BirEx JOURNAL
Budapest International Research in Exact Sciences
Medical, Biological, Argiculture, Engineering Science and other related areas
e-ISSN : 2655-7827
p-ISSN : 2655-7835
http://www.bircu-journal.com/index.php/birex

Physico-Chemical and Mineralogical Characterization of Analavory, Bemololo and Miandrivazo Clays

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Abstract: *The general objective of this study is to thoroughly characterize the clays of Analavory, Bemololo and Miandrivazo from a physico-chemical and mineralogical point of view. To this end, analyses were carried out on all nine samples. The results provided information on important clay parameters such as moisture content, density, pH, constituent chemical elements and specific surface area, and enabled the clays to be classified according to their clay qualities and plasticity.*

Keywords: *Clay, analysis, physicochemical, mineralogical, classification*

I. Introduction

The earth offers mankind a wealth of resources. For a long time now, mankind has been conducting research into how to exploit these resources to make daily life easier and better. Among the earth's resources is clay. In Madagascar and some African countries, clay is one of the most important materials used to make bricks to build their own houses [8]. Kaolinite (composed of kaolinite and halloysite), bentonite (composed of montmorillonite and attapulgite) and glauconie are the main clays found in Madagascar. Kaolinite is the most widespread.

About the clays of Analavory, Bemololo and Miandrivazo, what is the physicochemical and mineralogical characterization, and what implications does this have on their potential uses? The clays of these three localities present distinct properties in terms of physicochemical and mineralogical composition, which may influence their specific applications. This is why we can ask such questions: what is the physicochemical composition of the clays of Analavory, Bemololo and Miandrivazo? What is the mineralogy of the clays in these regions? How do these characteristics influence the properties of clays? What industrial applications can arise from these specific characteristics?

The aim of the present study is to thoroughly characterize the clays of Analavory, Bemololo and Miandrivazo from a physico-chemical and mineralogical point of view. Various analyzes were carried out in order to characterize these samples: analyze the chemical composition of clays. Determine the mineralogy of clays. Evaluate the physical properties of clays. Identify potential applications of clays based on their characteristics.

Budapest International Research in Exact Sciences (BirEx) Journal
Volume 6, No 2 April 2024, Page: 104-118
e-ISSN: 2655-7827 (Online), p-ISSN: 2655-7835 (Print)
www.bircu-journal.com/index.php/birex
email: birex.journal@gmail.com

II. Research Methods

2.1 Clay Sampling Site

The clays used in this study were sampled in three (3) different areas: Analavory; Bemololo and Miandrivazo.

- Analavory is about 120 km from Antananarivo. It lies in the Itasy Region, in the Antananarivo Province, in the Soavinandriana District. Two (2) samples were taken: yellow clay named ANLV 001 (X = 797 203 and Y = 421 353) and green clay named ANLV 002 (X = 797 065 and Y = 421 388).
- Bemololo is located in the Commune of Andranomanelatra, District of Antsirabe II, in the Vakinankaratra Region, on the RN7 national road, about 240km from Antananarivo. Four (4) samples were taken: green clay named BMLL 001 (X = 467843 and Y = 699631), white clay named BMLL 002 (X = 467970 and Y = 699748), greyish clay named BMLL 003 (X = 467978 and Y = 699743) and violet clay named BMLL 004 (X = 468063 and Y= 699757).
- Miandrivazo is located in the Menabe Region of Madagascar, on the RN34 national road, about 490km from Antananarivo. Three (3) samples were taken: green clay named MNDV 001 (X = 296426 and Y = 727533), orange-green clay named MNDV 002 (X = 296546 and Y = 727813) and red clay named MNDV 003 (X = 296559 and Y = 727774).

2.2 Sampling

Sampling in Bemololo, Miandrivazo and Analvory took place in February, April and May 2023 respectively. A GPS enabled us to access the geographical coordinates of the study area, so that we could position ourselves geographically. We also used a geological hammer, plastic bags and a marker to distinguish each sample taken.
The nine (09) samples collected were sent to the laboratory for analysis.

2.3 Laboratory Analysis

Before each test and analysis, the samples undergo appropriate pre-treatments. The purpose of these pre-treatments is to powder the clay. Each sample undergoes crushing, drying using an oven, grinding using a mill, and finally sieving according to the particle size required. This operation was carried out at the Laboratoire National des Travaux Publics et du Bâtiment (LNTPB) in Madagascar.

2.4 Methods for Characterizing Clay Soils Them

a. Humidity level

The quantity of liquid water present in a soil sample is determined by steaming in accordance with standard NF P 94 050 [3].
The amount of liquid water present in a soil sample is determined by drying in accordance with NF P 94 050 [3]. To do this, a mass of natural clay (Mh) was weighed and dried in an oven at 105°C for 24 hours. The new mass of dry clay is then taken and noted Ms. The moisture content is obtained by calculation:

$$TH = \frac{M_h - M_s}{M_h} \times 100$$

With:
Mh: sample mass before oven drying (g)
Ms: mass of dry sample after oven drying at 105°C for 24 hours (g)
TH: moisture content (%)

b. Specific gravity

The density of our sample was measured in accordance with standard NF P 94- 054 [4], carried out at the National Laboratory of civil engineering and building (LNTPB) Madagascar. The equipment used to determine the density is a pycnometer. A series of weighing operations was carried out to obtain the mass and volume of the sample (Photo 1). We took the mass of the empty pycnometer, the mass of the pycnometer filled with water to 1/3 of its volume, the mass of the pycnometer filled with water to 1/3 plus the sample having an unknown mass, the mass of the pycnometer with the sample and filled with water.

