ANALYSIS OF SAND DEPOSITS IN RIVER PETAGAS AND RIVER KIONSOM FOR CERAMIC INDUSTRY

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ABSTRACT

A combination of analytical techniques such as X-ray Diffraction (XRD), Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) and particle size distribution were employed to characterize sand samples from River Petagas and River Kionsom in Sabah. The XRD result suggests the presence of quartz, muscovite $2M_1$ and illite 1M in both samples which can be used in manufacture of bricks and ceramics. The chemical composition shows both samples are not expected to satisfy the requirement of clay due to the low content of silica and high content of alumina. However, the level of alkali (sodium and potassium) and alkaline earth metal (magnesium and calcium) oxides in River Petagas's sample is an advantage to the desired application in ceramics. Moreover, River Kionsom's sample show larger particle size giving positive expectation for higher rate of water diffusion, porosity and thermal shock resistant whereas River Petagas's sample tends to have more clay contents which is favorable in ceramic industries.

ANALISIS DEPOSIT PASIR SUNGAI PETAGAS DAN SUNGAI KIONSOM BAGI INDUSTRI SERAMIK

ABSTRAK

Gabungan teknik analisa seperti Pembelauan Sinaran-X (XRD), Pasangan Plasma Induktif- Optik Pelepasan Spektrometri (ICP-OES) dan taburan saiz zarah telah digunakan untuk mencirikan sampel pasir dari Sungai Petagas dan Sungai Kionsom di Sabah. Keputusan XRD menunjukkan kehadiran kuarza, muskovit $2M_1$ dan ilit 1M dalam kedua-dua sampel boleh digunakan dalam pembuatan batu bata dan seramik. Komposisi kimia menunjukkan kedua-dua sampel dijangka tidak dapat memenuhi keperluan tanah liat kerana kandungan silika yang rendah dengan kandungan aluminium oksida yang tinggi. Walau bagaimanapun, tahap alkali (natrium dan kalium) dan alkali bumi oksida logam (magnesium dan kalsium) dalam sampel Sungai Petagas adalah satu kelebihan untuk aplikasi yang dikehendaki dalam seramik. Selain itu, sampel Sungai Kionsom menunjukkan saiz zarah yang lebih besar memberikan jangkaan positif kepada peresapan air, keliangan dan kejutan haba tahan yang tinggi manakala sampel Sungai Petagas mengandungi lebih banyak kandungan tanah liat yang digalakkan dalam industri seramik.

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LIST OF SYMBOLS AND ABBREVIATIONS

µ	micro
k	kilo
m	meter
g	gram
mm	millimeter
°C	degree celsius
θ	theta
λ	wavelength
d	distance
mL	milliliter
ppm	parts per million
V	volts
Å	angstrom
BS	British Standard
rpm	revolutions per minute
°	degree
%	percent
$2M_1$, 1M	polymorphs

CHAPTER 1

INTRODUCTION

1.1 Research Background

Land masses are constantly changing. Most of the time changes happen at an unnoticeable rate so that it takes thousands of years for a marked change in the landscape to occur. Wind, rain and frost destroy the rocks at the surface of the earth. Water gets into cracks in the rock. When the weather gets cold, it freezes swells and break up the rocks. Gradually the minerals are separated and disintegrate further. The action of water or bacteria causes a change in the composition of minerals and the formation of new ones. Occasionally, the resulting sediments stay in the place but they mostly slip and creep downhill or are carried away by wind or water and deposited elsewhere. Small amount of heavy minerals separate from rocks and slip downhill under the influence of gravity. As the movement slows down, their weight causes them to settle; this provides selective deposition in order of weight, giving separated valuable mineral deposits containing small amounts of heavy minerals. Fast-flowing rivers carve out deep valleys and transport sediments and pebbles; sometimes boulders are rolled along the river bed by fast-flowing water, gradually reducing them in size and making them smooth, rounded and polished. As the gradient of the riverland levels out and the river slows down, rock fragments are dropped, first the larger and then progressively the finer particles (Cuff, 1996). Only the finest grains are carried out to sea, the rest being deposited at the mouths of rivers where deltas and sand spits may form. The wave of joint created between river and sea help to break up the rocks along the coast and sediments, mostly in the form of sand. The bulk of any sand consists of grains of quartz and abundant minerals that giving advantage to the desired application.

