Clay Typing for Sustainable Road Constructions in Some Parts of Niger Delta Using Magnetic Susceptibility Signature Technique

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Abstract
The dilapidated states of roads in the Niger Delta are major concerns on Governments that desire the best for her citizens. Several strategies have been employed by successive Governments in the region but none was sustainable. This work elucidates how such poor conditions can be averted and efficient and sustainable roads ensured in Rivers state by clay typing using magnetic susceptibility signature technique. Samples were randomly collected at points in two sources A and B and on two roads as sites X and Y proposed to be constructed. Volume Magnetic Susceptibility (VMS) measurements (S.I unit) were taken on the samples using MS2E Bartington instrument with in–built Bartsoft software and their corresponding Magnetically Derived Illite (MDI) contents (%) determined using Potter's Two Mineral Mixture Model. The Magnetically Derived Illite (MDI) contents (%) of the sources and sites were plotted against depth (m) and their spectra comparatively analysed for compatibility. The Volume Magnetic Susceptibility (VMS) ranges from (0.8-118.0) x 10^{-5} for Source A and (45-300) x 10^{-5} for Site X,(7.6-227.0)x10^{-5} for Source B and (56.5-183.8)x 10^{-5} for Site Y. The MDI ranges from 3.8%-300.0% for Site X and 14.1%-290.5% for Site X. The results demonstrated that clays of source A and Site X are compatible and economical likewise those of Source B and Site Y while the combinations of Source A on Site Y and Source B on Site X are incompatible and uneconomical. The essentials of this research can be employed by construction companies operating in the Niger Delta.

Key Words: *Volume Magnetic Susceptibility (VMS) Magnetically Derived Illite (MDI) Content, Compatibility, and Sustainability.*

Introduction

Clay is one of the oldest building materials on earth, among other ancient, naturally occurring geologic materials such as stone and organic material like wood. The term clay is referred to naturally occurring materials made primarily of fine–grained minerals that become plastic when mixed with a certain amount of water and hardens when fired or dried (Scarce et al., 2005). By structure, clay minerals are composed of planes or layers of cations, arranged in a sheet format, which may be tetrahedral or octahedral, combined with oxygen. They are described as 2:1 if they are composed of two tetrahedral and one octahedral or 1:1 if they are composed of alternating unit of tetrahedral and octahedral sheets. They form rocks known as shales, a significant part in nearly all sedimentary rocks. Its small size and special crystal structure provides platform for cation exchange, plasticity and swelling when wet, and low permeability (Hillers, 2003, Potter and Ivanhnenko, 2012).

The quality of a clay sample is basically controlled by depositional factors such as grain size, pore geometry, pore type, sorting and clay minerals; thermo-diagenetic factors such as compaction, grain dissolution during compaction and phase transformation. Clay minerals can be diamagnetic, paramagnetic (illite, smectite etc); ferromagnetic, ferrimagnetic, antiferromagnetic etc. based on their magnetic susceptibility. Magnetic Susceptibility is the degree to which a material can be magnetized in the presence of an external magnetic field (**B**). It is the ratio of the magnetization **M** to the magnetising field **B** expressed either in m^3/Kg as mass magnetic susceptibility $\boldsymbol{\chi}$ (MMS) or in S.I unit as Volume Magnetic Susceptibility $\boldsymbol{\kappa}$ (VMS). Generally, soils are heterogeneous assemblage of minerals. Magnetic susceptibility signatures are characteristics response of the soil type and contents of its mineralogy.

Every responsible government is entitled to provide efficient and sustainable roads for her citizenry in order to ease transportations of goods, persons and other activities of human endeavours which in turns can boost the economy of the country. It is of primary concern that the quick dilapidations of constructed roads in the Niger Delta are consequences of soil type, climatic variables, frequent heavy duty vehicular movements and use of substandard construction material with poor maintenance culture. Several efforts have been geared towards proffering solutions to these poor conditions by using established geotechnical tests which includes Atteberg test; cone penetration test etc. yet the results are indifferent. In addition, successes have been recorded on the use of magnetic susceptibility technique in reservoir and other geophysical and geotechnical investigations but none is geared towards the sustainability of road construction in Nigeria. Moreover, this research is aimed at ensuring efficient and sustainable road constructions in some part of Rivers state using magnetic sustainability signature technique.

Clays and Clay Minerals

Clays are small size ($< 2\mu m$), plastic geological deposits mainly composed of phyllosilicate minerals containing variable amount of water trapped in the mineral structure. Clays are plastic due to their water contents and become hard, brittle and non-plastic upon drying or firing (Scarce *et al.*, 2005). They form rocks known as shales which are prominent parts in nearly all sedimentary rocks. The small size of the particles and the special crystal structures gives clay materials special properties, such as cation exchange capabilities, plastic behavior when wet, swelling behavior, and low permeability (Hillier, 2003). They are also made of mixture of finer grained clay minerals and clay-sized crystals of other minerals such as quartz, carbonates, and metal oxides.