Before weighing the water-filled pycnometer with the sample, allow the poured sample to settle until the water becomes opaque. The sample's mass, volume and specific gravity are then calculated.

c. Hydrogen potential or pH

The pH of the samples was determined in the Génie des Procédés Chimiques et Industriels (GPCI) mineral chemistry laboratory at Ecole Supérieure Polytechnique d’Antananarivo (ESPA) - Vontovorona using a pH meter.

d. Methylene blue value and specific surface

Determination of the methylene blue value in accordance with French standard NFP 18-592 was carried out at the Laboratoire National des Travaux Publics et du Bâtiment (LNTPB) Madagascar.

To make this determination, a mass of sample me was taken and poured into a container. For 100g of test sample, 500ml of water was added. The suspension was stirred. Methylene blue solution at a concentration of 1g/l was then added gradually. After pouring in 5ml of methylene blue and stirring for 60s, the solution is picked up with a glass rod and placed on filter paper. The suspension is saturated when a light blue spot appears.
The methylene blue value (MBV) of a soil is given by the following relationship:

$$MBV = \frac{V_b}{m_e}$$

With:
V_b: volume of methylene blue added (ml)
m_e : test sample mass (g)

a. Atterberg limits

The determination of Atterberg limits according to the French standard NF P 94-051/52 **[5]** was carried out at the Laboratoire National des Travaux Publics et du Bâtiment (LNTPB) Madagascar. They constitute the liquidity limit and the plasticity limit for determining a soil's plasticity index.

The steps to follow for the determination are as follows: prepare a mixture of sample and water in a container to obtain a pasty mixture, mix well to make it homogeneous, lay the paw on the cup of the Casagrande apparatus, trace a groove using a tool in the shape of the letter V called a groove tool, subject the cup to regular blows until there is a 1cm closureof the traced groove, then take the two sides of the groove and put them in two different codedto measure their water content (Photo 3). The test is carried out on a 400µm passing sample.

The liquidity limit corresponds to the water content of the clay for a groove closure of 1 cm after 25 blows. To obtain this water content, it is therefore necessary to repeat the test several times to obtain several points, so that a straight line of water content as a function of the number of blows is obtained.

To determine the plasticity limit, the procedure is as follows: Roll the tab onto a marble plate by hand, until a roll of approximately 3mm diameter and 10cm in length is obtained. The rolls obtained are placed in two different codes to obtain two values of water content, which must be roughly equal. The plasticity limit is obtained by averaging these two values.

The plasticity index is then calculated.

$$Ip = W_L - W_P$$

With:
WL: liquidity limit
Wp: plastic limit

2.5 Mineralogical characterization of clays

a. Oxides rate

Determination of oxide levels was carried out at the Genie des Procédés Chimiques et Industriels (GPCI) mineral chemistry laboratory at Ecole Superior Polytechnique d'Antananarivo (ESPA) Vontovorona using the 20% Triethanolamine reagent.

Sample attack

Prior to manipulation for the determination of each element, the clays are acid- etched according to the following protocol.

0.5g of the sample is placed in a crucible (Photo 5) with 4g of Na_2NH_4

Bake this mixture in an oven (Photo 6) at 975°C for 45min.

After calcination and cooling, pour 50ml of HCl (50%) into the crucible and allow to dry in a sand bath.

Once dry and cool, 50ml HCl (10%) is poured into the crucible and heated in the sand bath for 15min.

Then filter through filter paper with boiling water until the reaction with $AgNO_3$ disappears.

Cool the filtrate and make up to the mark with distilled water.

The solution obtained is used for the determination of Fe_2O_3, Al_2O_3, CaO and MgO; and the filter paper is kept for the determination of SiO_2.

Determination of Fe_2O_3 and Al_2O_3

Iron oxide and alumina contents are obtained by titration and calculation. The protocol is as follows:

Place 100ml sample and 200ml water in a 600ml beaker.

Add 6 drops of bromophenol blue

Add a few drops of NH_4OH (50%) until the dark blue color changes.

Quickly pour in 20ml HCl (0.1N) and 15ml buffer solution

Add 20 drops of salicylic acid to obtain a purple-black color.

Heat at 40-50°C maximum for 1min 30s (Photo 7)

Titrate with EDTA to straw-yellow colour change

The volume obtained from this titration is used to calculate the content Fe_2O_3.

Add a few drops of ammonium acetate ($CH_3CO_2NH_4$) to the last solution.

Add 5ml acetic acid

Add 3 drops of copper complexano and 10 drops of PAN to obtain a purplish pink color.

Bring the solution to the boil and titrate with EDTA until straw-yellow.

Determination of CaO

The CaO level is determined according to this protocol:

Place 50ml sample in a 600ml beaker with 200ml water

Add two drops of methyl orange, and then pour in a few drops of NH_4OH (50%) until yellow turns.

Quickly pour in 20ml TEA and 40ml NaOH

Add PATON AND REEDER reagent

Titrate with EDTA until blue color appears.

Determination of MgO

MgO determination follows the following protocol:

Place 50ml sample in a 600ml beaker with 200ml water

Add a drop of methylorange to obtain a light pink color, and then add a few drops of NH_4OH (50%) until the color turns yellow.

Quickly pour in 30ml of TEA, then 6 drops of Mg indicator.

Titrate with EDTA until staining disappears

The value of the rate is obtained by the following formula:

With:

M: the element to be measured.

V: volume of EDTA added during titration

fEDTA/M = EDTA factor for M.

Determination of SiO_2

The determination of SiO_2 consists in weighing the mass of the empty crucible noted M1, then putting the dry filter paper containing the refusal at the time of the filtration of the solution in this crucible, calcining the contents at 975°C in an oven during 45min, and finally weighing the mass of the crucible which contains the calcined product noted M2.

