



## Particle Size Identification In Diatomaceous Soils \_ Hydrometry Vs Image Processing

Daniel A. Zuluaga-Astudillo<sup>1,2 \*</sup>, Yessica A. Ortiz-Murillo<sup>1</sup>, Carolina Gómez-Mora<sup>1</sup>

<sup>1</sup> Programa de Especialización en Diseño y Construcción de Vías y Aeropistas, Escuela de Ingenieros Militares. Ejército de Colombia, Bogotá 111611, Colombia, [estudianteyessica.ortiz@esing.edu.co](mailto:estudianteyessica.ortiz@esing.edu.co), [estudiantecarolina.gomez@esing.edu.co](mailto:estudiantecarolina.gomez@esing.edu.co)

<sup>2</sup> Programa de Doctorado en Ingeniería, Universidad Militar Nueva Granada. Bogotá 110111, Colombia.

### Abstract

The particle size distribution of soils greatly influences their mechanical and hydraulic behavior. Therefore, it is necessary to adequately characterize soils by applying standardized or alternative methods with a high level of precision. Diatomaceous soils are the product of sedimentation of fossilized frustules. They have a high silica content, a particle size ranging from nano to micro, and varied morphologies. These soils have particular properties, such as high porosity, low density, and great absorption capacity, and exhibit unusual geotechnical behavior. The distribution of particle sizes and its relationship with soil strength and compressibility have not been extensively studied. The distinctive nature and sizes of these particles necessitate identification and characterization through microscopic observation. In this study, we determined the particle size distribution of three diatomaceous soils of different origins (Colombia, Mexico, and Peru) and morphological characteristics using the traditional hydrometry method. These results were contrasted with the size distribution obtained from scanning electron microscopy (SEM) image processing and analysis. The goal of this study is to determine a possible correlation between the two methodologies so that size assessments can be performed efficiently and effectively. The results revealed differences between diatom species, and a significant numerical adjustment was established between the methods for samples of Colombian and Mexican origin.

**Keywords:** Diatomaceous soils, particle size distribution, scanning electron microscopy, hydrometry, image processing.

### Introduction

Diatoms are microscopic algae with a siliceous skeleton called a frustule [1], [2] that form in aquatic environments [3], [4], [5], soils, and moist surfaces [6] [7]. Their reproduction depends on the physical and chemical conditions of the environment in which they live (turbidity, temperature, light, pH, nutrients, salinity) [8].

Diatom soils originate from the sedimentation of frustules [4]. Frustules, composed mainly of silica [9], undergo deterioration or dissolution [10], fracturing due to friction and crushing due to geostatic loads, which modifies the size of their particles. Typical sizes range from 20 to 200  $\mu\text{m}$  [11], [12], [13].

The size of DS particles generally ranges from 0.002 mm to 0.075 mm. Frustules induce changes in the liquid limit (LL) of the soil [14], [15], the plasticity index (PI) [16], and the effective friction angle ( $\phi'$ ) [17], [18]. The size of the fossils determines the forces that govern at the micro and nano scales (capillarity, electrical, attraction, repulsion) [19].

Fine soils (silts and clays) are defined by their behavior and particle size [20]. Soils with representative fossil content cannot be explained by typical methods related to organic or inorganic soils. Methods based on plasticity (Casagrande) are inadequate for categorizing DS [5], [21], [22], [23]. The results obtained with FS are unexpected and do not agree with classical theories of soil mechanics, and they exhibit problematic or uncertain engineering properties [24], [25], [26], [27]. DS should be considered a separate soil type [28], and a new classification system should be created for "fossil-bearing soils" [21], [29].

The characterization of DS should include microscopic analysis [20], [30] in order to recognize fossil conditions. Scanning electron microscope observation [5], X-ray diffraction (XRD), and porosimetry tests facilitate understanding of the soil when regular mechanical tests are not sufficient [20], [31].

The size of the frustules defines the magnitude of the pores, density, water storage capacity [32], and surface patterns. In most cases, DS are complemented by small fractions of sand ( $>0.075$  mm) and clays ( $<2$   $\mu\text{m}$ ). The clay fractions could be fragments of frustules rather than phyllosilicates or alumina flakes (clays such as kaolinite, illite, montmorillonite, smectite) [31]. Therefore, the fossil concentration in DS could be greater than 50% [33].

Artificial intelligence and image processing methods are increasingly being adopted in geotechnical studies, particularly to determine physical properties, predict mechanical responses, define particle shape (sphericity, roundness, roughness) [34], establishing sand, silt, and clay fractions [35], describing soil texture [36], and determining the influence of cyanobacteria on soil crack patterns [37].

