



Integrating Density and Durability in Assessing Rock Types: Case Study of Nigeria Oldest Sedimentary Basin



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Abstract

Variation of rock densities and durability with rock petrologic types has been evaluated. The evaluation followed collecting ten rock samples of different petrologic types viz: igneous rocks, pelitic argillites and contact metamorphic rocks from quarry units of Albian Asu-River Group. The rock samples were each divided into two portions and the first portion subjected to density tests to determine their matrix and bulk densities. The second portion was subjected to short soaking and partial drying degradability test to determine their susceptibility to intra-seasonal degradability (durability). Results of the density tests show that the difference in matrix and bulk density ($\rho_{\text{mat-bulk}}$) for the pelitic argillites ranges from 0.09 to 0.12g/cm³; $\rho_{\text{mat-bulk}}$ for the contact metamorphic rocks ranges from 0.04 to 0.07g/cm³ while $\rho_{\text{mat-bulk}}$ for the igneous rocks ranges from 0.01 to 0.01g/cm³.

Results of the degradability test show that the percentage of mass lost (M_{lost}) by the pelitic argillites ranges from 11.63 to 26.76%; M_{lost} by the contact metamorphic rocks ranges from 0.12 to 0.8% while M_{lost} by the igneous rocks ranges from 0.00 to 0.03%. The results revealed that amongst the analyzed rocks, pelitic argillites have the highest $\rho_{\text{mat-bulk}}$ and least durability; the contact metamorphic rocks have intermediate $\rho_{\text{mat-bulk}}$ and durability while the igneous rocks have least $\rho_{\text{mat-bulk}}$ and highest durability. This work has shown evidence that densities and durability can serve as relative indices in distinguishing different rock petrologic types.

Keywords: Bulk density; Matrix density; Degradability; Pelitic argillite; Durability

Introduction

Durability is the resistance of rock to degradation (weathering) caused by agents like water, fluctuating temperature, organism or chemical substance. Works by Cobanoglu et al. [1] & Benavente [2] revealed that rock wetting (water absorptivity of rock), which also enhances the effect of other weathering agents like chemical substance, is mostly controlled by the effective porosity, density and mineralogy of the rock. The effective porosity of the rock is actually controlled by the rock texture (grain sizes and type of grain cementation). For example, Koch et al. [3] & Garci-del-Cura et al. [4] discovered that loosely compacted calcite sparitic coarse-grained rocks have higher effective porosity and water absorptivity and thus are more susceptible to deterioration (less durable) than highly compacted micritic fine-grained rocks. According to Tarhan [5] & Siegesmund [6], rock density is of two types namely bulk density and matrix density and is controlled by rock porosity and mineralogy respectively. According to the authors, rocks of high porosity have low bulk density while rocks composed mainly of dense minerals will have high matrix density and vice versa. Works

by Strohmeyer [7] & Hoffmann [8] further revealed that matrix density is always higher than bulk density and the difference between them (matrix and bulk density) is generally least for igneous rocks and highest for sedimentary rocks, which are both related to the petrologic origin of the rock in question.

The present work assesses the variation of rock densities and durability with the rock type using rocks of the Nigeria oldest sedimentary Basin. It is further evidence validating the relative inter-relationship amongst the density, durability and petrologic types of different rocks. Also, the work shows that density and durability can be used as preliminary tool in assessing rock petrologic types.

Regional Geology

Rocks used for this study were collected from five designated rock quarry units of the Albian Asu-River Group, which is the oldest stratigraphic unit of the Benue Trough. Benue Trough evolved as third failed arm of a triple rift system in the Neocomian/early

Gallic Epoch [9,10]. According to Olade [11], the rift formed due to violent mantle plume upwelling that resulted to stretching, uplift, faulting and subsidence of the major crustal blocks in Aptian/early Albian Stage. Murat [12] & Ojoh [13] reconstructed that the subsidence was spasmodic and that the upwelling reactivated in early-middle Turonian Stage after the basin had received its first phase of sediments, the Albian Asu-River Group, from bordering Basement complex. According to Nwachukwu [14] & Ofoegbu [15], the Benue Trough experienced another tectonic event in the Santonian Stage, which resulted to fracturing, uplifting and folding

of the Lower (southern) part. These three tectonic upheavals were all characterized by volcanic eruptions/intrusions. Obiora [16] & Obiora [17] reported that these volcanic ejecta intruded the low-grade regionally metamorphosed Asu-River Group at different places giving raise to igneous and contact metamorphosed rocks.

Study Methodology

A total of ten rock samples were collected from designated units of five quarries occurring in the Albian Asu-River Group of Southeastern Nigeria (Figure 1).