The percentage silica content is obtained by the formula:

With:

M1: mass of the empty crucible

M2: mass of the calcined product

b. Chemical element rates

The chemical elements making up the clay were determined in the Office des Mines Nationales et des Industries stratégiques (OMNIS) Antananarivo laboratory using an X-Ray apparatus. The carbon and nitrogen content of the clays studied was determined at the FOFIFA or Centre National de la Recherche Appliquée au Développement Rural Ampandrianomby laboratory.

The carbon and nitrogen content of the clays studied was determined at the FOFIFA Ampandrianomby laboratory.

Determination of carbon content

The principle of the test is to oxidize organic carbons with an excess of potassium dichromate solution in an acid medium. Determination is then made by titration using a ferrous sulfate solution.

Determination of nitrogen content

Analysis involves three stages: mineralization of organic nitrogen, distillation and titration. Mineralization consists in destroying nitrogenous organic matter and transforming the nitrogen into ammonia, which is fixed by sulfuric acid in the form of $(NH_4)_2SO_4$. An extract of the resulting solution is mixed with a soda solution and passed through a distiller. The aim is to vaporize the NH_3. It will then be fixed by a boric acid solution in the borate state. The last solution is dosed with a sulfuric acid solution.

III. Results and Discussion

3.1 Characterization of clay soils

a. Humidity level

Table 1 shows the results of the moisture content (MC) of each sample taken at Miandrivazo MNDV, Bemololo BMLL and Analavory ANLV.

Table 1. Moisture content (MC) of clays

SAMPLES	MNDV 003	MNDV 001	MNDV 002	BMLL 001	BMLL 003	BMLL 004	BMLL 002	ANLV 002	ANLV 001
MC (%)	0,39	4,51	2,43	23,04	9,23	13,12	13,79	7,64	1,29

(Source: Author, 2023)

To better illustrate the difference in moisture content between the samples, these results are plotted on the diagram in Figure 1.

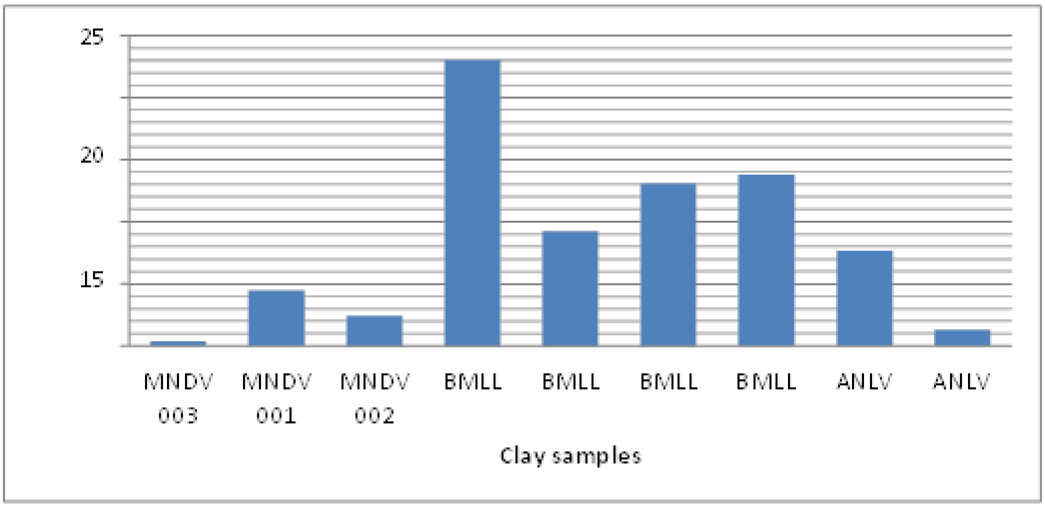

Figure 1. *Diagram of clay moisture content.*
(Source: Author, 2023)

The moisture content of the clays studied ranged from 0.39% to 23.04%. The Miandrivazo sample MNDV 003 has the lowest moisture content (0.39%), while the Bemololo sample BMLL 001 has the highest (23.04%). The moisture content explains the non-hygroscopic nature of the clays [7].

b. Weight volume

The weight by volume of each sample is shown in Table 2 below:

Table 2. Determination of sample density.

SAMPLES	**MNDV 003**	**MNDV 001**	**MNDV 002**	**BMLL 001**	**BMLL 003**	**BMLL 004**	**BMLL 002**	**ANLV 002**	**ANLV 001**
Density □ s (kN/m)^3	26,95	24,34	25,64	24,55	25,11	25,01	25,80	26,30	27,11

(Source: Author, 2023)

To better illustrate the difference in sample densities, these results are plotted on the diagram in Figure 2.