Clay minerals are octahedral sheets sandwiched in tetrahedral sheets composed of planes or layers of cations combined with oxygen. They are described as 2:1 if they are composed of two tetrahedral and one octahedral sheet or 1:1 if they are composed of alternating unit of tetrahedral and octahedral sheet. Geochemically, clay minerals are hydrous aluminum phyllosilicate, intercalated with variable amounts of iron, magnesium, alkali metals, alkaline earths, and other cations found on or near some planetary surfaces. Clay minerals form in the presence of water and have been important constituents of soils and fine grained sedimentary rocks (Nadeau, 2000; Hillier, 2003).

Clays are grouped into four; kaolinite, Montmorillonite-smectite, illite, and chlorite clays. (Churchman, 2016). Kaolinites are one of the most common groups of minerals that are hydrous aluminum silicates with chemical formula($Al_2\,Si_2\,O_5\,(OH)_2$) produced through the chemical weathering of feldspar .Dickite, Nactrite, Halloysite and Odinite are other members of this group. They are usually soft and white, grey, yellow, dark brown coloured earthly materials with a low shrink-swell capacity and low cation exchange capacity of 1-

15meq/100g.Structurally, having their layered silicate mineral, with one tetrahedral sheet of silicate (SiO_4) linked through oxygen atoms to one octahedral sheet of aluminum (AlO_6). (Pohl, 2011; Shu, 2012).

Montmorillonite is a very soft microscopic phyllosilicate precipitate of 2:1 clay crystals. It is white, pale pink, blue, yellow, red or green coloured member of the Smectite group having greater than 50% octahedral charge. Smectite group consist of clays which have the property to swell in contact with water. Other members include beidellite, nontronite, hectorite, saponite and sauconite. Crystals of Montmorillonite clay are translucent and loosely bound hydrated sodium aluminum magnesium silicate hydroxides $(Na,Ca)_{0.33}(Al,Mg)_2Si_4O_{10}(OH)_2.nH_2O$.Their loosely bound structural characteristic inherently causes them to be more permeable and higher shrink –swell capacity than Kaolinite. They are often intercalated with chlorite, muscovite, illite, and kaolinite (Lloyd, 2011).

Illite is a non- expanding small size monoclinic grey phyllosilicate precipitate or layered aluminum-silicate crystalline clay mineral having a 2:1 clay silica tetrahedron layers. It is formed through the weathering of muscovite and feldspar, and identified usually by X-ray diffraction or SEM analysis due to their microscopic nature. It is common in sedimentary rock, sediments, and soils and in some low grade metamorphic rocks. Illite has smaller cation exchange capacity (20-30 meq/100g) quite higher than that of kaolinite (Pironon *et al.*, 2003)

Magnetic Properties of Clay

Magnetism in clay can be classified as diamagnetic, paramagnetic, ferromagnetic, and antiferromagnetic, ferrimagnetic and spin scanted antiferromagnetic in terms of their behaviour and are distinguished by the values and polarity of their magnetic susceptibilities. Diamagnetism is exhibited in minerals whose outermost shells have completely filled electrons; the presence of an external magnetic field changes the spinning and the angular momentum of the electron. These changes cause the electron to undergo Lamoure precession that oppose and reduces the strength of the external magnetic field. The magnetic susceptibilities of diamagnetic minerals are very low and negative. Quartz, calcite, feldspar and dolomite are examples of diamagnetic minerals (Potter *et al*, 2008; Spaldin, 2006).

The diamagnetic susceptibilityk_D is expressed as (Spaldin, 2006):

$$\kappa_D = \frac{-\mu_0 NZe^2}{6m_e}\left\langle r^2 \right\rangle_{av} \qquad \text{..1}$$

Where μ_0 = the magnetic permeability of free space,

N = the number of atoms per unit volume,

m_e= the mass of electron = the total number of electrons,

e = the electronic charge (1.6x10^{-19}C) and r = the Orbital radius of the electrons. The equation by Spaldin implies that the susceptibility is dimensionless, negative, weak and independent of temperature (Salim, 2012).

Paramagnetic behavior is exhibited in minerals that have a net magnetic moment as a result of unpaired electrons in their partially filled orbits. Their magnetic susceptibilities are reversibly very low and positive and temperature dependent. However, their individual magnetic moments do not interact magnetically which each other; hence each atom of a paramagnetic material has magnetic moments which are randomly distributed. Paramagnetic susceptibility depends on the concentration of paramagnetic minerals present in a soil sample; paramagnetic contribution is usually higher than diamagnetic contribution in a soil (Salim, 2012).

Rodriquez *et al*, (2012) gives the paramagnetic susceptibility, k_P

$$\kappa_P = \frac{C}{T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{2}$$

Where k_P= paramagnetic susceptibility, C = the characteristics of the rock material,
T= absolute temperature.

Ferromagnetism is exhibited by minerals whose magnetic moments exhibit very strong interactions with each other given rise to parallel or antiparallel orientation of their magnetic moments (Ali, 2009). This produces a strong magnetization even in the absence of an applied magnetic field; minerals of this type are magnetite, and haematite (Okiwelu *et al.*, 2012, Dubey, 2014).