Silica is silicon dioxide and the most abundant mineral found in the earth crust. Pure silica occurs in two forms which are quartz and cristobalite. Quartz exists in many different shapes and crystalline structures. The different structures and symmetry of silica minerals have different physical properties. Minerals having a different crystal structures are called polymorphs. It is found in a variety forms and colours of natural crystalline silica quartz crystal. Multiple combinations of the various forms of the quartz could produce hundreds of unique possibilities. Quartz also has associated minerals of numerous and varied forms which includes: amazonite a variety of microline, tourmalines especially elbaite, wolframite, pyrite, rutile, zeolites, fluorite, calcite, gold, muscovite, topaz, beryl, hematite and spodumene (Ekpunobi *et al.*, 2013).

Mica is the name given to a group of silicate minerals that have silicon and oxygen as their two major components. The most easily recognizable characteristic are thin crystal layers. Mica is often used as an insulator in electrical applications as well as machinable ceramics. Besides, feldspar is an abundant constituent in modern sands of diverse origins. These sands most commonly occur as beach sands, sand dunes and river sands. River sands tend more feldspathic compositions than either dune or beach sands (Kogel, 2006). Na-Feldspar (albite) and K-Feldspar (ortochlase or microline) are important commercial minerals typically found in granitic, syenitic and pegmatitic rocks. Na-Feldspar and K-Feldspar are generally found together with quartz, mica Fe, Ti impurities (Misra and Vibhuti, 2004). Moreover, clay is a fined-grained, natural, earthy, argillaceous material. The particle size of clays is very fine and is generally considered to be about 2 μm or less by most clay scientists. These minerals are hydrous silicates composed mainly of silica, alumina and water.

Silica is widely used in various applications. The common use of silica is in glass, ceramics and refractory. Among various the coating systems for industrial and engineering applications, glass ceramic coatings have advantages of chemical inertness, high temperature stability and superior mechanical properties. Besides discovering required functional properties such as heat, abrasion and corrosion resistance to suit particular end use requirements, the glass ceramic coatings in general also provide good adherence, defect free surface and refractoriness

(Majumdar & Jana, 2000). On the other hand, porcelain enamels are glass like protective and decorative coatings obtained by applying frit or glass for enamel coating. The frit is made by fusing acidic refractory materials such as quartz, feldspar and basic fluxes. The chemical resistance increases with increasing silica content of the frit (Sivasankar, 2008). The resistance of porcelain enamel coatings to chemical corrosion has been recognized by certain segments of industry.

1.2 Objectives

This study leads to determination of physical, chemical and mineralogical characterization of river sands. In this study, the following objectives are to be achieved in order to obtain the potential use of the river sands in River Petagas and River Kionsom in ceramic industry.

i) To determine the particle size distribution using wet sieve analysis and sedimentation test of pipette method.
ii) To identify the minerals in river sands using X-ray Diffraction.
iii) To determine the chemical composition of metal elements using ICP-OES.
iv) To compare the river sand samples between River Petagas and Kionsom for characterization listed above.

1.3 Problem Statement

Feldspar and quartz are critical minerals used as raw materials in the manufacturing of ceramic tiles and sanitary ware. Conventional enamel coatings and glass ceramic coatings are still imported into Malaysia nowadays.

1.4 Hypothesis

The rivers contain most sediments and minerals if they are located in close proximity of mountains. As we can see from Figure 1.1, River Petagas has a great potential to have high levels of sediments.

1.5 Scope of Study

A sand sample will be collected from a river and dried under the sun. Sample preparation should result in fine grain size. The sand sample will be characterized using x ray diffractometer, Philips PW 3040/ 60. Phase identification is accomplished by comparing the data (peaks and relative intensities) from specimen with peaks and relative intensities from a set of data provided by International Center for diffraction Data (ICDD). Computer searching will be more efficient since manual searching is time consuming. The function of the search-match and phase identification program is to scan the reference data base selecting the phase with highest possibility of comprising the unknown sample. However, there are some limitations of this program. Less effective search programs limit the input of user knowledge about the sample.

Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), Perkin Elmer Optima 5300 DV is used to determine the element information of sand sample. Acid digestion needs to be done on the sample since it is in solid state. Each run of a set of samples must be accompanied by a set of known standards. Concentration value can be obtained by drawing a calibration curve plotting the emitted intensities from these standards versus their known concentrations the emitted intensities from unknown samples. ICP-OES systems typically can determine more than 73 elements per minute in individual samples. However, ICP is limited by the time required for equilibration of the plasma with each new sample, typically about 15-30 seconds.

Wet sieve analysis and sedimentation test by pipette method will be employed to determine the particle size distribution of the sand sample. The sand sample to be tested is dried and passed through the series of sieves. An automatic sieve-shaker, run by an electric motor.will be used about 10 to 15 minutes. Larger particles are caught on the upper sieves while the smaller filter through to be caught on one of the smaller underlying sieves. If the sand sample is clay then it cannot be easily passed through the 75-µ sieve in dry condition. In such a case, the material is to be washed through it with water which is mixed with 2 g of sodium hexametaphosphate per litre, until the wash water is fairly clean. The material which passes through the sieve is obtained by evaporation. This is called wet sieve analysis.

On the other hand, the sedimentation test using pipette method will be carried out for the sand sample which is finer than 75-μ size. It is mixed with a known volume of distilled water in sedimentation jar. Addition of hydrogen peroxide and heating would remove organic matter. A dispersing agent, sodium hexametaphosphate is added to the solution (Venkatramaiah, 2006). The mixture is shaken thoroughly and the test is started by drawing off the sample suspension with pipette at predetermined time interval. Each of the samples taken is transferred to a sampling bottle and dried in an oven. The mass of solid can be found by weighing. The pipette analysis is very simple and inexpensive, but it is tedious and requires very sensitive weighing apparatus.

1.6 Study of Location

The red mark in Figure 1.1 shows the location of River Petagas in Putatan, Sabah. On the other hand, the green mark shows the mountain and the starting point of River Petagas flowing. The latitude and longitude of River Petagas is 5°55'0" N and 116°3'0" E. The red mark in Figure 1.2 shows the location of Kionsom waterfall in Inanam, Sabah is the starting point of River Kionsom flowing. The latitude and longitude of River Kionsom is 5°58'32" N and 116°12'52" E.

Figure 1.1 The map location of River Petagas in Putatan, Sabah.