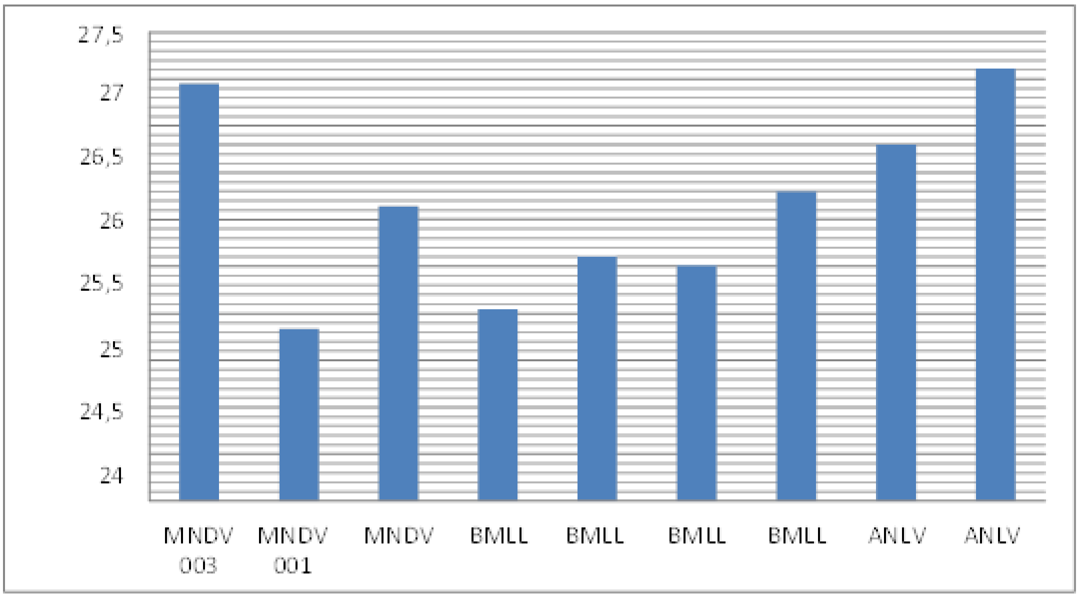

Figure 2. *Density diagram for clay samples.*
(Source: Author, 2023)

Sample densities range from 24.34kN/m3 to 27.11kN/m3. According to the diagram in Figure 2, ANLV 001 and MNDV 003, which have high density values, have a high sand content compared with the other seven samples. MNDV 001 and BMLL 001 have the lowest volumic weights and therefore a low sand content compared with the others.

c. Hydrogen potential

Table 3. pH of clays as a function of temperature

SAMPLES	MNDV 003	MNDV 001	MNDV 002	BMLL 001	BMLL 003	BMLL 004	BMLL 002	ANLV 002	ANLV 001
pH	9,72	9,03	7,85	8,72	5,84	6,62	9,75	9,95	10,75
T°C	15,7	15.7	15,5	15,5	16,8	16,8	14,6	15,3	14,8

(Source: Author, 2023)

Sample pH ranged from 5.84 to 10.75 at temperatures between 14.6°C and 16.8°C. Samples BMLL 003 and BMLL 004 have the lowest pH (5.84 and 6.02 respectively). This may be due to the influence of the 16.8°C test temperature. And the other samples have a basic character, such as alkaline carbonates and bicarbonates or silicates [7], indicated by the pH values in Table 3.

d. Methylene blue value and specific surface

Table 4 below shows the methylene blue value and specific surface area of the samples.

Table 4. Methylene blue value (MBV) and specific surface (SS) area of samples

SAMPLES	MNDV 003	MNDV 001	MNDV 002	BMLL 001	BMLL 003	BMLL 004	BMLL 002	ANLV 002	ANLV 001
MBV	0,1	3	5	12,5	7,5	6,5	8,2	2,6	0,15
SS (m^2 /g)	2,09	62,79	104,65	261,63	156,98	136,05	171,63	54,42	3,14

(Source: Author, 2023)

A better comparison of the results can be seen in the following diagrams:

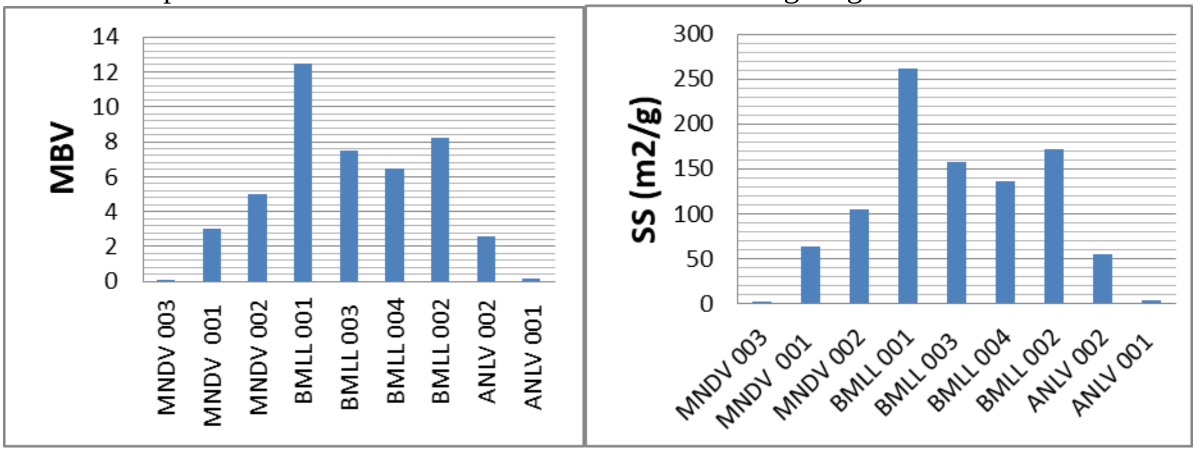

Figure 3. *Diagram of methylene blue value (MBV) and specific surface (SS) area of clays. (Source: Author, 2023)*

The methylene blue values of the nine samples ranged from 0.1 to 12.5, and their specific surface areas from 2.09m^2 /g to 261.63m^2 /g. The lowest methylene blue value (MBV), like the smallest specific surface (SS) area, belongs to MNDV 003 and the highest to BMLL 001. Compared with the reference value of Chen (2016), whose illite specific surface area SS ranges from 50 to 200 m²/g [6], these are the samples MNDV 001, MNDV 002, BMLL 003, BMLL 004, BMLL 002 and ANLV 002 corresponding to this value.
In addition, according to the NF P94-068 standard for soil classification and the results obtained in Table 4, a classification of the clays studied according to their category is shown in the following Table 5.

