STUDY OF MINERALOGY IN THE CLAY FRACTION IN REPRESENTATIVE SOILS OF PUCALLPA, PERU, BASED ON PLITHOGENIC NUMBERS

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ABSTRACT
Clay is a decomposed sedimentary rock consisting of aggregates of hydrated aluminum silicates, from the decomposition of rocks containing feldspar, such as granite. Clay has plastic properties, which means that by moistening it can be easily modeled. When dried, it becomes firm and when subjected to high temperatures, chemical reactions occur that, among other changes, cause the clay to become a permanently rigid material, called ceramics. Clays have wide use in the pottery industry, construction, and winemaking, among many other applications of economic and social importance. This research aims to classify clays according to different types of clays existing in the soils of Pucallpa, Peru, through the use of plithogenic sets. This novel theory was selected because it allows us to represent multiple attributes where each consists of different possible elements, including indeterminacy and vagueness. The classification of different types of clay is not simple; some of its physicochemical characteristics are common to more than one type of this mineral. To the knowledge of the authors, it is the first time that plithogenic sets are used in the classification of minerals. In this paper we provide a method based on plithogenic sets, such that 18 types of clays of Pucallpa can be classified.

KEYWORDS: clay fraction, plithogenic set, neutrosophic set.

MSC: 92E99, 92F99.

RESUMEN
La arcilla es una roca sedimentaria descompuesta que consiste en agregados de silicatos de aluminio hidratados, provenientes de la descomposición de rocas que contienen feldespato, como el granito. La arcilla tiene propiedades plásticas, lo que significa que al humedecerla se puede modelar fácilmente. Al secarse adquiere firmeza y al someterla a altas temperaturas se producen reacciones químicas que, entre otros cambios, hacen que la arcilla se convierta en un material permanentemente rígido, denominado cerámica. Las arcillas tienen un amplio uso en la industria de la cerámica, la construcción y la vinificación, entre muchas otras aplicaciones de importancia económica y social. Esta investigación tiene como objetivo clasificar las arcillas según los diferentes tipos de arcillas existentes en los suelos de Pucallpa, Perú, mediante el uso de conjuntos plitogénicos. Se seleccionó esta novedosa teoría porque nos permite representar múltiples atributos donde cada uno consta de diferentes elementos posibles, incluida la indeterminación y la vaguedad. La clasificación de los diferentes tipos de arcilla no es sencilla; algunas de sus características fisicoquímicas son comunes a más de un tipo de este mineral. Para conocimiento de los autores, es la primera vez que se utilizan conjuntos plitogénicos en la clasificación de minerales. En este artículo se provee de un método basado en conjuntos plitogénics, tal que 18 tipos de arcillas de Pucallpa pueden ser clasificadas.

PALABRAS CLAVES: fracción arcillosa, conjunto plitogénico, conjunto neutrosófico.

1. INTRODUCTION

The nature and properties of clay minerals are more varied in the tropics than in the temperate zone, [11]. They are also less defined and understood. Although, until 1940, soil clays were considered amorphous, with the advent of X-ray spectrometry, this idea was discarded and mineralogists concentrated on the study of the various crystalline forms, [17].
The term clay fraction refers to a granulometric class. The fundamental crystallographic unit in clays – as in all silicates – is the anionic group $[SiO_4]^{4}$- (siloxane) and, from the mineralogical point of view, encompasses a group of minerals (clay minerals), phyllosilicates for the most part, whose physicochemical properties depend on their structure and their grain size, very fine (less than $2x10^{-9}$m), [8][12].
The important applications of this group of minerals lie in their physicochemical properties [7]. These properties derive mainly from its extremely small particle size (less than 2 microns). As a consequence of this factor, they have a high surface area value and a large amount of active surface.

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In the agronomic field, clays directly influence several soil properties, related to physical and chemical fertility, such as: cation exchange capacity (CEC), water adsorption, texture, structure, plasticity-stickiness, bulk density, porosity, aeration, [7][8][11]. In addition to these applications, clays have a number of properties for different industrial uses such as ceramics, steel, papermaking, asphalt, linoleum, plastics, glues, paints, leather manufacturing, pharmacology, cosmetology, decolorants, and clarifiers of wines and oils.