Materials and Methods

The Volume Magnetic Susceptibility (VMS) measurements were taken using MS2E Bartington instrument/sensor (Plate 3.1a) connected to a MS2 meter through a TNC-TNC coaxial cable that is hooked up with a laptop that allow automatic transfer of all measurements into a spreadsheet format by Bartsoft software and in the order of 10^{-6}SI units on the soil samples collected in the field. The MS2E Bartington instrument is a high-resolution and very sensitive volume magnetic susceptibility-measuring instrument with an area response of 3.8mm by 10.5mm and a depth response of 50% at 1mm or 10% at 3.5mm (www.bartington.com/retrieved 3 September2017).

Plate 1: MS2E Bartington sensor (www.bartington.com/retrieved 3 September2017).

The followings are the measures taken in order to ensure accurate results:

1. The soil samples were collected evenly in the fields at different points to ensure unbiased representation of the whole source population(soil)
2. Measurements were taken on the samples at insitu conditions.
3. The meter was allowed to warm up for about five minutes to activate the sensitivity of the sensor before measurements.
4. The sensor was calibrated by holding it in air for about 10seconds to record the magnetic susceptibility of the laboratory

5. For full induction, the sensor was placed on the sample for a minimum period of 10 seconds
6. The instrument was checked for drift and possibly drifts correction effected between successive measurements, by suspending the sensor in air whose magnetic susceptibility is equal to zero.

The measured unprocessed volume magnetic susceptibility values represent the total volume magnetic susceptibility κ_T at each measurement depth on the samples. These values represent the combined response or characteristic signal from all the minerals at each measurement depth.
The Volume Magnetic Susceptibility data were processed using Potter's Two Mineral Mixture equations (Potter, 2007) in equation (3.1) modified by Asime (2014) in equation (3.2):

$$F_I = \frac{(\kappa_T - \kappa_Q)}{(\kappa_I - \kappa_Q)} \times 100\% \qquad \text{...3}$$

$$F_I = 0.2343(\kappa_T + 14.3) \qquad \text{...4}$$

Where F_I = magnetically derived illite (MDI) content (%), κ_I = Volume magnetic susceptibility of illite, κ_Q = volume magnetic susceptibility of quartz, and κ_T = total volume magnetic susceptibility of the sample at measured depth which is the value the instrument record. The values for the volume magnetic susceptibility of illite κ_I and that of quartz κ_Q will be extracted from (Hunt *et al.*, 1995; Potter and Ivanhnenko, 2008) in (Table 3.1) for the computation of magnetically derived illite content (%) and magnetically derived quartz.

Table 1: Common soil minerals, their densities and Magnetic susceptibilities (Hunt *et al*, 1995; Potter and Ivanhnenko, 2008)

Mineral Types	Minerals	Mass Magnetic Susceptibilities (MMS)*$10^{-8}m^3Kg^{-1}$	Densities*$10^3(Kgm^{-3})$	Volume Magnetic Susceptibility(VMS)* 10^{-5}SIUnit
Diamagnetic Matrix Mineral	Quartz	-0.50 → -0.60	2.6	-1.3 → -1.56
	Feldspar	-0.49 → -0.67	2.65	-1.299 → -1.776
Paramagnetic Permeability Controlling Clay Minerals	Illite	15	2.75	41.25
Scanted Antiferromagnetic Mineral	Haematite	10 → 760	5.26	52.6-3997.6

The determined magnetically derived illite content (%) of the control (site clay) materials was plotted against depth as logs likewise those of the source material on the same plot to have two spectra. Finally, the trends of the two spectra were examined to determine the compatibility of the source material and the site clay.

Results

Table 2: Magnetically Derived Illite contents MDI (%) of source and sites clays with depths (m) for Road X

Depth(m)	VMS SI Unit	MDI(sourc (%) A	VMS(SITE)	MDI(SITE)
0.2	159.1024	43.54134	204.1024	51.17168
0.3	16.3869	7.705481	61.3869	17.73344
0.4	83.8491	24.64524	128.8491	33.53983
0.5	38.21283	13.18597	83.21283	22.84726
0.6	10.7719	6.295554	55.7719	16.41785
0.7	17.65215	8.023185	62.65215	18.02989
0.8	2.33073	4.175976	47.33073	14.44008
0.9	1.8774	4.062145	46.8774	14.33386
1	0.912405	3.819835	45.91241	14.10777
1.1	2.082768	4.113713	47.08277	14.38198
1.2	0.8155	3.795502	45.8155	14.08506
1.3	13.7798	7.050838	58.7798	17.1226
1.4	1.7448	4.028849	46.7448	14.3028
1.5	1.57864	3.987127	46.57864	14.26387
1.6	1.07899	3.861664	46.07899	14.1468
1.7	2.2407	4.15337	47.2407	14.41899
1.8	8.67312	5.76855	53.67312	15.9261
1.9	1.1434	3.877838	46.1434	14.16189
2	38.9456	13.36997	83.9456	23.01894
2.1	4.7987	4.795684	49.7987	15.01833
2.2	21.6951	9.03837	66.6951	18.97715
2.3	5.8485	5.059288	50.8485	15.26429
2.4	1.0154	3.845697	46.0154	14.1319
2.5	6.552	5.235937	51.552	15.42912
2.6	10.8419	6.313131	55.8419	16.43425
2.7	217.8398	58.2903	262.8398	64.93386
2.8	10.7625	6.293194	55.7625	16.41564
2.9	4.2423	4.655972	49.2423	14.88796
3	4.1005	4.620366	49.1005	14.85474
3.1	3.7076	4.521708	48.7076	14.76268
3.2	3.2475	4.406177	48.2475	14.65488
3.3	174.3759	47.37652	219.3759	54.75026
3.4	483.9917	125.121	528.9917	127.2932
3.5	542.2434	139.748	587.2434	140.9416
3.6	498.9216	128.8699	543.9216	130.7913
3.7	168.655	45.94	213.655	53.40986
3.8	1180.554	300.0278	1225.554	290.4977
3.9	942.6045	240.2787	987.6045	234.7462
4	1037.382	264.0774	1082.382	256.9526