Table 5. Classification of the clays studied according to their methylene blue value (MBV).

Soil category	NF P94-068	SAMPLES
Sandy soil	VBS < 0.2	ANLV 001 MNDV 003
Silty soil	0.2 ≤ VB < 2.5	-
Silty-clay soil	2.5 ≤ VBS < 6	MNDV 001 MNDV 002 ANLV 002
Clay soil	6 ≤ VBS < 8	BMLL 003 BMLL 004
Very clayey soil	VBS > 8	BMLL 001 BMLL 002

(Source: NF P94-068 and Author, 2023)

e. Atterberg limits

The Atterberg limits are the liquidity limit (WL) and the plasticity limit (WP), used to determine a soil's plasticity index (IP).

The analytical results for the nine (9) samples, MNDV 001, MNDV 002, MNDV 003, BMLL 001, BMLL 002, BMLL 003 BMLL 004, ANLV 001 and ANLV 002, are given in the following Table 6.

Table 6. Atterberg limits of clay samples.

SAMPLES	W_L (%)	W_P (%)	I_P (%)
MNDV 003	24,5	15,8	8,7
MNDV 001	37	21,16	15,84
MNDV 002	39,20	20,5	18,70
BMLL 001	105,1	60,2	44,9
BMLL 003	63,8	36,6	27,2
BMLL 004	82,85	47,5	35,35
BMLL 002	50,4	28,89	21,51
ANLV 002	38,95	22,3	16,65
ANLV 001	31,3	18	13,3

(Source: Author, 2023)

The results of the plasticity index are plotted on the diagram in Figure 4 to better see the difference for each sample.

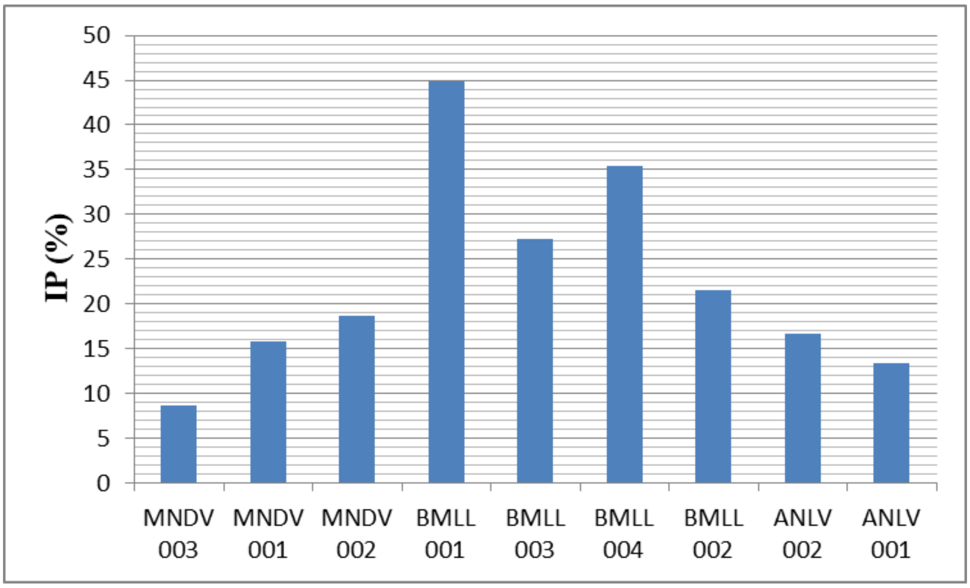

***Figure 4**. Diagram of sample plasticity index*
(Source: Author, 2023)

The diagram shows that sample BMLL 001 has the highest plasticity index and sample MNDV 003 the lowest. The plasticity index of the nine samples is limited to between 8.7% and 44.9%. From our measurements, using Casagrande's diagram [2] for the classification of fine soils (see Figure 5), it emerges that samples MNDV 003 and ANLV 001 are not very plastic clays, samples MNDV 001, MNDV 002, ANLV 002, BMLL 003, BMLL 004 and BMLL 002 are plastic and the remainder, BMLL 001, is very plastic. The non-plastic clays, ANLV 001 and MNDV 003, are justified by their sandy state. And in the same hypothesis, the plasticity of the other seven is due to their silty clay, clay or very clay state.