The types of clay are formed from different factors that influence the formation of soils such as temperature and humidity, vegetation, soil component minerals, tectonics, among others. That is why the classification of different types of clay can become a difficult task, [13]. However, this task is essential because of the economic importance of this material.

This research has as its main objective the creation of a mathematical model that allows the classification of the clays of Peru from specific models of representative clays of the Pucallpa region. Because clays arise from dynamic processes of interaction of various physical, chemical, tectonic, climatic, water elements, among others, we determine that an accurate way to represent and classify clays is through plithogenic sets, [20][21][22]. However, this classification can have indeterminate values because some physicochemical characteristics are common to different types of specific clays, therefore this classification is not simple.

Plithogeny is the dynamics of many types of opposites, and/or their neutrals, and/or non-opposites and their organic fusion. Plithogeny is a generalization of dialectics (dynamics of a kind of opposites: <A> and <antiA>), the neutrosophy (dynamics of a kind of opposites and their neutral: <A> and <antiA>, and <neutA>), because plithogeny studies the dynamics of many types of opposites and their neutral and not opposite (<A> and <antiA>, and <neutA>, <B> and <antiB> and <neutB>, etc.), and many that are not opposites (<C>, <D>, etc.) altogether. A particular application and concept derived from plithogeny is the plithogenic set, as it is an extension of the classical set, fuzzy set, intuitionist fuzzy set and neutrosophic set, and has many scientific applications.

Plithogenic sets represent elements in sets composed of several attributes, where each attribute can take different values, and where in turn the imprecision and vagueness within these values may be present.

Plithogeny is a novel theory that emerged from the theory of neutrosophy. To the authors' knowledge, plithogenic sets have only been applied in decision-making problems in some contexts such as management in hospitals, in the supply chain or education, [1][2][4][5][14][18], never in the classification of minerals such as clay.

In the literature the classical methods consist in classifying the clay according to its chemical components, and then, they are compared with a crisp pattern of percents of each of them ([3][9][15]). The method that we propose here includes the indeterminacy of classification by using plithogenic sets. This idea is important because some clay cannot be classified in a crisp way. On the other hand, for the first time plithogenic sets are applied in physic-chemical problems, and do not in medicine, education, logistic or decision making as we can read in literature ([1][2][6][14][16]). Therefore, this work contains a twofold combination of novelty, in the subject of application and in the way of application.

The present paper is divided into the following sections; section 2 contains the preliminary concepts related to clay and plithogenic sets. Section 3 sets out the model proposed in this research. Last section contains the conclusions of the article.

2. PRELIMINARIES

This section is dedicated to summarizing the main concepts of clays in subsection 2.1 and plithogenic sets in subsection 2.2.

2.1. Clays

Physically, clays are considered colloids of extremely small particles and smooth surface. The diameter of the clay particles is less than 0.002 mm in the clay textural fraction there may be non-mineral particles, phytoliths. Chemically it is a hydrated alumina silicate, the formula of which is Al_2O_3 $2SiO_2$ H_2O, [8][11][12].

It is characterized by acquiring plasticity when mixed with water and sonority and hardness when heated above 800°C. Clay hardened by the action of fire was the first ceramic made by humans, and is still one of the cheapest and most widely used materials. Bricks, cooking utensils, art objects and even musical instruments such as the ocarina are made from this material. It is also used in many industrial processes, such as paper making, cement production, and chemical.

Clays can be classified according to several factors, [17]. Thus, depending on the geological process that originated them and the location of the deposit in which they are located, they can be classified into:

- Primary clay: this name is used when the deposit where it is located is the same place where it originated. Kaolin is the only known primary clay.

- Secondary clays: are those that have been displaced after their formation, by physical or chemical forces. These include secondary kaolin, refractory clay, ball clay, surface mud and stoneware.

If we attend to the structure of its components, filitense clays and fibrous clays are distinguished.

Clays can also be distinguished according to their plasticity. There are plastic clays (kaolinitic) and low plastic clays (smectic, which absorb fats).

Finally, there are also calcareous clays, clay with blocks (clay, gravel and stone blocks of moraines), descaling clay and clay shale.