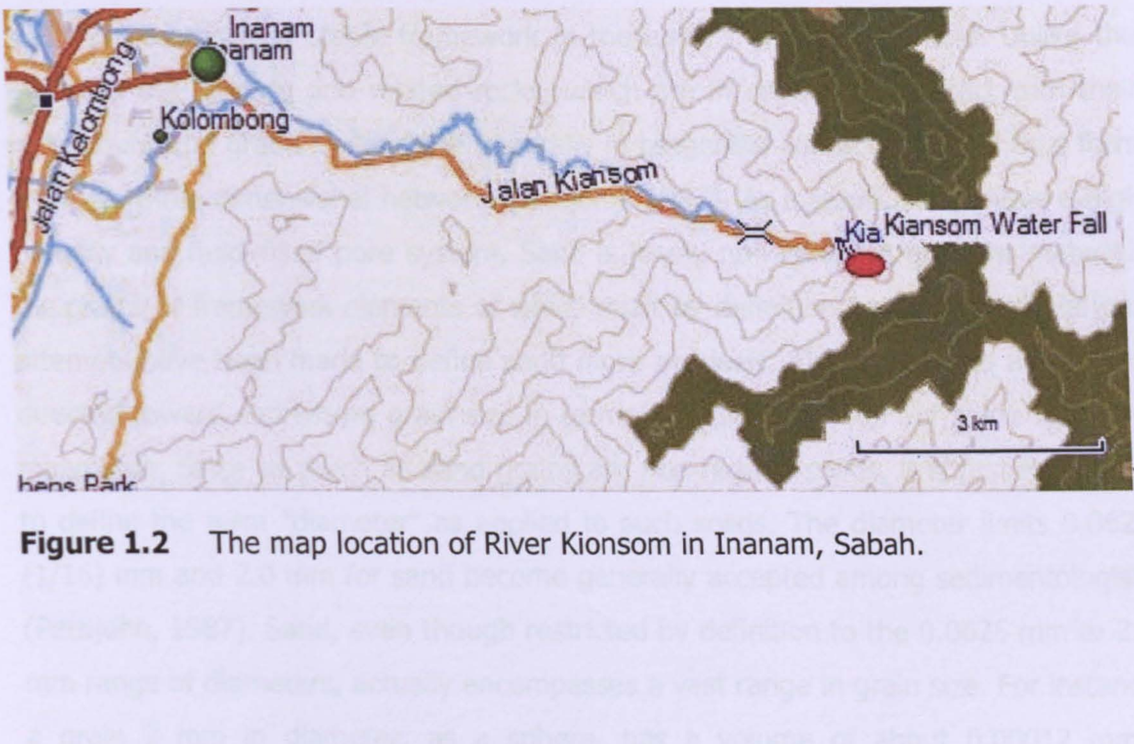

Figure 1.2 The map location of River Kionsom in Inanam, Sabah.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition of Sand

Sand and clastic sediments in general differ from the igneous and other crystalline rocks in possessing a stable framework in the earth's gravitational field. Unlike the grains of the igneous and related rocks, which are in continuous contact with their neighbours, the grains in sand are generally in tangential contact only and thus form an open, three dimensional network (Pettijohn, 1987). As a result, sands have a high porosity and fluid–filled pore system. Sand is loose, non cohesive granular material, the grains or framework elements of which must by definition be sand-sized. Various attempts have been made to define sand more precisely. These attempts are largely directed toward expressing grain size in terms of grain "diameter" of some specified magnitude. Since as much as sand grains are non-regular solids, it is first necessary to define the term "diameter" as applied to such solids. The diameter limits 0.0625 (1/16) mm and 2.0 mm for sand become generally accepted among sedimentologists (Pettijohn, 1987). Sand, even though restricted by definition to the 0.0625 mm to 2.0 mm range of diameters, actually encompasses a vast range in grain size. For instance, a grain 2 mm in diameter, as a sphere, has a volume of about 0.00012 mm^3, whereas a grain 1/16 (0.0625) mm in diameter has a volume of about 0.00012 mm^3 (Pettijohn, 1987). The larger volume is 34688 times greater than the smaller. In shorts, while sand has a 32 fold range in diameter, it has nearly a 35000 fold range in volume.

Definitions of "sand" as a deposit as distinct from a size term are diverse. No generally accepted usage is apparent from a review of the literature. Two of the various alternatives as shown in Figure 2.1, together with suggested nomenclatural solutions to the problem of sands with various admixtures of other grades. Both as a size tem and as a deposit is defined without reference to composition or to genesis.

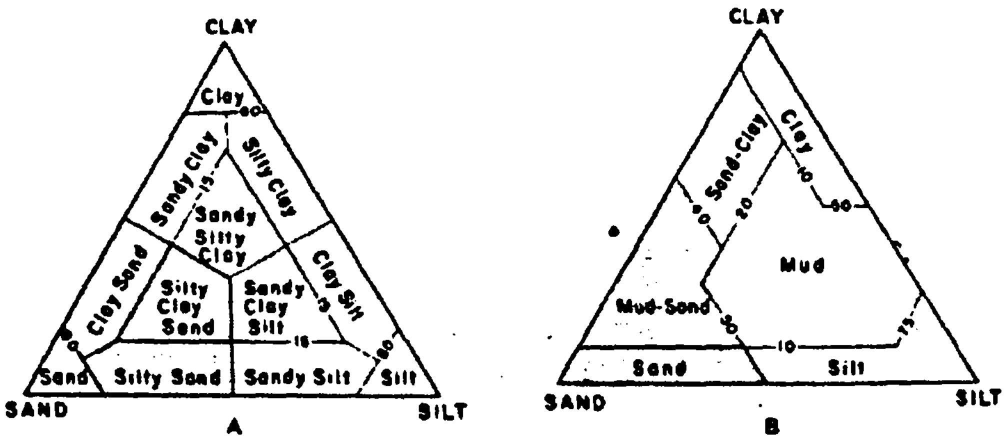

Figure 2.1 Two examples of nomenclature of mixed clastic sediments: A) symmetrical conceptual scheme and B) asymmetrical scheme, the latter based on actual usage of marine geologists (Pettijohn, 1987).