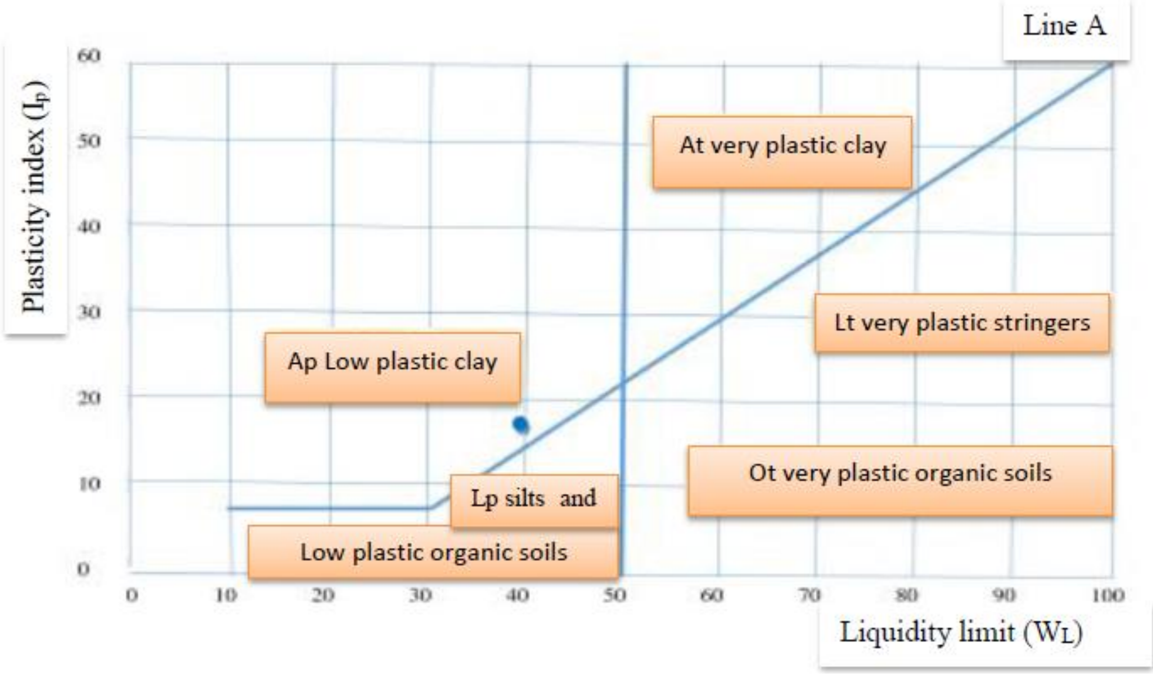

Figure 5. *Casagrande diagram*
(Source: NF P 94-052-1. 1993)

3.2 Mineralogical characterization of clays

a. Oxides rate

The oxide content of the clay samples in this study is shown in the following Table 7.

Table 7. Clay oxide content.

SAMPLES	MNDV 003	MNDV 001	MNDV 002	BMLL 001	BMLL 003	BMLL 004	BMLL 002	ANLV 002	ANLV 001
SiO_2 (%)	64,00	90,00	86,00	74,00	80,00	78,00	18,00	56,00	38,00
Fe_2O_3 (%)	4,48	3,36	3,14	7,17	8,51	13,00	5,60	11,88	4,03
Al_2O_3 (%)	1,72	5,58	3,43	1,29	2,00	2,58	0,86	3,29	0,43
CaO (%)	3,78	5,35	3,46	5,35	5,04	2,52	23,92	5,67	35,25
MgO (%)	4,07	5,43	3,39	0,23	0,23	0,45	26,70	3,39	24,21

(Source: Author, 2023)

To see the difference in rates for each clay, this same result is plotted in the following diagram.

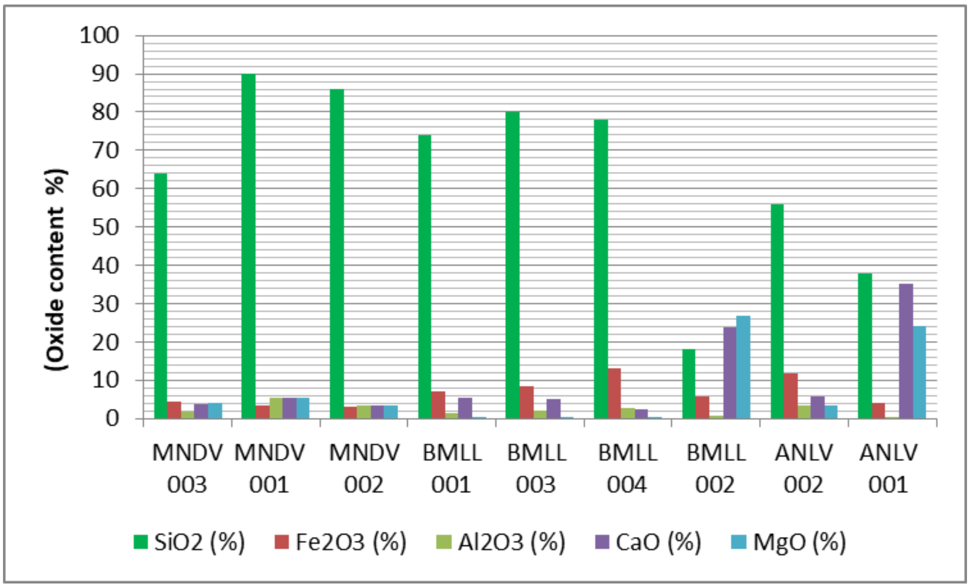

Figure 6. *Histogram of clay oxide content.*
(Source: Author, 2023)

The iron oxide content (Fe2O3) of the samples ranged from 3.14% to 13%. Alumina (Al2O3) ranged from 0.43% to 5.58%. Calcium oxide (CaO) ranged from 2.52% to 35.25% and magnesium oxide (MgO) from 0.23% to 26.70%.

Silicon dioxide (SiO2) has a remarkable percentage, varies from 18% to 90%, compared to other oxides. This indicates a significant amount of free silica in the sample. This is in agreement with the work of Amari et al. (2018) [9]. But, compared to the value of the chemical analysis of the laterire of Vontovorona, 31.54% of SIO2 [10], the samples studied in this study have a very important value except that the sample BMLL 003. The overall rate of other oxides is low, except for BMLL 002 and ANLV 001. This low percentage indicates that these clays are pure. BMLL 004 and ANLV 002 are rich in hematite Fe2O3; this explains their coloring.Chemical element rates

Table 8, below shows the chemical elements present in samples taken at MNDV, BMLL and ANLV.

Table 8. Chemical elements present in the samples.