Clay minerals are usually defined according to idealized chemical compositions. The amount of silica (SiO_2) in the formula is a key determinant in the classification of clay minerals.

- Kaolinite group: includes the minerals kaolinite, dickite, haloisite, and nacrite.
- Some sources include the serpentines group for its structural similarities.
- Smectite group: includes pyrophyllite, talc, vermiculite, sauconite, saponite, nontronite, montmori-llonite.
- Illita group: includes clay micas. Illite is the only mineral.
- Chlorite group: includes a wide variety of similar minerals with considerable chemical variation.

Clay minerals are hydrated aluminum phyllosilicates sometimes with varying amounts of iron, magnesium, alkali metals, alkaline soils, and other cations. Clay minerals are generally microscroscopic. In nature, clay minerals are important components of shale and soils. They originate from weathering or hydrothermal alteration of feldspars, pyroxenes and micas. Some plastic materials and particles of size equal to or less than 2 micrometers are also called clay which is the single or most common size of all clay minerals.

2.2. Plithogenic sets

Definition 1. ([20]) A *plithogenic set* (P, A, V, d, c) is a set P that includes numerous elements described by a number of attributes $\mathrm{A} = \{\alpha_1, \alpha_2, \dots, \alpha_m\}$, $m \geq 1$, which has values $\mathrm{V} = \{v_1, v_2, \dots, v_n\}$, for $n \geq 1$. For V there exists two main features attributes values, they are the *appurtenance degree function* $d(x, v)$ of the element *x*, with respect to some given criteria, and the *contradiction* (*dissimilarity*) *degree function* $c(v, D)$ which is the one realized between each attribute value and the most important (dominant) one.

Given A a non-empty set of uni-dimensional attributes $\mathrm{A} = \{\alpha_1, \alpha_2, \dots, \alpha_m\}$, $m \geq 1$, and let $\alpha \in \mathrm{A}$ be an attribute with its value spectrum is the set S, where S can be defined as a finite discrete set, $\mathrm{S} = \{s_1, s_2, \dots, s_l\}$ $l \in [1, \infty)$, or infinitely countable set $\mathrm{S} = \{s_1, s_2, \dots\}$, or infinitely uncountable (continuum) set $\mathrm{S} = (a, b)$, $\mathrm{S} = (a, b]$, $\mathrm{S} = [a, b)$, or $\mathrm{S} = [a, b]$.

Definition 2. ([20]) The *degree of appurtenance* is defined for fuzzy, intuitionistic fuzzy, or neutrosophic degree of appurtenance to the plithogenic set. It is defined as follows:

$$\forall x \in P, d: P \times V \to \mathcal{P}([0, 1]^z) \tag{1}$$

$d(x, v)$ is a subset of $[0, 1]^z$, $\mathcal{P}([0, 1]^z)$ is the power set of $[0, 1]^z$, where $z = 1, 2, 3$, for fuzzy, intuitionistic fuzzy, and neutrosophic degrees of appurtenance, respectively.

Definition 3. ([20]) The attribute value *contradiction degree function* is defined as follows:

$$c: V \times V \to [0,1] \tag{2}$$

Such that $c(v_1, v_2)$ represents the dissimilarity between two attribute values v_1 and v_2, and satisfies the following axioms:

- $c(v_1, v_1) = 0$, that means the contradiction degree between the attribute value and itself is zero,
- $c(v_1, v_2) = c(v_2, v_1)$.

Definition 4. ([20]) Given a plithogenic set (P, A, V, d, c) a *Plithogenic Neutrosophic Aggregation Operator* is defined as in Equation 3:

$$(a_1, a_2, a_3) \mathrm{AND_p} (b_1, b_2, b_3) = \Big((1 - \bar{c})(a_1 \wedge_F b_1) + \bar{c}(a_1 \vee_F b_1), \frac{1}{2}[a_1 \wedge_F b_1 + a_1 \vee_F b_1], (1 - \bar{c})(a_1 \vee_F b_1) + \bar{c}(a_1 \wedge_F b_1)\Big) \tag{3}$$

Where $\bar{c} \in [0, 1]$, $\wedge_F$ is a t-norm and $\vee_F$ is a t-conorm, see [18].