Sand may be defined in terms of certain randomly agreed upon size limits as indicated as above. However, some investigators have supposed that there are some "natural" limits which set sand apart from other materials. Wentworth (1933) presumed that the size limits of the several principal classes of clastic sediments-sand, silt, clay were genetically restricted because of the mode of derivation from the parent rock and certain fundamental modes of transport by running water. Sand, unlike the finer materials, is largely transported by rolling and sliding along the bottom or by saltation and only to a smaller extent by turbulent suspension. Bagnold (1941, p.6) placed the lower limit of sand as that which the terminal fall velocity is less than the upward eddy currents and the upper limit as that size such that a grain resting on the surface ceases to be movable either by direct pressure of the fluid or by the impact of other moving grains. He defined the lower limit of what could be called as sand as grains that are too big to be picked up "by the average surface wind," suspended and swept away as dust. In other words, the speed at which the grain falls is too slow for it to compete with wind and settle on the ground; it stays in the air. The upper limit is anything that is too big to be even nudged along the ground by the wind or the impact of flying grains (Welland, 2009).

Bagnold noted that materials designated "sand" have one peculiar characteristic which is not shared by coarser or finer materials which is called the power of self-accumulation. It utilizes the wind energy of the transporting medium to collect their scattered components together in definite heaps, leaving the intervening surface free of grains. According to Bagnold (1941, p.6), sand alone of all artificial solids has the power of self-accumulation. Two primary factors are necessary for the accumulation of sand into sand sheets: 1) an adequate supply of sand and 2) winds strong enough and persistent enough to move the sand (McKee, 1979). If these two conditions are met, large quantities of sand can be transported hundreds and even thousand of miles.

2.2 The Detrital Minerals

In this study, the term "sand" is used for unconsolidated sediment composed of sand-sized grains and "sandstone" is used to describe its consolidated equivalent. Sand-sized grains, which have been derived from mechanical-chemical disintegration of a parent rock, will be described herein as detrital.

2.2.1 Silica

Only one crystalline polymorph of SiO_2, low quartz, is thermodynamically stable under sedimentary conditions and it is one of the most common minerals in sandstones (Frondel, 1962, p. 3). Other well crystallized polymorphs such as tridymite and cristobalite are rarely found. Cristobalite and tridymite are metastable, high-temperature polymorphs of quartz that transform slowly with time to quartz. Quartz grains are the common detrital constituents of most sandstones and because quartz occurs in so many igneous and metamorphic rocks, attempts were made long ago to use them for source rock determination. Quartz is coupled with its chemical resistance to weathering and mechanical resistance to abrasion during transport (Boggs, 2009). The terms mono and polycrystalline are often used to describe quartz varieties. Monocrystalline quartz refers to grains consisting of single crystal and polycrystalline refers to aggregates of crystals. The term unit and composite are also used. Young (1976) has shown that polycrystalline quartz can develop from monocrystalline quartz during metamorphism.

The optical characteristics of monocrystalline and polycrystalline quartz, together with the nature of their inclusions, their shapes and grain boundaries are important in provenance determinations. The characters first used for differentiating quartz varieties were the nature of undulatory extinction (Mackie, 1896) and types of inclusions (Gilligan, 1920, pp. 259-260). Many quartz grains display undulatory extinction, a pattern of sweeping extinction as the stage is rotated. Undulatory extinction is caused by deformation of quartz after crystallization, which results in displacement of the C crystallographic axis in the optic plane of the grain. Extinction angles, measured by rotation of a microscope stage, may be as great as 30 degrees. Quartz having an extinction angle greater than about 5 degrees is called undulatory quartz; quartz with extinction angles of 5 degrees or less is nonundulatory quartz. Many quartz grains contain inclusions, either bubbles or mineral inclusions. The bubble s also called vacuoles, are filled with liquid, liquid and gas, or gas alone. They are distributed randomly through the quartz, in contrast to the oriented bubble trains of Bohm lamellae and may be extremely abundant or very sparse.