ELEMENTS	**MNDV 003**	**MNDV 001**	**MNDV 002**	**BMLL 001**	**BMLL 003**	**BMLL 004**	**BMLL 002**	**ANLV 002**	**ANLV 001**
Fe(%)	5,36	5,33	5,56	11,79	12,46	13,29	5,47	13,11	1,94
Al(%)	6,08	5,94	4,80	4,36	4,28	7,89	2,54	1,78	4,76
Si(%)	10,80	9,69	8,40	7,45	6,75	6,18	3,64	7,17	0,89
P(%)	0,24	0,11	0,09	0,26	0,12	0,17	0,56	0,16	0,85
K(%)	0,81	1,00	0,86	1,49	0,00	0,03	0,00	0,31	0,00
Ca(%)	0,03	0,00	0,00	0,02	0,01	0,01	0,20	0,04	0,84
Ti(%)	0,40	0,41	0,37	0,79	1,51	2,19	0,30	0,39	0,12
Mg(%)	0,78	1,29	0,86	0,75	0,70	0,70	0,47	0,74	1,84
Sr(%)	0,04	0,03	0,02	0,04	0,06	0,11	0,13	0,08	0,48

V(%)	0,01	0,02	0,02	0,03	0,03	0,04	0,01	0,02	0,01
Cr(%)	0,01	0,02	0,02	0,03	0,05	0,05	0,02	0,05	0,03
Mn(%)	0,00	0,05	0,00	0,00	0,00	0,00	0,00	0,09	0,06
Co(%)	0,00	0,00	0,00	0,01	0,01	0,03	0,00	0,01	0,00
Ni(%)	0,03	0,03	0,03	0,03	0,03	0,04	0,04	0,03	0,03
Cu(%)	0,03	0,02	0,01	0,03	0,01	0,03	0,06	0,03	0,03
Zn(%)	0,01	0,01	0,01	0,01	0,01	0,02	0,01	0,01	0,01
As(%)	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Se(%)	0,01	0,00	0,01	0,00	0,01	0,01	0,00	0,00	0,01
Zr(%)	0,05	0,04	0,03	0,04	0,07	0,07	0,03	0,02	0,02
Rb(%)	0,01	0,02	0,02	0,01	0,00	0,00	0,00	0,01	0,00
Ba(%)	0,15	0,11	0,16	0,17	0,07	0,13	0,12	0,05	0,02
W(%)	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04	0,04
Ta(%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Au(PPM)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Hg(PPM)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pb(%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cd(%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Sn(%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Sb(%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Ag(%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Mo(%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
S(%)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

(Source: Author, 2023)

According to Table 7 above and reference [2], the nine (9) samples studied contain the following clay constituents: Silicon (Si), Aluminium (Al), Iron (Fe), Magnesium (Mg), Calcium (Ca) and Potassium (K). In this study, Iron (Fe), Aluminium (Al) and Silicon (Si) are the dominant constituents. Their levels are grouped together in the following diagram (Figure 7) to show how they vary from one clay to another.

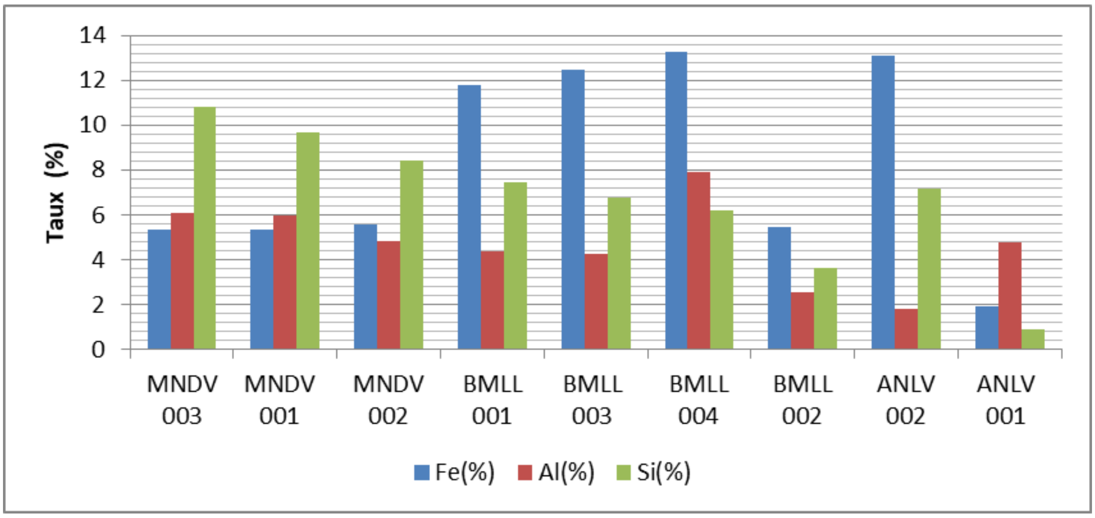

Figure 7. *Diagram of the three major components of the samples*
(Source: Author, 2023)

These three elements are in the majority. The high silicon and aluminum content is justified by the structure of the clay, which is made up of SiO2 and Al2O3.
P, K, Ca, Ti, Mg and Sr are present but at low levels. The diagram in Figure 8 below clearly illustrates these results.

The percentage of elements considered toxic is very small compared to the others. Elements with high percentages are not considered toxic or moderately toxic. All samples are free of Sb, Cd, Pb, Hg, Mo, Ta, Au, Sn, Ag and S.