(Source: Field work, 2017)

Table 3: Magnetically Derived Illite (MDI) Content (%) of source and site clays with depths (m) for Road Y

Depth(m)	VMS*10^- SI Unit	MDI (%)	VMS(SITE)	MDI(SITE)
0.3	68.1074	20.6925	71.6925	20.14804
0.4	64.8087	19.86419	70.86419	19.95397
0.5	114.4728	32.33485	83.33485	22.87585
0.6	89.9993	26.18955	77.18955	21.436
0.7	48.8417	15.85488	66.85488	19.01459
0.8	19.5659	8.503727	59.50373	17.29221
0.9	33.1324	11.91028	62.91028	18.09037
1	35.0221	12.38478	63.38478	18.20154
1.1	37.6073	13.03392	64.03392	18.35364
1.2	34.9422	12.36472	63.36472	18.19684
1.3	47.8137	15.59675	66.59675	18.95411
1.4	35.0174	12.3836	63.3836	18.20127
1.5	38.7011	13.30858	64.30858	18.41799
1.6	146.4395	40.36169	91.36169	24.75653
1.7	182.9691	49.53427	100.5343	26.90567
1.8	97.1291	27.97985	78.97985	21.85547
1.9	38.7967	13.33258	64.33258	18.42361
2	221.7451	59.27092	110.2709	29.18697
2.1	153.0878	42.03108	93.03108	25.14767
2.2	227.2134	60.64401	111.644	29.50868
2.3	51.5046	16.52354	67.52354	19.17125
2.4	48.9502	15.88213	66.88213	19.02097
2.5	19.7663	8.554048	59.55405	17.304
2.6	98.2397	28.25872	79.25872	21.92081
2.7	51.4775	16.51673	67.51673	19.16966
2.8	94.9093	27.42246	78.42246	21.72487
2.9	27.3912	10.46866	61.46866	17.7526
3	11.5404	6.488524	57.48852	16.82005
3.1	10.4798	6.222208	57.22221	16.75765
3.2	11.2249	6.409302	57.4093	16.80149
3.3	9.5582	5.990794	56.99079	16.70343
3.4	8.6545	5.763875	56.76387	16.65027
3.5	7.6232	5.504916	56.50492	16.58959
3.6	50.02619	50.02619	101.0262	27.02093
3.7	132.8325	132.8325	183.8325	46.42244
3.8	19.83	19.83	70.83	19.94596
3.9	20.31	20.31	71.31	20.05842
4	37.1903	37.1903	88.1903	24.01348

(Source: Field work, 2017)