It is a *Plithogenic Neutrosophic Intersection* when $\bar{c} = 0$ and it is a *Plithogenic Neutrosophic Union* when $\bar{c} = 1$, [20]. This aggregator is more accurate than both the n-norms and n-conorms between neutrosophic sets, [19].

A plithogenic neutrosophic set can be converted into a crisp value using the following formula, [1]:

$$\mathcal{S}(T, I, F) = \frac{1}{3}(2 + T - I - F) \tag{4}$$

Maybe for the first time one logical theory admits any logical theory to realize a semantic evaluation, in this case plithogenic logic can use either fuzzy, intuitionistic fuzzy, neutrosophic logics or even a more general semantic for evaluating the propositions or logical formulas. So, it depends of the authors and the problem to be solved the choice to make with respect to the logic. Evidently, fuzzy logic is the simpler one, but the less accurate, so simplicity is opposite to accuracy.

Additionally, this novel theory seems to be designed for making complex decision-making. Explicitly, one must define the attributes we investigate for, and they are associated with a set of possible values, which can be represented in an imprecise form. Therefore, now the degree of appurtenance is the function used to introduce the selected semantic, which is either that of fuzzy logic, intuitionistic fuzzy logic, neutrosophic logic, or others, see Equation 1.

Because of we have to deal with many attributes and their evaluations, we have to define the relationships among all of them. Thus, the contradiction degree function is defined for this purpose, which must have commonsense properties; like that one value has not contradiction with itself and the symmetry of the contradiction between two values.

Equation 3 is used for aggregation, which generalizes the notion of fuzzy t-norm and fuzzy t-conorm depending of one parameter that is the degree of contradiction between two values. However, F. Smarandache modeled the indeterminacy component independent of this parameter of contradiction.

Finally, Equation 4 is used for obtaining a single value from a neutrosophic number. This operation is useful when we have to make a decision and a three component vector is not the simpler representation to choose the best option.

3. PLITHOGENIC MODEL OF PERUVIAN CLAY CLASSIFICATION

The area under study includes the districts of Calleria, Campo Verde and Yarinacocha of the province of Coronel Portillo, Department of Ucayali, Peru.

Seven different types of soils have been identified in the study area, viz., Barrizal, Restinga, Cashibococha, Yarinacocha, Aguajal, Campo Verde and Colina. Morphologically soils Barrizal, Restinga and Cashibococha have profiles type A/C; Yarinacocha, Aguajal and Colina profiles type A/Bw/C and Campo Verde profile types A/Bt/C. The soil Barrizal and Restinga have a high prevalence of the fraction silt in the soil, in Cashibocochait is the predominant fraction sand along the entire profile, highlighting the fine sand. On the ground, in Yarinacochait is the predominant fraction clay, with the exception of the Ap horizon, where stand out the fine sand; on the ground Aguajal, sand predominates decreasing in function of the depth, while the clay increases with depth from the horizon AB; in the ground, Campo Verde, in the horizons: A, AB, and BC are the predominant in sand (fine and very fine), while in the horizons Bt1, Bt2 and Bt3 stands out clearly the clay, forming a typical horizon of diagnosis argilic; in the soil Colina there is a high predominance of sand, decreasing depending on the depth.

The study of the mineralogy of the clay fraction in the representative soils of the Pucallpa area, has been carried out by selecting samples of horizons of the representative profiles of each physiographic unit, such that in the profiles Barrizal, Restinga and Cashibococha (recent alluvial soils), samples of the horizons A and C were taken; while for the profiles Yaronacocha (middle terrace), Aguajal, Campo Verde (high terrace) and Colina (low hill) samples were taken of horizons A, B and C.

The analysis of clay minerals was carried out by the method of X-ray Diffractometry, in the Spectrometry Laboratory of the Faculty of Geology of the National University of Engineering-UNI.

For the analysis by X-ray Diffractometry, the following steps have been followed: Air drying, stove drying at l05°C for 2 hours, sieving at mesh-325, sedimentation of the clay fraction, separation and assembly of the clay fraction, after treatment with glycol or "glycolate", saturated with magnesium, and reading on the diffractometer. The diffractograms were obtained using a XZNEL diffractometer HZ G4/C-2 R.D.A., Cu K alpha radiation/ nickel filter, current voltage 40 KV/35 m.a., record speed 2°/minute, and sweep between 3° and 50°.

