table-2, the values of shear parameters of these shales are in the low range and as such result in low shear strength and hence lower bearing capacity value. Overloading or excavation by humans may also often results in failure. Shales of Dharwar system are hence considered to be one of the weak sub-strata for construction. The excavation in shales is experienced to be quite problematic due to the possible regain and rebound of bottom and sides of excavation on the removal of overburden load. From permeability point of view, these shales are impermeable except where silt or sand occurs in alternating layers within the shale mass. When these shales are weathered, it breaks and slakes easily. They slake almost immediately when exposed to air, which causes a problem during construction of tunnel and other underground openings in shale mass. The shales of Dharwar system and the soils derived from them, thus exhibit nearly similar behaviour as that of clayey or black cotton soils. There are some properties of these shales which are desirable even though these rocks are problematic for engineers and designers. Due to their low conductivity, the shales and soils derived from them are useful in certain engineering works as barriers in preventing soil contamination; similar to as those of clay liners. They also prove to be useful in prevention of degradation of quality of ground water. Further, the shales being soft rocks and their soil derivatives being fine grained, offer lesser resistance to penetration. Excavation in these soils hence is easy and ripping, blasting and drilling etc. in these soils is generally not necessitated.

Uses of shales of Dharwar system

Shales of Dharwar system exhibit certain special properties that make them useful resources. Some of the possible uses of these shales are briefly mentioned below, which may open up scope and prospects even for exploring oil and natural gas, apart from yielding certain minerals.

Clay products: Shales of Dharwar system prove useful in forming the clay. As it is known, many products such as bricks, tiles, pots etc. are normally made from natural clay. However, such enormous and incessant use has resulted in depletion of most of the clay deposits, necessitating the need for a new source of similar raw material. The paste of finely powdered shale and water is found to exhibit the same desirable properties as that of natural clay. As a result, many of clay products such as bricks, tiles, pottery and decorative items can be manufactured using the shale-based clay. These shales can thus be a substitute for the natural clay thereby reducing its overexploitation.

Table-2: Range of values of index and geotechnical properties of Shales of Dharwar systems hales and their engineering evaluation[13].

Parameter	Typical Range of values for shales	Desirable range of values for construction	Average value of shales of Dharwar System	Evaluation of Shales of Dharwar System as engineering material for construction
Natural moisture content (%)	20-34	5-20	18	Marginally acceptable.
Dry density (kN/m^3)	1.12-1.78	1.8-2.5	1.60	Marginally acceptable / Indicative of moderate strength.
Activity ratio	0.75-2.0	0.35-0.75	0.65	Highly Plastic. Acceptable but high volume change is expected
Predominant clay mineral	Illite/ Montmorillonite	Kaolinite / Chlorite	Montmorillonite	Unfavourable / High swell-shrink character expected.
Swell potential (%)	3-15	1-3	4.2	Unfavourable / High swell potential
Coefficient of Permeability(cm/sec)	$1x10^{-5}$- $1x10^{-10}$	$>1x10^{-5}$	$0.85x10^{-5}$	Marginally acceptable / Poor drainage property expected.
Angle of internal friction (degrees)	10-20	20-45	18	Unfavourable/Indicative of low shear strength and low bearing capacity.
Cohesion (kN/m^2)	35-700 kN/m^2 (3.5-70 t/m^2) (35-700 KPa)	700-10000	32	Critical / Indicative of low bearing capacity.
Unconfined Compressive Strength (UCS) (kN/m^2)	340-2070 kN/m^2 (0.34-2.07 MPa)	2000-35000	3600	Marginally acceptable but critical / Indicative of poor strength characters.

Cement: These shales offer scope to produce cement as well, by crushing the shale and lime stone and then subjecting the crushed mixture to heating at high temperatures. The lime stone is converted into oxides of calcium and carbon on the total evaporation of the moisture present in it. The carbon dioxide is emitted out and the remaining heated powder contains calcium oxide which in fact combines with the shale in heated state and subsequently yields a powder which is similar to cement and which gets hardened on mixing with water and allowed to dry. Such cement can be a suitable substitute for the traditional cement and can be used for the construction works as well as in the manufacture of concrete products. Manufacture of shale based cement can thus be another area that offers scope for the possible commercial exploitation of the abundant deposits of shales of Dharwar system.

Hydrocarbons: Organic matter of shales is generally found in the form of mixture of hydrocarbons derived from deceased plant and animals. As such this organic matter can yield back hydrocarbons in the form of gas or liquid. Oil shales, in particular, can give considerable yield of hydrocarbons on subjecting them to heat treatment along with solvent. Though the direct rock drilling may result in the better yield of oil or gas, the process has undesirable effect on the environment. The gaseous emissions and the waste produced during the extraction results in considerable environmental degradation. However, offsetting this with the advancing technology, shales may be looked upon as the source rocks for hydrocarbons, offering scope for commercial exploitation.

Oil and natural gas: The black organic shales of Dharwar system are the source rocks for the deposits of oil and natural gas. In the process of sedimentation, the mud containing organic matter particles results in the formation of black shales which have the typical black colour. The burial of the organic mud in the earth accompanied by the warmth led to the possible transformation of the organic material into oil and natural gas. The oil and gas thus formed move out and upwards in the sediment due to its low density and subsequently get stored in the voids of pores in the rock mass; which then easily flow into the extraction well as in case of a conventional oil/gas reservoir. Though the extraction of large quantities of oil and natural gas is possible by way of drilling, it is found to be difficult to extract that portion which is entrapped within the minute pores of the rock. However, steps in the direction to explore oil and natural gas from the shales of Dharwar system are yet to be initiated and their importance to the petroleum industry is yet to be established. Large scope thus exists to carry out the explorative works on shales of Dharwar system on this point of view.

Conclusion

In the literature only a few studies are available that have been focussed and exclusively carried out on Dharwar system shales. Based on the limited horizon of the study carried out in this work, following broad conclusions are drawn.

It may be noted that, the Dharwar system rocks offer a great scope further for elaborate studies particularly pertaining to their possible commercial exploration. i. Shales of Dharwar system are the sedimentary rocks formed with the laminates of fine-grained silt and clay as predominant detrital particles. Other major constituents include organic matter and cementing materials. The minerals contained in these shales are distributed in the silts, clays, cementing materials and organic matter. ii. Clays and quartz are the main minerals constituting these shales. The other common minerals of these rocks include feldspars, calcite, mica, pyrites, iron oxides and organic carbon. iii. Texture, mineralogical composition, cementing materials, organic matter content, depositional environment and strength criteria can be considered for classifying these shales depending on mineralogical composition and depositional environment. They are found to vary in colour ranging from white to red and green to grey or black. They are water sensitive with low strength and low permeability. iv. The Dharwar system shales exhibit poor to moderate geotechnical properties and their engineering evaluation indicates that these rocks as well as their derived soils are considerably plastic in nature, weak in strength and hence are considered as problematic substrata for construction. v. The occurrence of black shales of Dharwar system can be found as source rocks, and reservoir rocks for prospecting oil and gas. These rocks may also offer prospects for being explored to manufacture clay products, cement and gaseous hydrocarbons.

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