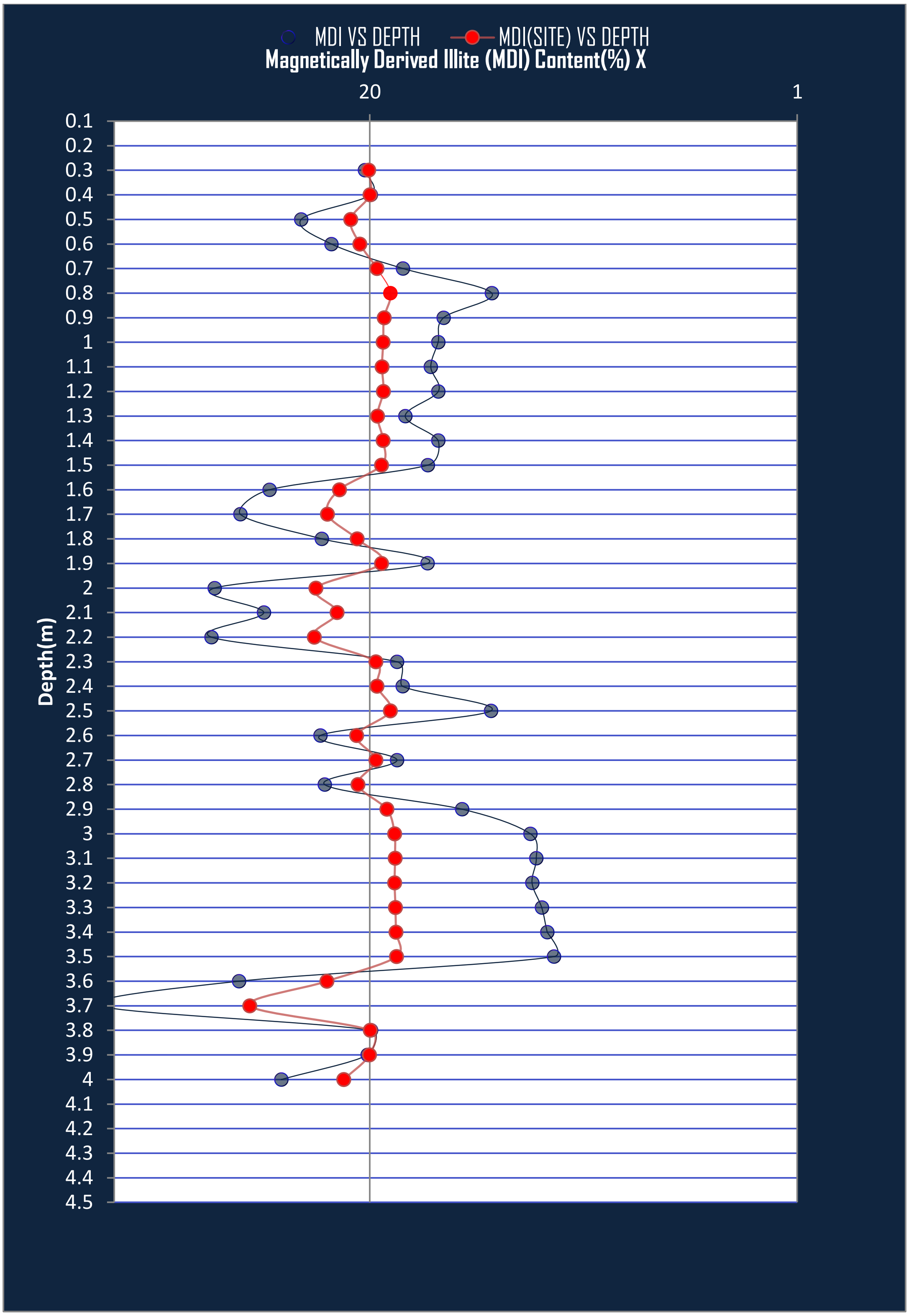

Figure 1: The log of Magnetically Derived Illite (MDI) content (%) of both source A (S.I unit) and Site X (S.I unit) Clays with Depth (m).