The preparation of clay specimens requires: drying, mechanical preparation (spraying and sieving), sedimentation and glycolation. The basis of this analysis by diffractometry, is the following: A stream or beam collimated (aligned) X-ray monochromatic wavelength is incident on a sample crystal clay, will produce diffracted beams obeying the Law of Bragg (l9l3), which allows the determination of the distances spacings that depend specifically of the network parameters (a, b, c, alpha, beta, gamma) and Miller's indices; which are characteristic of each crystal showing the disturbed values due to crystalline imperfections.

The procedure for identifying the species and types of clays in the diffractograms was as follows:

Each peak in the diffractogram according to its location on the scale of 2 is between 3 and 50 degrees (sexagesimal), was measured with precision up to hundredths of a decimal. This calculated value is compared in the table of interplanar distances of common minerals (reference ASTM PD American Society

for Testing and Materials).
As for the percentage has been estimated semi-quantitatively as a function of the intensity (area under the peak) and reflections characteristic of each mineral (the most outstanding), compared with patterns and with the evidence of peaks related to defined symmetries of internal planes.
The results of the semi-quantitative analysis are expressed in approximate percentage (%), the same that correspond to two groups:

(a) clays themselves, including montmorillonite, kaolinite, chlorite, fine mica or illite, halloysite and nacrite;

(b) other clay minerals in which alpha quartz, orthoclase, muscovite, albite, anortite, calcite and Fe-Delta hydroxide have been found.

These approximate percentages are those that define the fuzzy plithogenic membership values to the clay type models and that are represented by plithogenic sets. The appurtenance functions are defined as follows from Equation 1:

$$d: P \times V \times [0, 100] \rightarrow \mathcal{P}([0,1]) \quad (5)$$

Where P is the plithogenic set which means the type of clay fraction being treated, V is the set of the attributes that are measured from the groups (a) and (b) mentioned above. Whereas $d(P, v_i, p)$ is the truth value corresponding to the fuzzy degree of appurtenance of the ith soil component (belonging to groups (a) or (b) mentioned above) and such P contains a p% of v_i within its composition.
In particular we will use a triangular membership function from $[0\%, 100\%]$ to $[0, 1]$ which denotes the truth value corresponding to the percent of v_i that exists in the K-type fraction clay represented by the plithogenic set P_K. Because these approaches do not take an exact value of the percent, but an approximation of $\pm 2\%$, we specifically define the following membership function:

$$trian(x, M) = \begin{cases} \frac{1}{2}(M + 2 - x), if\ M \leq x \leq M + 2 \\ \frac{1}{2}(x - M + 2), if\ M - 2 \leq x \leq M \\ 0, \text{otherwise} \end{cases} \quad (6)$$

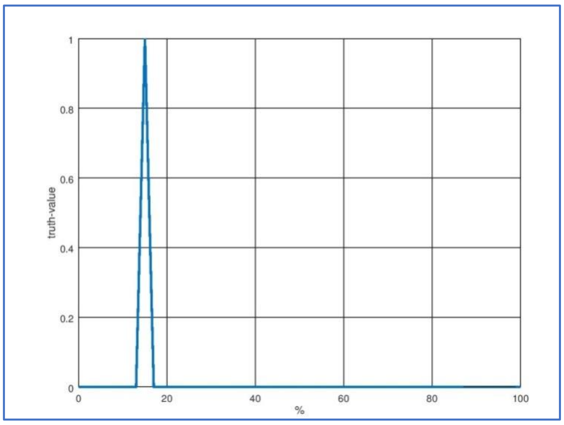

Figure 1: Generic triangular membership function defined in Equation 6

Where x is a percentage of the chemical substance v_i is part in x% of the clay fraction of type K, while M is the value of the percentage where the maximum is reached according to tests made to the soil with type K.
Figure 1 shows the graphical representation of this membership function.
Let us note that we preferred the simpler model for semantic, i.e., we selected both fuzzy logic and triangular membership functions. These kinds of functions are widely used for modeling fuzzy numbers because they satisfy desirable properties for calculation.