Chalcedony is composed of sheaflike bundles of radiating, thin fibers of quartz ~0.1 mm but range from ~20 μm to 1 mm. Microcrystalline quart consists of aggregates of nearly equant crystals that are commonly <5 μm but range to ~20 μm. Chalcedony and microquartz are the principal minerals that make up chert, which may also contain opal. Opal is rare as a detrital mineral in most sandstone but may occur as cement, particularly in volcaniclastic sandstones.

2.2.2 Feldspars

Feldspars are the most common framework mineral in sands and sandstones after quartz. Data on the feldspar content of Holocene and Pleistocene sands of North America compiled by Pettijohn (1987, p. 35) indicate that feldspar make up about 22 percent of the average river sand and 10 percent of the average beach and dune sand. The overall average content of feldspar in these Holocene and Pleistocene sands is about 15 percent. Sandstones containing more than 25 percent feldspar are considered feldspar-rich. Feldspars are commonly divided into two main groups: alkali feldspar (potassium feldspars) and plagioclase feldspars. Potassium feldspars are generally regarded to be more abundant than plagioclase feldspars in the

REFERENCES

Bagnold, R. A. 1941. *The Physics of Blown Sand and Desert Dunes*. Chapman and Hall. London.

Baileypottery. (n.d.). *Clay-About our clays and chemicals.* http://www.baileypottery.com/clay/aboutclays-chem.htm

Beblo, J. E. & Wilcox, A. 2013. An analysis of naturally derived marine clay as a ceramic medium. *Explorations,* **7**: 7-20.

Bennight, C. (n.d.). Chemistry lab cookbook. http://odplegacy.org/PDF/Operations/Science/Lab_Procedures/Cookbooks/Chemistry/Chem_ICP_Method.pdf

Boggs, S. 2009. *Petrology of Sedimentary Rocks*. Cambridge University Press. New York.

BorneoPost Online. April 24, 2012. *Putatan needs water treatment and sewerage systems – Yahya.* http://www.theborneopost.com/2012/04/24/putatan-needs-water-treatment-and-sewerage-systems-yahya/

Ceramicweb. April 2012. *Glaze and clay tutorial 5.* http://ceramicsweb.org/articles/glaze_tech/fluxes_silica_alumina.html

Cuff, Y. H. 1996. *Ceramic Technology for Potters and Sculptors*. University of Pennsylvania Press.

Cullity, B. D. 2011. *Elements of X Ray Diffraction*. BiblioBazaar. United States.

Diehl, M. W. & LeBlanc, S. A. 2001. *Early Pithouse Villages of the Mimbres Valley and Beyond: The McAnally and Thompson Sites in Their Cultural and Ecological Contexts*. Peabody Museum Press.

Doyle, L. J., Carder, K. L. & Stewart, R. G. 1983. The hydraulic equivalence of micas. *J. Sediment. Petrol.,* **53**: 643–648.

Ekpunobi, U. E., Duru, C. B. & Ogbuagu, A. S. 2013. Characterization of clay deposit in Nkisi River of Onitsha North LGA, Anambra State Nigeria. *J. Chem Chem Eng.,* **7**: 246-250.

Ekpunobi, U. E., Duru, C. B. & Obumselu, F. 2013. XRD characterization of sand deposit in river Niger (South Eastern Nigeria). *American Chemical Science Journal,* **3**(3): 287-293.

Frondel, C. 1962. *Dana's System of Mineralogy*. 7th Ed . J. Wiley & Sons. New York.

Galligan, A. 1920. The petrography of the milestone Grit of Yorkshire. *Geol. Soc. London Quartz. Jour.,* **75**: 251-294.

Gorea, M. & Benea, M. 2002. Characterization of some clays used for whiteware ceramics. *Studia Universitatis Babes-Bolyai, Geologia,* **47**: 77-84.

Grapes, R. 2010. *Pyrometamorphism.* Springer. New York.

Greenfield, S., Jones, I. L. & Berry, C. T. 1964. High-pressure plasma as spectroscopic emission sources, *Analyst,* **89**(11): 713–720.