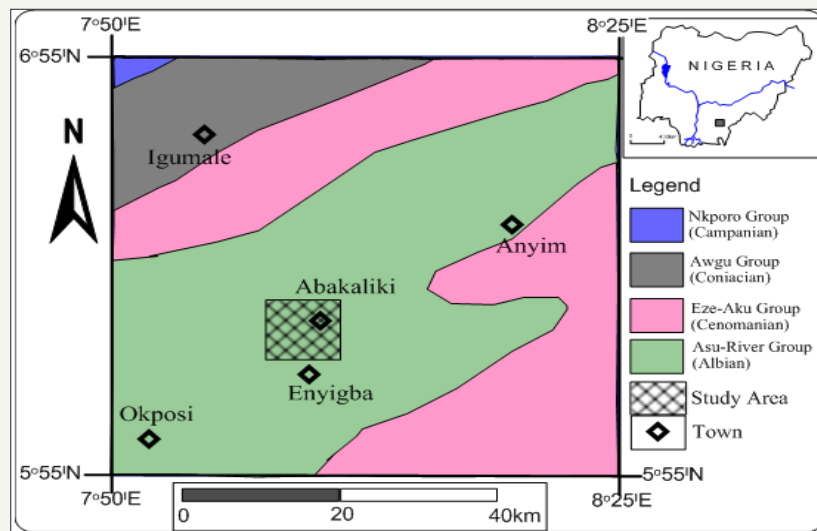


Figure 1: Geologic map of the study area.

The samples were each divided into two portions and the first portion subjected to matrix and bulk density tests following the weighing and water immersion methods described by Balco [18]. Three tests were done using three test samples for each of matrix and bulk density tests and each of the averages calculated as the matrix and bulk density of the sample.

The second portion was subjected to version A degradability test following the 14 cyclic short soaking and partial drying

methods described by Ugwoke [19] & Okogbue [20] to simulate and ascertain the effect of wetting and partial drying that occurs during wet season in Nigerian climate.

Results and Discussion

The matrix (ρ_{mat}) and bulk densities (ρ_{bulk}) of the rock samples are shown in Figure 2a while the density differences ($\rho_{mat-bulk}$) are shown in Figure 2b.

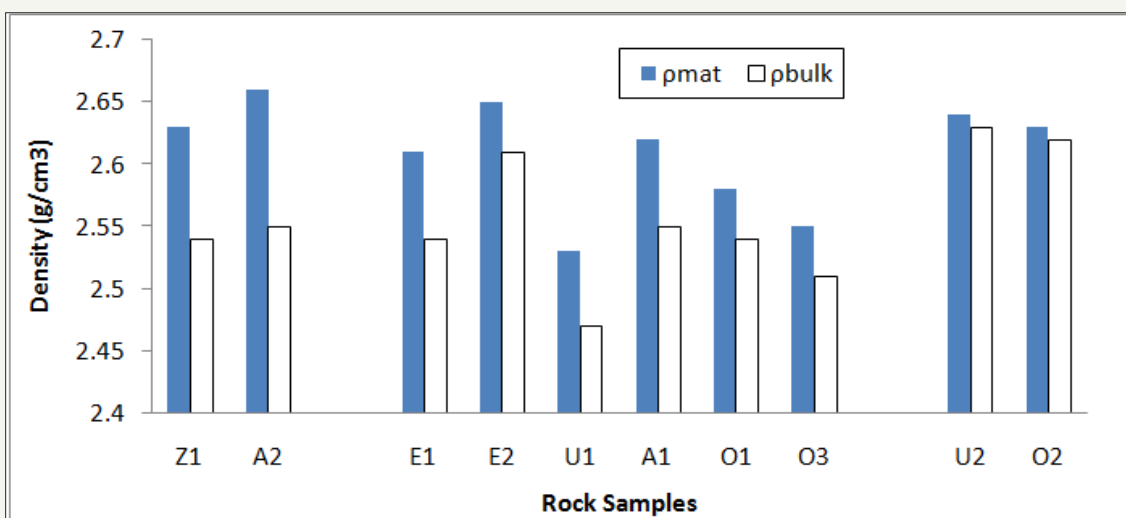


Figure 2a: Matrix and bulk densities of the rock samples.