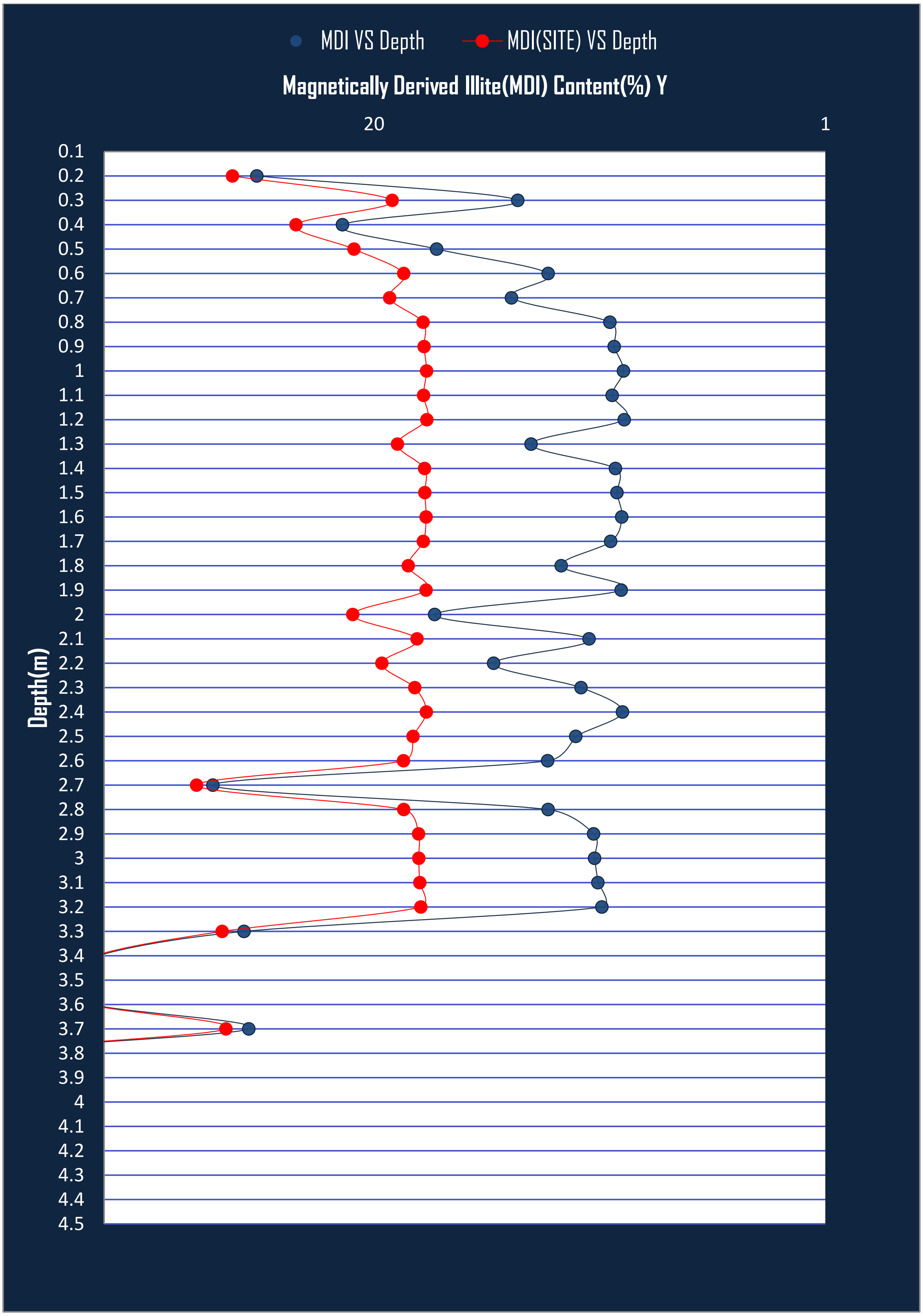

Figure 2: The log of Magnetically Derived Illite (MDI) content (%) of both source B (S. unit) and Site Y (S.I unit) Clays with Depth (m).

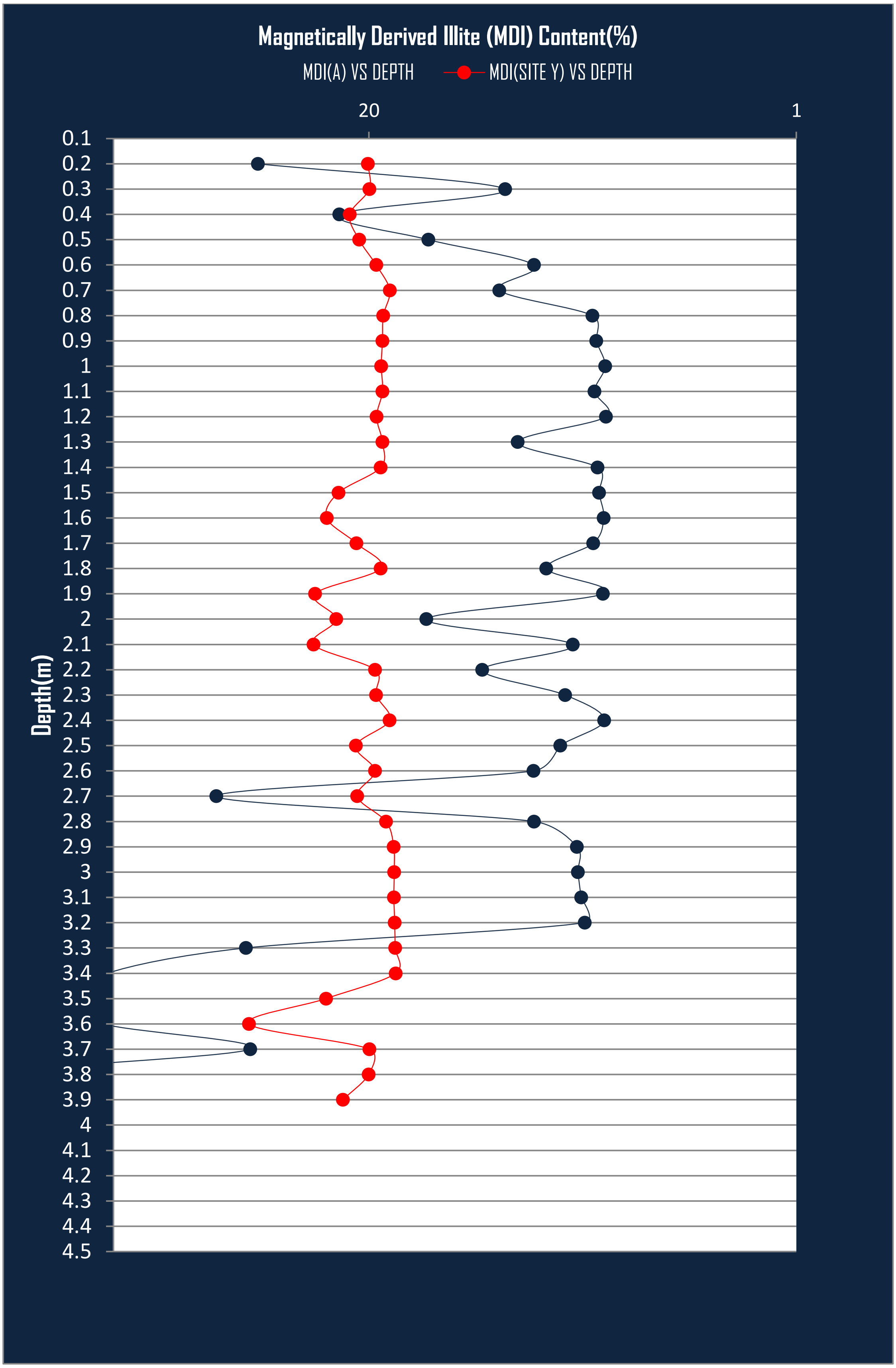

Figure 3: The log of Magnetically Derived Illite (MDI) content (%) of both source A (S.I unit) and Site Y (S.I unit) Clays with Depth (m).