Grim, R. E. 1953. *Clay Mineralogy.* McGraw-Hill. New York.

Hendricks, S. B. & Fry, W. H. 1930. The results of X-ray and microscopical examinations of soil colloids. *Soft Sci.,* **31**: 25-45.

Houghton, H. F. 1980. Refined technique for staining plagioclase and alkali feldspars in thin section. *J. Sediment. Petrol.,* **50**: 629–631.

JCPDS-International Centre for Diffraction Data & American Society for Testing and Materials. 1981. *Selected powder diffraction data for minerals: Data book. Supplement.* International Centre for Diffraction Data.

Kogel, J. E. 2006. *Industrial Minerals & Rocks: Commodities, Markets, and Uses.* SME. United States.

Kotoky, P., Bezbaruah, D., Baruah, J., Borah, G. C. & Sarma, J. N. 2006. Characterization of clay minerals in the Brahmaputra river sediments in Assam,India. *Current Sci.,* **91**(9): 1247–1250.

Majumdar, A. & Jana, S. 2001. Glass and glass-ceramic coatings, versatile materials for industrial and engineering applications. *Bull. Mater. Sci.,* **24**(1): 69–77.

Mackie, W. 1896. The sands and sandstones of Eastern Moray. *Edinburg Geol. Soc. Trans.,* **7**: 148-172.

Mathai, M. P. & Simon, A. 2004. Water diffusion through pottery discs of varying porosity. *Journal of Tropical Agriculture,* **42**: 63-65.

McKee, E. D. 1979. *An Introduction to The Study of Global Sand Seas.* University Press of the Pacific.

Misra, G. V. R. & Vibhuti, N. 2004. *International Seminar on Mineral Processing Technology (MPT-2004).* Allied Publishers. New Delhi.

Naik, P. V. 2010. *Principle of Physics.* PHI Learning Pvt. Ltd. New Delhi.

O'Flaherty, C. A. 2002. *Highways. Fourth Edition.* Elsevier. United States.

Ogbebor, J. O., Okeimen, F. E. & Okwu, U. N. 2010. Characterization of Ugbegun clay deposit for its potentials. *International Journal of Chemistry Research,* **1**(2): 22–23.

Osabor, V. N., Okafor, P. C., Ibe, K. A. & Ayi, A. A. 2009. Characterization of clays in Odukpani, south eastern Nigeria. *African Journal of Pure and Applied Chemistry,* **3**(5): 79–85.

Pettijohn, F. J., Potter, P. E. & Siever, R. 1987. *Sand and Sandstone.* 2nd edn. Springer-Verlag. New York.

Plog, S. 1980. Village autonomy in the American Southwest: An evaluation of the evidence. *In Models and Methods in Regional Exchange,* edited by Robert E. Fry, pp. 135-146, SAA Papers, No. 1. Society for American Archeology, Washington, D. C.

Ranjan, G. & Rao, A. S. R. 2007. *Basic and Applied Soil Mechanics.* New Age International. New Delhi.

Rapp, G. R. 2002. *Archaeomineralogy.* Springer. New York.

Rüdel, H. Kösters, J. & Schörmann, J. (n.d.). Determination of the elemental content of environment samples using ICP-OES. http://www.ime.fraunhofer.de/content/dam/ime/en/documents/AE/SOP_ICP-OES_en.pdf

Sivasankar. 2008. *Engineering Chemistry.* Tata McGraw-Hill Education. New Delhi.

Venkatramaiah, C. 2006. *Geotechnical Engineering.* New Age International. New Delhi.

Welland, M. 2009. *Sand: The Never-Ending Story.* University of California Press. United States.

Wendt, R. H., and Fassel, V. A. 1965. Induction-coupled plasma spectrometric excitation source. *Anal. Chem.,* **37**(7): 920–922.

Wentworth, C. K. 1933. Fundamental limits to the sizes of clastic grains. *Science,* **77**: 633-634.

Worrall, W. E. 1986. *Clays and Ceramic Raw Materials.* Springer. New York.

Young, S. W. 1976. Petrographic textures of detrital polycrystalline quartz as an aid to interpreting crystalline source rocks. *J. Sediment. Petrol.,* **46**: 595–603.