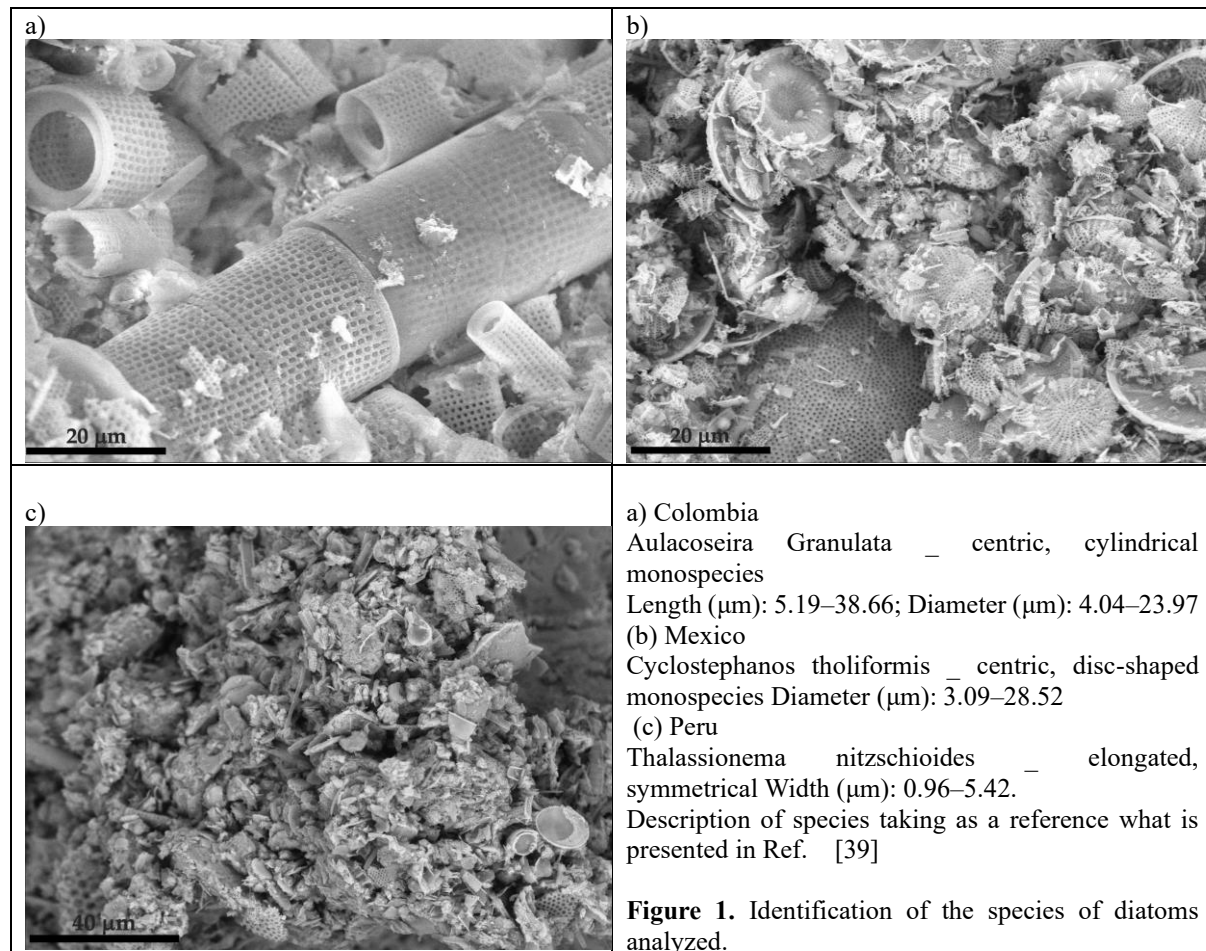
These applications are driven by time and cost savings (image analysis vs. conventional laboratory testing), by the understanding of the physical response of a material at the micro and nanoscale, and by the possibility of quantifying the organization of particles within the soil [38].

Image processing methods provide more detailed data and make it easier to understand soil structure and heterogeneity. The information obtained through these techniques can improve efficiency (large volumes of data) in industrial and environmental applications.

The objective of this research was to determine the particle size distribution of the studied diatomaceous soils (Colombia, Mexico, Peru) by means of the traditional hydrometry method and to contrast it with the distribution obtained from the processing and analysis of scanning electron microscopy (SEM) images. This is in order to propose possible correlations between the two methodologies and to assess particle sizes in an assisted and efficient way.

## Materials And Methods

The hydrometry tests and scanning electron microscopy observations were carried out on samples of frustular soils from three different origins (Colombia, Peru and Mexico) which on a micro scale stood out for having distinctive morphologies (**Figure 1**). This is derived from the differentiation of species in the diatoms that originated each soil.



Each of the soils was subjected to a process of agitation (30 cycles) and mixed within a liquid medium (regular water), in a soil:2 volumetric ratio of 1:2, and its subsequent rest (7 days) within columns that allowed the progressive sedimentation of the particles, with the understanding that those of greater size and weight would precipitate with a greater rate to the deepest part of the cylindrical container (diameter 3 inches, total mixing height 90 cm).