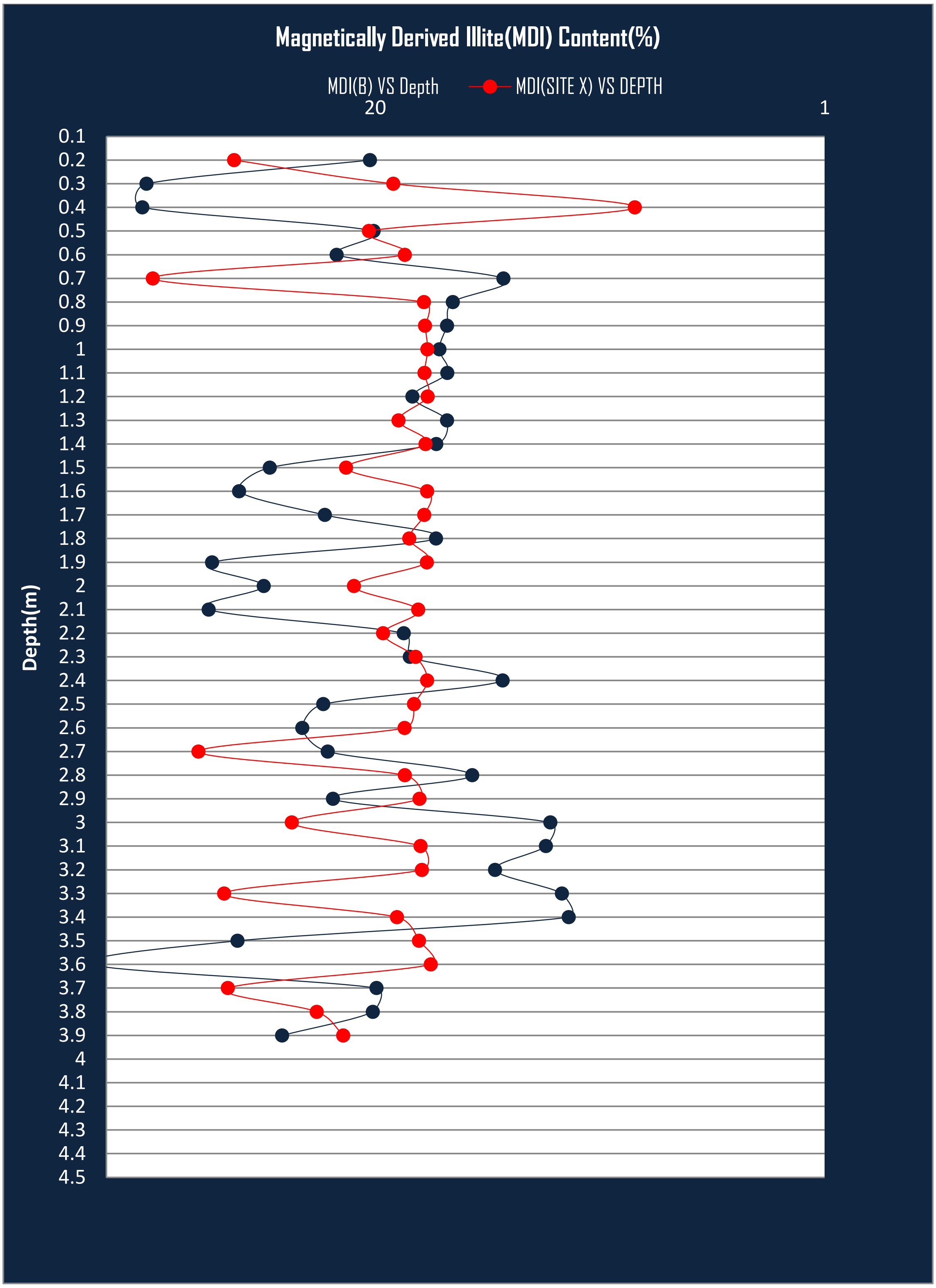

Figure 4: The log of Magnetically Derived Illite (MDI) content (%) of both source B (S.I unit) and Site X (S.I unit) Clays with Depth (m).