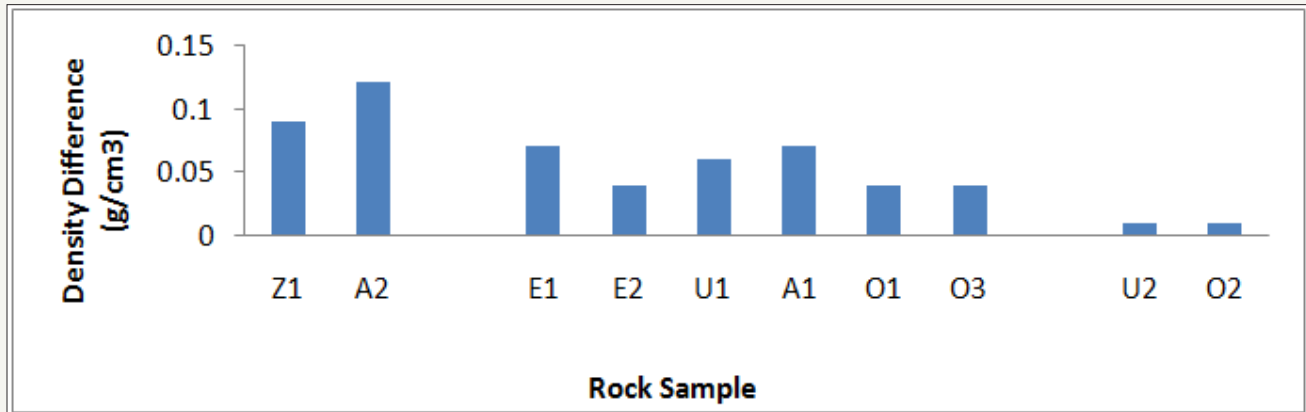


Figure 2b: Density difference ($\rho_{\text{mat-bulk}}$) of the rock samples.

Figure 2a reveals that, for each of the analyzed samples, matrix density is more than bulk density which agrees with the findings of Strohmeyer (2003) and Hoffmann and Siegesmund (2007). There is no clear variation amongst the matrix density of the rock samples but the bulk density of samples O2 and U2 are clearly more than the bulk density of other samples. Also, as shown in Figure 2b, the difference in matrix and bulk density ($\rho_{\text{mat-bulk}}$) varies among the samples. It ($\rho_{\text{mat-bulk}}$) is least in the cases of U2 and O2; highest in those of A2 and Z1 and intermediate in the other 6 samples. Following work by Hoffmann and Siegesmund (2007), as stated earlier, these variations in difference of matrix and bulk densities suggest that the analyzed rocks are not of the same petrologic origin/type. This is in concordance with works of Ugwoke (2014) and Okogbue and Ugwoke (2015) that the analyzed rocks are not of the same petrologic type. According to the authors, samples U2 and O2 are igneous rocks; A2 and Z1 are pelitic argillites, E1, E2, A1 and U1 are hydrothermally altered pelites while O1 and O3 pelitic hornfels.

It implies that rocks of different petrology types have varying relative $\rho_{\text{mat-bulk}}$. In the present work, argillites, which are high grade sedimentary rocks, have the highest $\rho_{\text{mat-bulk}}$; hornfels and hydrothermally altered pelites, which are contact metamorphic rocks, have intermediate $\rho_{\text{mat-bulk}}$ while igneous rocks have lowest $\rho_{\text{mat-bulk}}$. Understandably, these different rock types are also expected to show varying degradability (durability).

The cumulative percentage of rock mass lost in the degradability tests is shown in Figure 3a and the degradability history curves of the samples that showed significant ($\geq 1\%$) degradation is shown in Figure 3b. 1% was used as the significant degradation in order to be as conservative as possible.

It can be seen from Figure 3a that the rock samples showed varying degrees of degradation; only the pelitic argillites (A2 and Z1) showed significant ($< 1\%$) degradation. Based on findings of Koch et al. [3], Garci-del-Cura et al. [4] & Ugwoke [19], the varying degradation shown by rocks is due to difference effective porosity and/or mineralogy.