In this way, and once the soil was settled, the excess water was extracted and the soil column was removed, which was divided into three fractions of equal height (deep, medium, upper), each of which was associated with an expected particle size, that is, in the deep part the highest concentration of large size (whole frustules) was expected. while in the upper part the highest content of fine material (clay or fossil fragments) was expected.

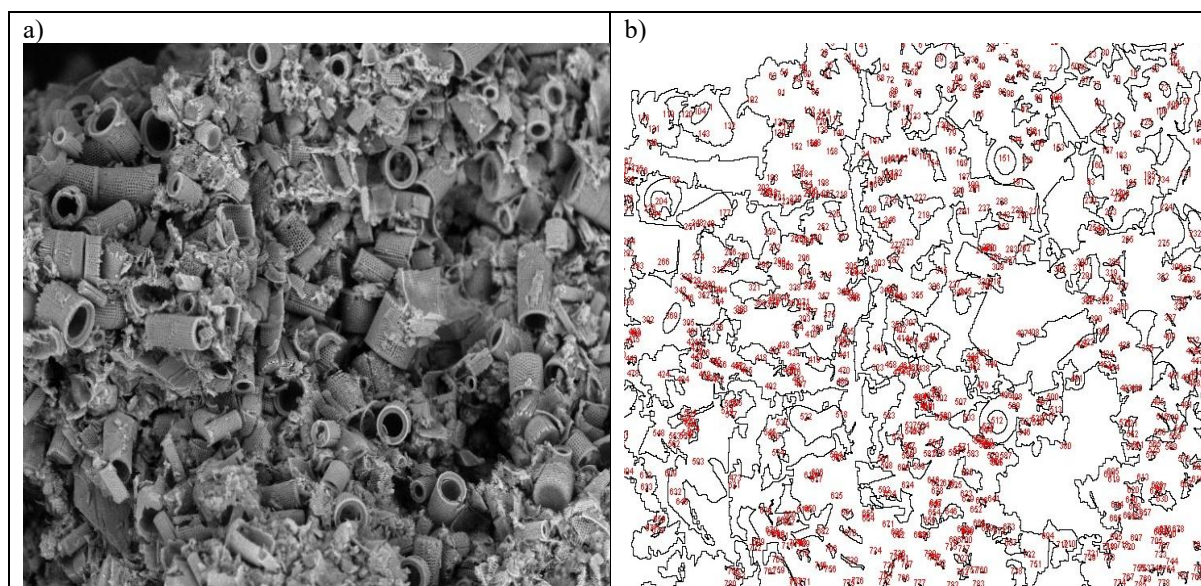
The separated soil fractions were subjected to drying and then the procedure described in the INV E 123-13 standard in order to determine the size and distribution of particles in soils by hydrometer for particles less than 75 µm. A total of twenty-seven particle size records were obtained, nine for each type of soil, and three for each fraction.

Subsequently, each fraction (upper, middle, lower) of each soil type was observed by Scanning Electron Microscope (SEM) in a variable magnification range between 400X – 13000X. The condition selected for the comparative analysis was 1600X (scale that allows the identification of details in individual particles with and the interaction between them, by simple contact or agglomeration - approximate area 7842 µm<sup>2</sup> )

The MEB used is of the Carl Zeiss Evo HD 15 reference, which has a LaB6 emitter (lanthanum hexaboride) and uses the "Smart SEM version 5.07" software. Analyses were performed in low-vacuum mode to preserve sample integrity. Previously, the samples were gold-coated using a Quorum Q150R ES metallizer to ensure good conductivity and image quality, and to minimize loading effects.

Once the images were defined, they were processed in the "Image J" software (version 1.53). On the duplicate of each of them, the scale was fixed and the conversion to 8-bit format was made, which allowed a binarization process to be applied. Then a triple erosion was applied, gaps were filled, and finally the particle analysis (calculation of areas) was done.

The ImageJ software and this type of procedures have previously been applied to the study of diatom frustules, in particular to assess areas of areolas and to project the profiles of the surfaces of the fossil, which is relevant in this study [40].