The elements of V are denoted as follows:
v1. Montmorillonite,
v2. Kaolinite,
v3. Chlorite,
v4. Fine Mica or illita,
v5. Halloysite,
v6. Nacrite.
Other clay minerals that have been found are as follows:
v7. Alpha quartz,
v8. Orthoclase,
v9. Muscovite,
v10. Bleached,
v11. Calcite,
v12. Anorthitis,
v13. Fe-Delta hydroxide,
v14. Others.

v_i	M% of horizon Ap	M% of horizon 2C
v_1	40%	0%
v_2	0%	0%
v_3	10%	30%
v_4	0%	30%
v_5	0%	0%
v_6	0%	0%
v_7	20%	15%
v_8	15%	10%
v_9	5%	10%
v_{10}	5%	0%
v_{11}	5%	5%
v_{12}	0%	0%
v_{13}	0%	0%
v_{14}	0%	0%

Table 1: Values of M% of Equation 6 for the minerals the clay fraction in the Barrizal profile, AP and 2C horizons.

v_i	M% of horizon Ap	M% of horizon 3C
v_1	20%	0%
v_2	0%	0%
v_3	0%	0%
v_4	20%	0%
v_5	15%	45%
v_6	0%	0%
v_7	20%	20%
v_8	20%	0%
v_9	0%	20%
v_{10}	0%	0%
v_{11}	5%	0%
v_{12}	0%	15%
v_{13}	0%	0%
v_{14}	0%	0%

Table 2: Values of M% of Equation 6 for minerals in the clay fraction. in the Restinga profile, Ap and 3C horizons.

v_i	M% of horizon A	M% of horizon 2C
v_1	75%	45%
v_2	0%	0%
v_3	0%	20%
v_4	0%	0%
v_5	0%	0%
v_6	0%	0%
v_7	25%	30%
v_8	0%	0%
v_9	0%	0%
v_{10}	0%	5%
v_{11}	0%	0%
v_{12}	0%	0%
v_{13}	0%	0%
v_{14}	0%	0%

Table 3: Values of M% of Equation 6 for minerals in the clay fraction in in the profile Cashibococha, horizons A and 2C

v_i	M% of horizon Ap	M% of horizon Bw2	M% of horizon Cg
v_1	75%	70%	60%
v_2	0%	0%	15%
v_3	0%	0%	0%
v_4	0%	0%	0%
v_5	0%	0%	0%
v_6	0%	0%	0%
v_7	20%	20%	20%
v_8	0%	0%	0%
v_9	0%	0%	0%
v_{10}	0%	0%	0%
v_{11}	0%	0%	0%
v_{12}	0%	0%	0%
v_{13}	0%	5%	0%
v_{14}	5%	5%	5%

Table 4: Values of M% of Equation 6 for minerals in the clay fraction in the Yarinacocha profile, Ap, Bw2 and Cg horizons.

v_i	M% of horizon Ap	M% of horizon Bw2	M% of horizon Cg
v_1	80%	80%	75%
v_2	0%	0%	0%
v_3	0%	0%	0%
v_4	0%	0%	0%
v_5	0%	0%	0%
v_6	0%	0%	0%
v_7	20%	20%	25%
v_8	0%	0%	0%
v_9	0%	0%	0%
v_{10}	0%	0%	0%
v_{11}	0%	0%	0%
v_{12}	0%	0%	0%
v_{13}	0%	0%	0%
v_{14}	0%	0%	0%

Table 5: Values of M% of Equation 6 for the minerals in the clay. fraction in the Aguajal profile, horizons A, Bwg and Cg.

v_i	M% of horizon A	M% of horizon Bw1	M% of horizon 2C
v_1	35%	70%	0%
v_2	0%	0%	35%
v_3	0%	0%	0%
v_4	0%	0%	30%
v_5	0%	0%	0%
v_6	25%	0%	0%
v_7	20%	20%	30%
v_8	0%	0%	0%
v_9	0%	0%	0%
v_{10}	15%	0%	0%
v_{11}	0%	0%	0%
v_{12}	0%	0%	0%
v_{13}	0%	10%	0%
v_{14}	5%	0%	5%