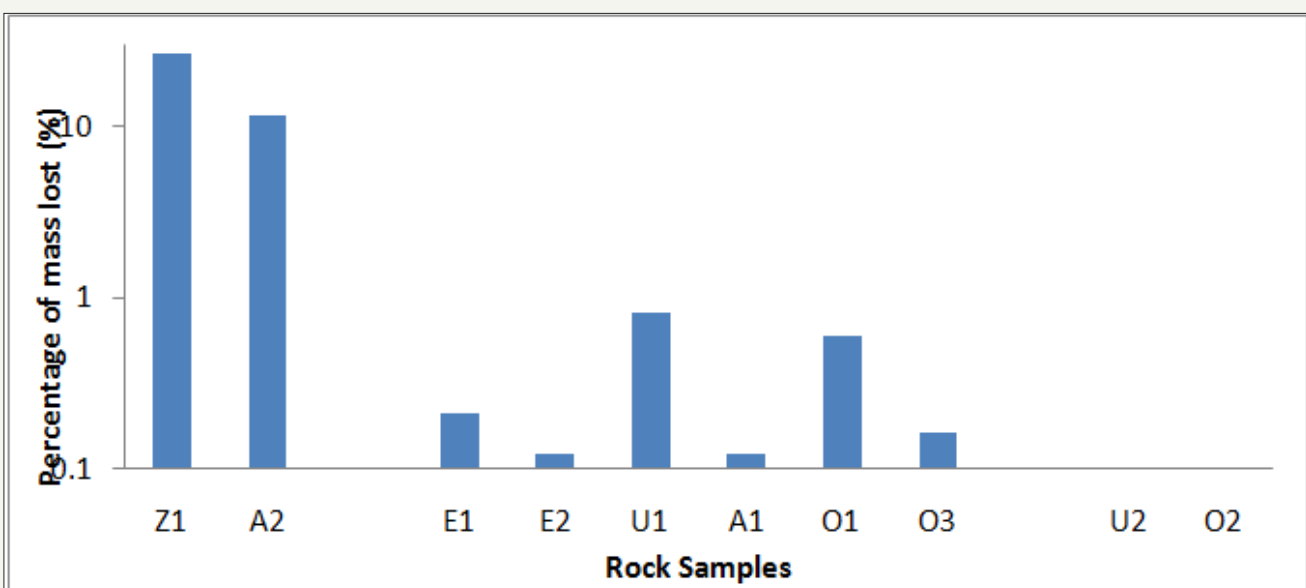


Figure 3a: Cumulative percentage of mass lost.

As these two properties (effective porosity and mineralogy) are integral aspect of a rock, this is an additional indication that the studied rocks are of different petrologic types agreeing with earlier assertion that the petrologic type of the rocks also controls their durability. Comparing Figure 3a & 2b, it can be seen that rocks that showed the highest degradation have also the highest difference in matrix and bulk densities ($\rho_{\text{mat-bulk}}$) and vice versa. This is to say that durability (inverse of degradation) of rock has an inverse relationship with $\rho_{\text{mat-bulk}}$ of the rock. The factor controlling this relationship is the rocks' petrologic type.

Figure 3b reveals that none of the samples started degrading in the first cycle; both started degrading in subsequent cycle. This shows that degradation of the rocks was caused by repeated wetting (soaking) and drying and not by ordinary wetting or drying. The sample that showed highest initial degradation is not the sample that showed the highest cumulative deterioration. Sample A2 showed the highest initial degradation while Z1 showed the highest cumulative degradation. This indicates that rocks that first show evidence of degradation (weathering) due to repeated wetting and drying are not necessarily the most susceptible to degradation.

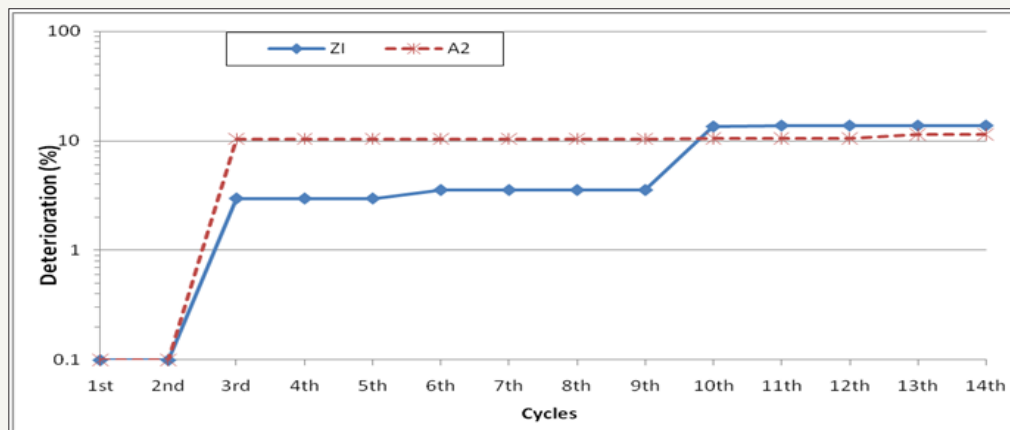


Figure 3b: Degradability history curve of the samples that showed significant deterioration.

Conclusion

The following conclusions are drawn from this work:

- Rock matrix and bulk density difference ($\rho_{\text{mat-bulk}}$) and durability can be used as preliminary relative indices in distinguishing different rock petrologic types.
- Durability of rocks has an inverse relationship with the difference in matrix and bulk densities ($\rho_{\text{mat-bulk}}$) of rocks. This relationship is attributed to be also controlled by the rocks' petrologic types.
- Rocks of different petrologic types show varying relative difference in matrix and bulk densities ($\rho_{\text{mat-bulk}}$). In present work, the pelitic argillites showed the highest $\rho_{\text{mat-bulk}}$ while the igneous rocks showed the least $\rho_{\text{mat-bulk}}$.

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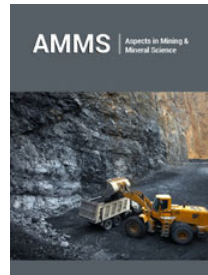
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