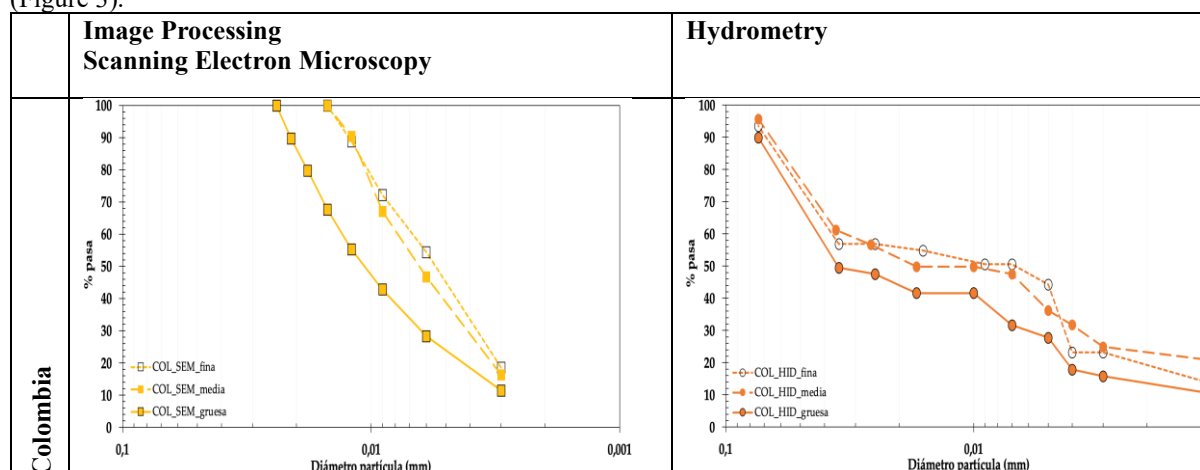


**Figure 2.** Example of the sequence in the processing of images \_ Colombian species.

a) Initial condition \_ Microscopy imaging b) delimitation and counting of particles.

## RESULTS

Next, the results of the distribution of particle sizes obtained by the hydrometry method and by image processing in each soil (Colombia, Mexico, Peru) are presented, discriminating each of the phases: fine, medium, coarse (Figure 3).



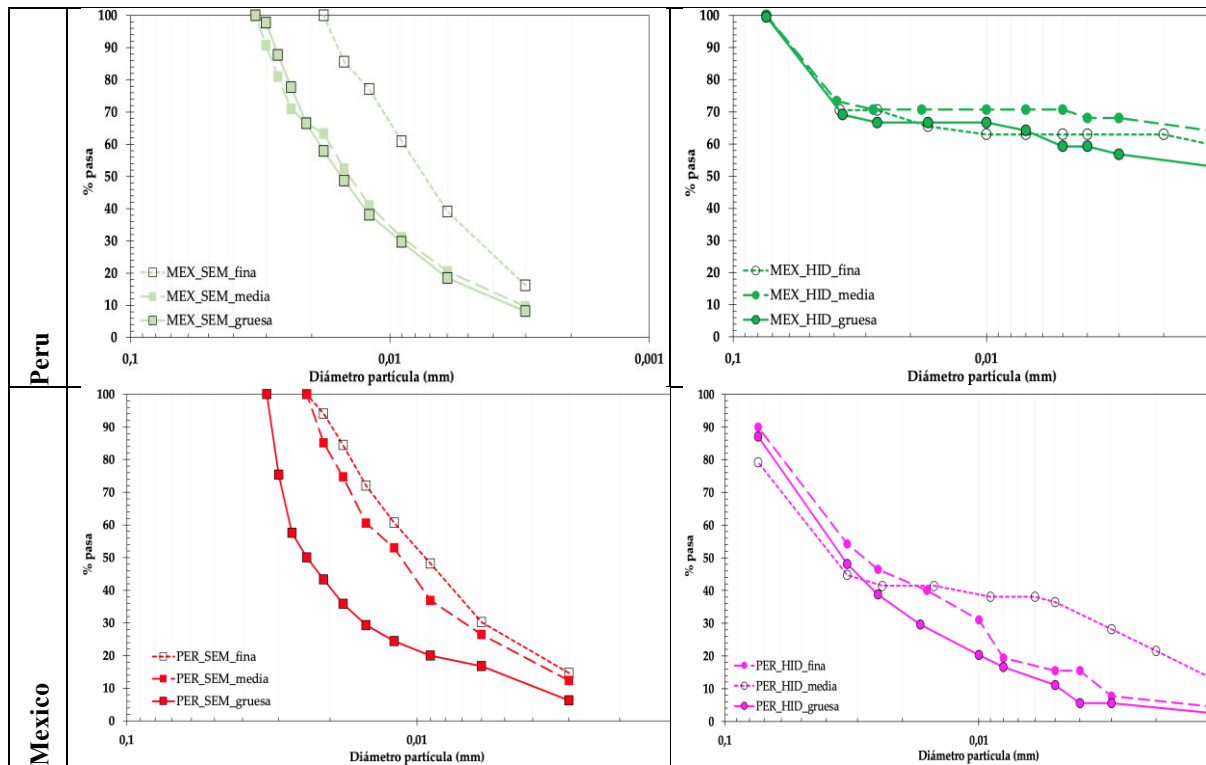
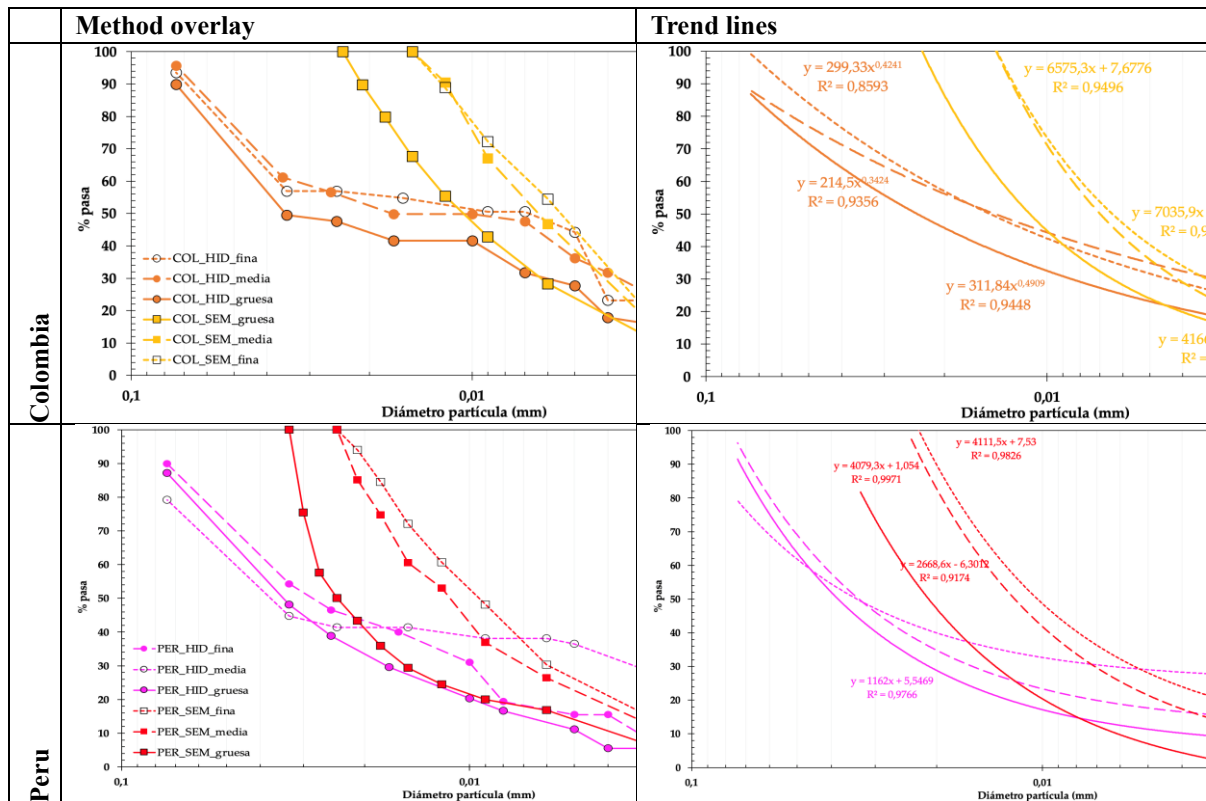