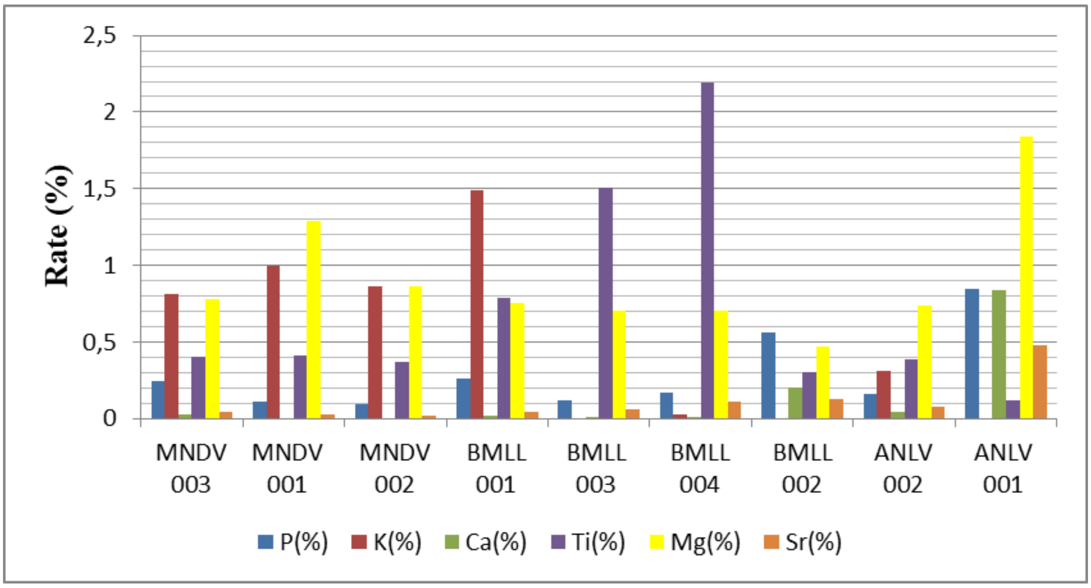

Figure 8. *Diagram of chemical elements*
(Source: Author, 2023)

As has a maximum value of 0.01%; all samples contain Nickel at 0.04% and 0.03%; they are composed of 0.01% Zinc except for BMLL 004, which represents 0.02%. Five of the samples contain Selenium at 0.01%; the Ba content varies from 0.02% to 0.17%; four of the samples contain Cobalt, with a maximum value of 0.03% (BMLL 004), and BMLL 001, BMLL 003 and ANLV 002 contain 0.01%. All the clays studied contain copper, with a maximum value of 0.06% (BMLL 002) and a minimum value of 0.01% (MNDV 001 and

BMLL 003). The maximum content of the elements Rb, Cr, V and Zr is 0.07% (for BMLL 003 and BMLL 004). Sr represents up to 0.48% for ANLV 001.

The carbon and nitrogen content of the clays studied was determined at the FOFIFA Ampandrianomby laboratory. Table 9 below shows the results obtained experimentally, together with the organic matter content and C/N ratio.

Table 9. Carbon and nitrogen content, organic matter content and C/N ratio of the clays studied.

	MNDV 003	**MNDV 001**	**MNDV 002**	**BMLL 001**	**BMLL 003**	**BMLL 004**	**BMLL 002**	**ANLV 002**	**ANLV 001**
C (%)	0,542	1,132	0,574	0,634	0,577	0,043	0,634	0,303	0,143
MO (%)	0,934	1,952	0,989	1,093	0,995	0,075	1,093	0,522	0,246
N (%)	0,007		0,070	0,280	0,035		0,210	0,560	0,042
C/N (%)	77,40		8,20	2,26	16,48		3,02	0,54	3,40

(Source: Author, 2023)

Carbon content ranges from 0.043% to 1.132%. Nitrogen content ranges from 0.007% to 0.560%. Due to a lack of resources, the determination of the nitrogen content of BMLL 004 and MNDV 001 could not be completed.

The majority of samples are low or very low in nitrogen ($N < 0.1\%$). On the other hand, ANLV 002, BMLL 002 and BMLL 001 were rich in nitrogen ($N > 0.15\%$).
The percentage of organic matter in the majority of samples does not exceed 1%, meaning that samples MNDV 003, MNDV 002, BMLL 003, BMLL 004, ANLV 002 and ANLV 001 are low in organic matter. Samples MNDV 001, BMLL 001, BMLL 002 contain a medium level of organic matter ($1<MO<3$).

IV. Conclusion

The aim of the present study is to thoroughly characterize the clays of Analavory, Bemololo and Miandrivazo from a physico-chemical and mineralogical point of view. In order to carry out an efficient and reliable study, various analyzes were carried out such as the determination of moisture content, density, pH, constituent chemical elements and specific surface area, and enabled the clays to be classified according to their clay qualities and plasticity.. The results of these analyses revealed the moisture content of the nine samples, ranging from 0.39% to 23.04%; their specific gravity, from 24.34kN/m3 to 27.11kN/m3; their pH, showing that seven of these clays are alkaline, BMLL 003 is moderately acidic and only BMLL 004 is neutral. Methylene blue values show that ANLV 001 and MNDV 003 are sandy clays; MNDV 001, MNDV 002 and ANLV 002 are silty-clayey; BMLL 003 and BMLL 004 are clayey and; BMLL 001 and BMLL 002 are very clayey. In addition, the specific surface area values of clays MNDV 001, MNDV 002, BMLL 003, BMLL 004, BMLL 002 and ANLV 002 suggest that these samples may be illite. And finally, the plasticity index leads to the interpretation that ANLV 001 and MNDV 003 are moderately plastic, MNDV 001, MNDV 002, BMLL 003, BMLL 004, BMLL 002 and ANLV 002 are plastic and only BMLL 001 is very plastic.

This study can contribute to: optimize industrial processes using these clays. Guide the choice of clays for specific applications such as ceramics, construction, or other fields. Improve understanding of local geological resources and their sustainable exploitation.

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