Table 6: Values of M% of Equation 6 for minerals in the clay fraction in the Campo Verde profile, horizons A, Bt2 and BC.

v_i	M% of horizon A	M% of horizon Bw1	M% of horizon 2C
v_1	35%	70%	0%
v_2	0%	0%	35%
v_3	0%	0%	0%
v_4	0%	0%	30%
v_5	0%	0%	0%
v_6	25%	0%	0%
v_7	20%	20%	30%
v_8	0%	0%	0%
v_9	0%	0%	0%
v_{10}	15%	0%	0%
v_{11}	0%	0%	0%
v_{12}	0%	0%	0%
v_{13}	0%	10%	0%
v_{14}	5%	0%	5%

Table 7: Values of M% of Equation 6 for minerals in the clay fraction in the Colina Baja profile, horizons A, Bw1 and 2C.

Tables 1-7 show the values of M% of Equation 6 obtained from the tests performed on soils, for each profile with each of its horizons, for the v_i minerals, according to the order that appears in the previous paragraph. Let us remark that we processed the data supported in Octave 4.2.1 and its m programming language ([10]), See that according to these results we cannot characterize each horizon for its physicochemical properties, e.g., the distribution of components represented in Table 4 is more or less similar for the three studied horizon, so it is easy to confound one with other.

To detrmine if a clay fraction corresponds to any of the 18 profiles and horizons characterized by the values in Tables 1-7, using Equations 5, 6, proceed as follows:

1. If P_u denotes the plithogenic number representing the unknown clay material to be classified. Suppose $p_i$are the percent of v_i contained in the unknown material.
   Values $t_{ij} = \mathrm{d_j}\left(P_j, v_i, p_i\%\right)$ (i=1,2,...,13)(j = 1,2,...,18) are calculated, where t_{ij} is the truth value of the statement "p_i percent of the substance v_i is part of P_j", which is evaluated using the fuzzy degree of appurtenance of Equation 5, for each of the profiles and horizons shown in Tables 1-7.
   For each profile j, for $\bar{c} = 0$ the Plithogenic Neutrosophic Intersection corresponding to Equation 3 with the triple $\left(t_{ij}, p_i/100\,, 1 - t_{ij}\right)$ is used. Let us call $PN_j = \left(T_j, I_j, F_j\right)$ (j = 1, 2,...,18) the aggregated values of $\left(t_{ij}, p_i/100\,, 1 - t_{ij}\right)$ with Equation 3.
2. A minimum truth value is set to $\epsilon \in [0, 1]$, which means the threshold truth-value for P_u to be considered within one of the types of profiles and horizons (j = 1,2,...,18).
3. If $R_{\hat{j}} = max_j\{\mathcal{S}(PN_j)\}$ where $\mathcal{S}(\cdot)$ corresponds to Equation 4, such that $R_{\hat{j}} \geq \epsilon$, then P_u is classified within the profile and horizon represented by the ĵth element. Otherwise, P_u is said to remain unclassifiable.

Let us comment the points of the method defined above. In point 1 we assign a three component vector to the data. Equation 6 converts the percentage scale into a [0, 1] scale, such that the real percent is evaluated with respect to the parameters of the ideal values, so it is a first step toward the classification in the method. The indeterminate component is defined as a percentage divided by 100; here we consider the criterion that the most determinate percent is 0%. Point 2 is used for fixing the threshold for classification. In point 3 we convert the vector values in scalars, and it is where the decision is made. The criterion is that the final numeric value must surpass the threshold for being classified like the target kind of horizon. Obviously, the selected threshold serves as a measure of accuracy of the classification. The precedent algorithm can be used in the classification of clays in any geographical region, not only the Peruvian ones.