Figure 3. Particle size distribution discriminated by origin and fraction.

Figure 4 shows the superposition of the curves of both methods (hydrometry – microscopy) for each of their phases, as well as the projection of the trend lines that best describe their behavior with  $r^2$  values greater than 0.82. The latter are useful in the calculation of differences and in the determination of adjustment factors.



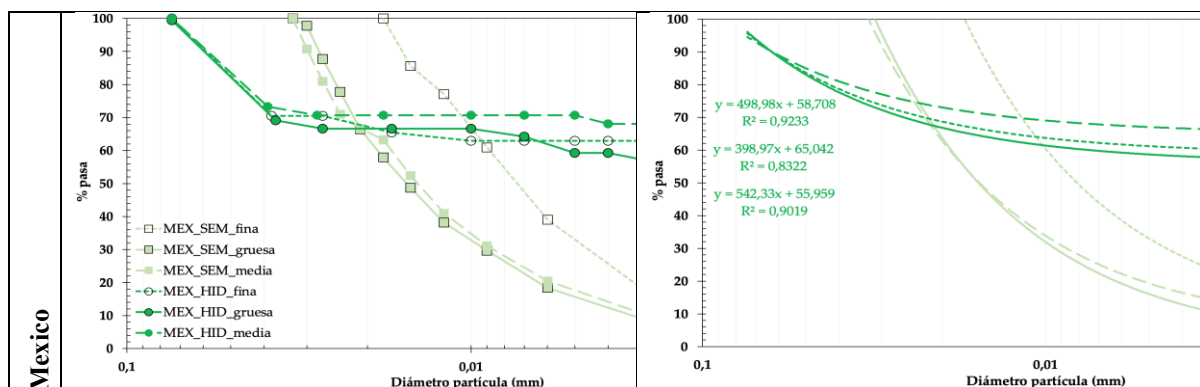


Figure 4. Method overlay and trend lines.

Once the corresponding adjustment models were applied to the particle diameter detected in the image processing, the curves of both methods were approximated, finding a good correspondence in the samples of Colombian and Peruvian origin. However, in the Mexican sample the adjustment was not positive given the difference not only in the particle size but also in the percentages of material that would pass in each size (Figure 5).