Discussions

The clay materials from the sites were the control while those from the source locations were constraint on them for compatibility in order to ensure efficient and sustainable road construction. In Table 2 and Table 3, the depths of measurements ranges from 0.2m to 4m and 0.3m to 4m for the Site X and Y respectively. This difference on the measurement depths results from levelling due to topographic differences and nature of the ground surfaces on both sites. In Table 2, the Volume Magnetic Susceptibility (VMS) ranges from $0.8 x10^{-5}$S.I unit to 118 $x10^{-5}$S.I unit for Source A and 45 $x10^{-5}$S.I unit to 300 $x10^{-5}$S.I unit for site X. In Table 3, the Volume Magnetic Susceptibility (VMS) ranges from 7.6232 $x10^{-5}$S.I unit to 227 $x10^{-5}$S.I unit for Source B and 56.50492 $x10^{-5}$S.I to 183.8325 $x10^{-5}$S.I for site Y. The Magnetically Derived Illite (MDI) content (%) ranges 3.78 to300 for site X and 14.086 to 290.5 for site Y. The range and variability of illite contents in the clay material of site X is higher than that of site Y.

There are four types of clay mineral which includes kaolinite, Montmorillonite of smectite group, illite and chlorite out of which illite was chosen as the control clay mineral due its structure and destructive characteristics. According to Pironon *et al* (2005), the strongly bounded structural characteristic of illite inherently causes them to be less permeable and lower shrink –swell capacity and most common than others in soil. Illite do not expand, having smaller cation exchange of 20-30meq/100g.The presence of higher concentration of illite in clay results in abnormal heat generation and rebound of the clay in response to loading after compaction during road construction. There is need for the spectra of the concentration of the illite contents for both site and source clay material to be in phase depicting compatibility, hence the choice of it.

From Figure 2, the spectrum of the magnetically derived illite content of the source A clay is point to point in phase with the spectrum of the Magnetically Derived Illite content of Site X,both having almost the same trend, and the former noisy at 3.7m depth of measurement. The noise might be an indication of the presence of scanted antiferrimagnetic minerals such as heamatite in the clay. The spectra intersects at 0.2m, 0.3m, 0.7m, 1.5m, 1.9m, 2m, 2.3m ,2.6m ,2.7m ,2.8m ,2.9m ,3.6m ,3.8m, and 3.9m.The in-phase relationship of both spectra with their numerous points of intersection depicts that the two clays are compactible and sustainability of the road can be achieved after filling and compaction in course of the construction.
From Figure 3, both spectrum of the magnetically derived illite content of the source B clay is a point to point in phase with the spectrum of the magnetically derived illite content of Site Y, both having almost the same trend with no depth points of intersection, and the later noisy between 3.4m- 3.7m and at 3.8 m depths of measurement. The in phase relationship of both spectra depicts that the two clays are compactible though there were no points of intersection as the magnetic susceptibility values of the source clay are higher than those of the site clay. Though they were not as good as the combination on site X of Figure 3 and the road sustainability can be achieved.

In Figure 4, the magnetically derived illite content of the source A clay is plotted on the same graph with the magnetically derived illite content of Site Y. This measure was taken in consideration to the proximity of source A to site Y that might be of economic advantage in cost of transportation. It was observed at the two spectra are point to point out of phase in majority of the depth points between 0.2m and 2.2m while being in phase at the deeper, having points of intersection at 0.24m,0.4m, 2.64m,2.75m,and 3.26m. This implies that the combination is only compactible at clays materials from depth greater than 2m. It will be uneconomical and time wasting to excavate all clays from ground surface to depths more than 2m before loading, therefore, such combination is not advisable.

In Figure 5, the magnetically derived illite content of the source B clay is plotted on the same graph with the magnetically derived illite content of Site X. This measure was taken in consideration to the availability and low cost of labour of source B to Site X. It was observed at the two spectra are point to point out of phase, having points of intersection at 0.24m,0.5m, 0.62m,1.16m, 1.4m,1.72m,2.2m,2.44m,2.85m,3.2m,3.46m,3.65m, and 3.96m. Though there are many points of intersection in this combination, it is unadvisable to use source B on Site X, because the high level of non-compatibility as observed in the comparison of both spectra.
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Conclusion

In view of the findings of this research, it can be concluded that:

1. The magnetic susceptibility signature technique is a viable tool for the compatibility test of construction materials such as clay for efficient and sustainable road constructions in Rivers State
2. The magnetic susceptibility signature technique is more safe, economical and rapid in comparison to other compatibility test.
3. Clays of Source A and Site X are compatible combination likewise Source B and Site Y while the combination of source A on Site Y and Source B on Site X are non-compatible and uneconomical.
4. The Volume Magnetic Susceptibility (VMS) ranges from $0.8\text{x}10^{-5}$S.I unit to 118 $\text{x}10^{-5}$S.I unit for Source A and 45 $\text{x}10^{-5}$S.I unit to 300 $\text{x}10^{-5}$S.I unit for site X, from 7.6232 $\text{x}10^{-5}$S.I unit to 227 $\text{x}10^{-5}$S.I unit for Source B and 56.50492 $\text{x}10^{-5}$S.I to183.8325 $\text{x}10^{-5}$S.I for Site Y.
5. The Magnetically Derived Illite (MDI) content (%) ranges 3.78 to300 for site X and 14.086 to 290.5 for site Y.
6. The range and variability of illite contents in the clay material of site X is higher than those of site Y.

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