Example 1: Suppose a clay material is obtained from Peruvian soil, let us denote it by P_u. It is desired to compare with each of the types of soil that have been studied above. The results of the P_u study produced the results shown in Tables 8-9.

v_i	P_u	Barrizal Ap	Barrizal 2C	Restinga Ap	Restinga 3C	Cashibococha A	Cashibococha 2C	Yarinacocha Ap	Yarinacocha Bw2	Yarinacocha Cg
v_1	35.1%	0	0	0	0	0	0	0	0	0
v_2	0%	1	1	1	1	1	1	1	1	0
v_3	0%	0	0	1	1	1	0	1	1	1
v_4	0%	1	0	0	1	1	1	1	1	1
v_5	0%	1	1	0	0	1	1	1	1	1
v_6	24.99%	0	0	0	0	0	0	0	0	0
v_7	20.1%	0.95	0	0.95	0.95	0	0	0.95	0.95	0.95
v_8	0%	0	0	0	1	1	1	1	1	1
v_9	0%	0	0	1	0	1	1	1	1	1
v_{10}	14.93%	0	0	0	0	0	0	0	0	0
v_{11}	0%	0	0	0	1	1	1	1	1	1
v_{12}	0%	1	1	1	0	1	1	1	1	1
v_{13}	0%	1	1	1	1	1	1	1	0	1
v_{14}	4.88%	0	0	0	0	0	0	0.05	0.05	0.05

Table 8: p_i% values for P_u, and its t_{ij} truth values for each of 9 profiles and horizons. I_j is included.

v_i	P_u	Aguajal A	AguajalBwg	Aguajal Cg	Campo Verde A	Campo Verde Bt2	Campo Verde BC	Colina baja A	Colina baja Bw1	Colina baja 2C
v_1	35.1%	0	0	0	0	0	0	0.95	0	0
v_2	0%	1	1	1	1	1	1	1	1	0
v_3	0%	1	1	1	1	1	1	1	1	1
v_4	0%	1	1	1	1	1	1	1	1	0
v_5	0%	1	1	1	1	0	1	1	1	1
v_6	24.99%	0	0	0	0	0	0	0.995	0	0
v_7	20.1%	0.95	0.95	0	0	0.95	0.95	0.95	0.95	0

v_8 0%	1	1	1	1	1	1	1	1	1
v_9 0%	1	1	1	1	1	1	1	1	1
v_{10} 14.93%	0	0	0	0	0	0	0.965	0	0
v_{11} 0%	1	1	1	1	1	1	1	1	1
v_{12} 0%	1	1	1	1	1	1	1	1	1
v_{13} 0%	1	1	1	1	1	1	1	0	1
v_{14} 4.88%	0	0	0	0.05	0.05	0.05	0.05	0	0.05

Table 9: p_i% values for P_u, and its t_{ij} truth values for each of 9 profiles and horizons. I_j is included

Evidently, from the results obtained from Tables 8, 9 the profile closest to P_u corresponds to Colina Baja horizon A. Suppose $\epsilon = 0.9$ is fixed.

By aggregating the results of this profile and horizon, using the Plithogenic Neutrosophic Intersection for the values$(0.95, 0.05, 0.05), (1, 0.05, 0), (0.995, 0.05, 0.005), (0.965, 0.05, 0.035)$, we have $PN_{16} = (0.95, 0.05, 0.05)$.

This value is converted to a unique value using Equation 4 obtaining $\mathcal{S}(PN_{16}) = 0.95 > \epsilon = 0.9$. So, P_u is considered a Colina Baja horizon A.

4. CONCLUSION

This paper was dedicated to design a method based on plithogenic numbers for the classification of clay fractions, corresponding to 18 different types of collected clays in some Peruvian areas, especially in Pucallpa, rich in this material of great economic and social importance. With this method it is possible to determine whether a clay material corresponds to one of these profiles, which in turn makes it possible to determine its possible practical use. As far as the authors' knowledge goes, this is the first time that the novel theory of plithogenic sets has been used to solve mining problems, which serves as proof that plithogeny is applicable in the modeling of other real-life problems, beyond decision-making, education and management. This is a novel method when comparing with the other ones appeared in the scientific literature, because here we deal with uncertainty and indeterminacy in the classification, whereas the precedents methods are crisps. Also, the obtained result can be used in the classification of soils in other regions of the Peruvian territory. In fact, they were proposed to some mining enterprises in the zone as a useful application to solve real-world problems. The method of classifying clays based on plithogenic sets can be generalized to other studies. In future works we will publish the effectiveness of applying this method to classify clays in many Peruvian regions with similar composition of oils.

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