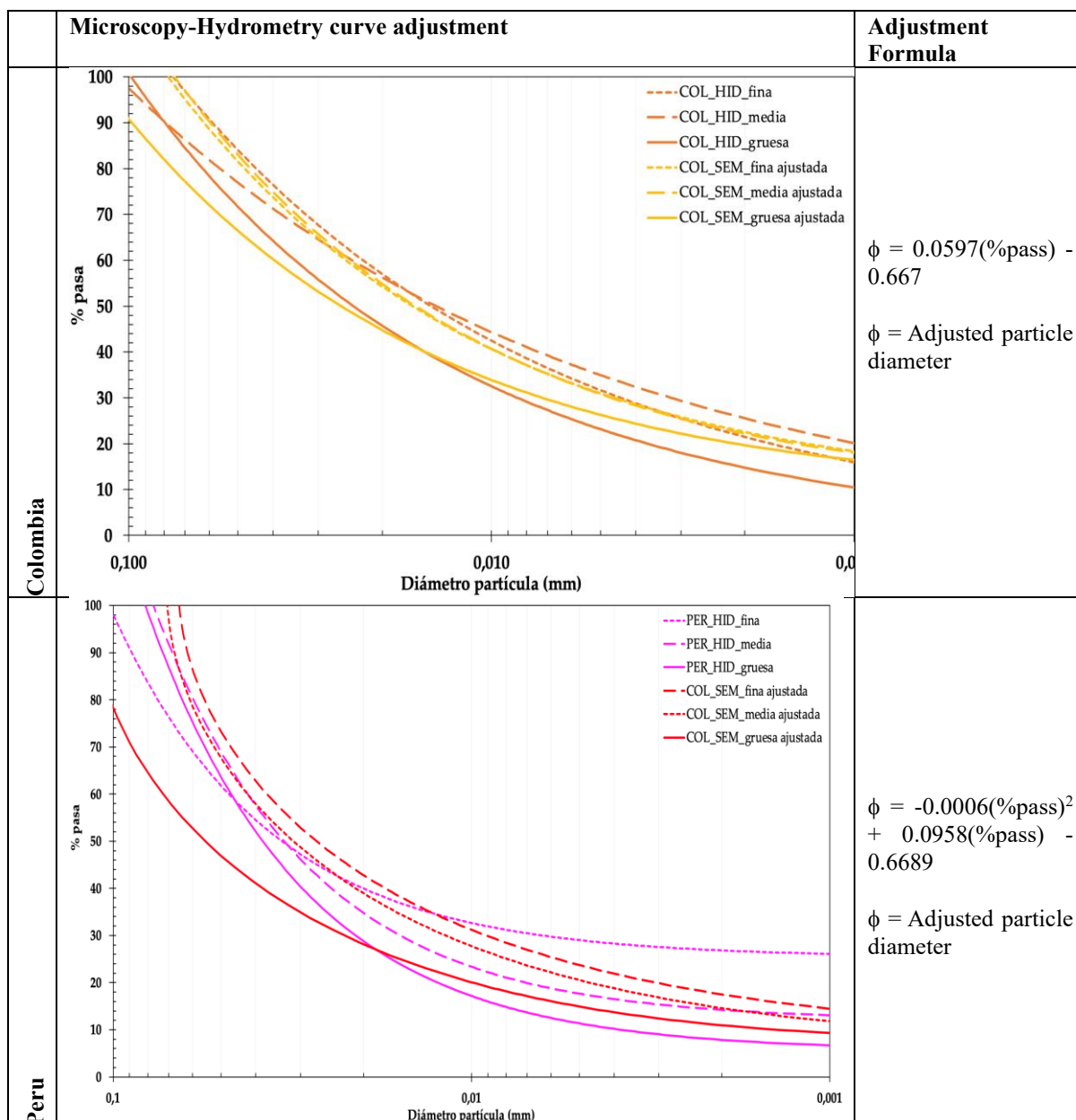


Figure 5. Adjustment of curves between Microscopy-Hydrometry methods

### Conclusion

- The evaluation carried out by scanning electron microscopy allowed to obtain detailed images of the particles present in the diatomaceous soils, identifying frustules belonging to different species. The variations observed in

morphology and size between species facilitated their classification, contributing significantly to the understanding of the distribution of particles in these soils. These findings offer a solid basis for future studies on the ecological and sedimentary characteristics of diatomaceous soils.

- The results obtained show that, although there is a correlation (for the Colombian and Peruvian sample) between the distribution of particle sizes measured by hydrometry and the dimensions determined by scanning electron microscopy (image processing), the latter method proved to be more detailed in the characterization at the particle level since the individual dimension can be observed, but the hydrometry turns out to be more detailed in terms of the total distribution of the soil mass. The high resolution and discrimination capacity of microscopy techniques allow the identification of morphological and dimensional variations that hydrometry cannot capture, positioning them as fundamental tools for advanced studies of particle characterization and validation of traditional physical methods.
- Based on these results, it is recommended to prioritize the use of image processing techniques in research that requires high resolution and precision in the characterization of particles, as well as to develop complementary studies that explore the application of predictive models and multivariate analysis to optimize the integration between physical and digital methods in the analysis of diatomaceous soils.

## References

- [1] M. Lutynski, P. Sakiewicz, and S. Lutynski, "Characterization of Diatomaceous Earth and Halloysite Resources of Poland," *Minerals*, vol. 9, no. 670, pp. 1–17, 2019.
- [2] Z. V. Finkel and B. Kotrc, "Silica use through time: Macroevolutionary change in the morphology of the diatom *fustule*," *Geomicrobiol J*, vol. 27, no. 6–7, pp. 596–608, 2010, doi: 10.1080/01490451003702941.
- [3] H. Al Shatnawi and P. Bandini, "Oedometric Behavior of a Diatom-Kaolin Mixture," in *Geo-Congress 2019*, C. Meehan, S. Kumar, M. Pando, and J. Coe, Eds., Philadelphia: ASCE Library, 2019, pp. 673–681.
- [4] R. J. Flower, *Diatomites: Their Formation, Distribution, and Uses*, 2nd ed. Elsevier B.V., 2013. doi: 10.1016/B978-0-444-53643-3.00220-X.
- [5] A. Covarrubias, J. Wang, D. Moug, M. Evans, and A. Walter, "Geo-Congress 2022 ASCE," in *Relating the Proportion of Diatom Particles to the Physical Properties of Natural Diatomaceous Soil*, ASCE, Ed., 2022, pp. 479–489.
- [6] I. C. Gebeshuber, "Biotribology inspires new technologies," *Nano Today*, vol. 2, no. 5, pp. 30–37, 2007.
- [7] F. Sterrenburg, R. Gordon, M. A. Tiffany, S. Nagy, and J. Seckback, "Diatoms: Living in a Constructal Environment," in *Algae and Cyanobacteria in Extreme Environments*, 1st ed., Joseph Seckbach, Ed., Dordrecht: Springer, Dordrecht, 2007, ch. Diatoms: L, pp. 141–172. doi: <https://doi-org.ezproxy.umng.edu.co/10.1007/978-1-4020-6112-7>.
- [8] J. F. Ponce and M. Fernández, "Diatom Analysis," in *Climatic and Environmental History of Isla de los Estados*, SpringerBriefs in Earth System Sciences, 2014, ch. Diatom Ana, pp. 87–104. doi: 10.1007/978-94-007-4363-2\_8.
- [9] M. Hasan, T. Saidi, A. Muayisir, Y. R. Alkhaly, and M. Muslimsyah, "Characteristic of calcined diatomaceous earth from Aceh Besar District - Indonesia as cementitious binder," *IOP Conf Ser Mater Sci Eng*, vol. 933, no. 1, 2020, doi: 10.1088/1757-899X/933/1/012008.
- [10] J. P. Warnock and R. P. Scherer, "Diatom species abundance and morphologically-based dissolution proxies in coastal Southern Ocean assemblages," *Cont Shelf Res*, vol. 102, pp. 1–8, 2015, doi: 10.1016/j.csr.2015.04.012.
- [11] U. College London and M. Olney, "Microfossil Image Recovery and circulation for learning and education," *Micropalaeontology Unit*. Accessed: Nov. 15, 2021. [Online]. Available: <https://www.ucl.ac.uk/GeolSci/micropal/diatom.html>
- [12] J. López, "Comportamiento cíclico de suelos diatomáceos," *Universidad Nacional Autónoma de México*, 2009.
- [13] Y. Lozano, "LISTADO DE DIATOMEAS (BACILLARIOPHYTA) REGISTRADAS PARA EL MAR CARIBE COLOMBIANO," *Bol. Invest. Mar. Cost.*, vol. 39, no. 1, pp. 83–116, 2010.
- [14] J. Díaz, "Comportamiento monotónico de suelos diatomáceos," *Rev. Int. de Desastres Naturales, Accidentes e Infraestructura Civil*, vol. 12, no. 1, pp. 27–34, 2011.
- [15] D. Shiwakoti, H. Tanaka, M. Tanaka, and J. Local, "Influences of Diatom microfossils on engineering properties of soils," *SOILS AND FOUNDATIONS 土と基礎* Japanese Geotechnical Society, vol. 42, no. 3, pp. 1–17, 2002, doi: 10.3208/sandf.47.887.
- [16] B. Caicedo, D. Zuluaga, and C. Slebi, "Effects of micro-features of fossil diatom on the macroscopic behaviour of soils," *Geotechnique Letters*, vol. 9, no. 4, pp. 322–327, 2019, doi: 10.1680/jgele.18.00204.
- [17] G. Arenaldi and C. Ovalle, "Compresibilidad y propiedades dinámicas de suelos diatomáceos de Mejillones Compressibility and dynamic properties of diatomaceous soils of Mejillones Introducción Sector de estudio Material de ensayo," *Obras y Proyectos*, vol. 25, pp. 6–14, 2019.
- [18] G. Arenaldi, C. Ovalle, and A. Barrios, "Compressibility and creep of a diatomaceous soil," *Eng Geol*, vol. 258, no. May, p. 105145, 2019, doi: 10.1016/j.enggeo.2019.105145.
- [19] GeoInstitute and C. Santamarina, *US. Terzaghi Lecture - Energy Geotechnology: Habilitando nuevos conocimientos sobre el comportamiento del suelo*, (2014).
- [20] N. Ural, "The significance of scanning electron microscopy ( SEM ) analysis on the microstructure of improved clay : An overview," *DE GRUYTER Open Geosciences*, vol. 13, pp. 197–218, 2021.
- [21] J. Locat and H. Tanaka, "A new class of soils: fossiliferous soils?," in *XV International Conference of Soil Mechanics and Geotechnical Engineering*, Istanbul: Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), 2001, pp. 2295–2300.

- [22] Y. Xu, X. Zhang, X. Liu, and G. Wang, "Alterations of physical properties and microstructure of marine diatomite owing to variation of diatom content," *Marine Georesources & Geotechnology*, vol. 0, no. 0, pp. 1–12, 2022, doi: 10.1080/1064119x.2022.2046664.
- [23] T. M. Evans and D. Moug, "Diatomaceous soils: a less than cromulent engineering material," *Geotechnics for Sustainable Infrastructure Development*, vol. 62, pp. 709–716, 2020, doi: [https://doi.org/10.1007/978-981-15-2184-3\\_92](https://doi.org/10.1007/978-981-15-2184-3_92).
- [24] J. Wang, E. Yazdani, and T. Evans, "Case study of a driven pile foundation in diatomaceous soil. I: Site characterization and engineering properties," *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 13, no. 2, pp. 431–445, 2021, doi: 10.1016/j.jrmge.2020.10.006.
- [25] C. Ovalle and G. Arenaldi, "Mechanical behaviour of undisturbed diatomaceous soil," *Marine Georesources and Geotechnology*, vol. 39, no. 5, pp. 623–630, 2020, doi: 10.1080/1064119X.2020.1720049.
- [26] B. Caicedo, C. Mendoza, F. López, and A. Lizcano, "Behavior of diatomaceous soil in lacustrine deposits of Bogotá, Colombia," *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 10, no. 2, pp. 367–379, 2018, doi: 10.1016/j.jrmge.2017.10.005.
- [27] J. L. Qu and D. X. Zhao, "Comparative research on tillable properties of diatomite-improved soils in the Yangtze River Delta region, China," *Science of the Total Environment*, vol. 568, pp. 480–488, 2016, doi: 10.1016/j.scitotenv.2016.06.056.
- [28] G. Rajasekaran, "Influence of microfossils and pyrites on the behaviour of oceanbed sediments," *Ocean Engineering*, vol. 33, no. 3–4, pp. 517–529, 2006, doi: 10.1016/j.oceaneng.2005.02.015.
- [29] G. Wiemer, R. Dziadek, and A. Kopf, "The enigmatic consolidation of diatomaceous sediment," *Mar Geol*, vol. 385, pp. 173–184, 2017, doi: 10.1016/j.margeo.2017.01.006.
- [30] D. Igoe and K. Gavin, "Characterization of the Blessington sand geotechnical test site," *AIMS Geosci*, vol. 5, no. 2, pp. 145–162, 2019, doi: 10.3934/geosci.2019.2.145.
- [31] J. Ruge, X. Palacios, F. Molina-Gómez, and J. Rojas Suárez, "Mineralogical, microstructural and porosimetry analysis in three different clayey soils," *J Phys Conf Ser*, vol. 1388, no. 1, pp. 1–8, 2019, doi: 10.1088/1742-6596/1388/1/012014.
- [32] M. Dobrosielska et al., "A new method of diatomaceous earth fractionation—a bio-raw material source for epoxy-based composites," *Materials*, vol. 14, no. 7, 2021, doi: 10.3390/ma14071663.
- [33] H. Tanaka and J. Local, "A microstructural investigation of Osaka Bay clay: The impact of microfossils on its mechanical behaviour," *Canadian Geotechnical Journal*, vol. 36, no. 3, pp. 493–508, 1999, doi: 10.1139/t99-009.
- [34] L. Gao, D. Wang, and Y. Miao, "A review of two-dimensional image-based technologies for size and shape characterization of coarse-grained granular soils," *Powder Technol*, vol. 445, no. June, p. 120115, 2024, doi: 10.1016/j.powtec.2024.120115.
- [35] M. K. Vakilzadeh Ebrahimi, H. Lee, J. Won, S. Kim, and S. S. Park, "Estimation of soil texture by fusion of near-infrared spectroscopy and image data based on convolutional neural network," *Comput Electron Agric*, vol. 212, no. February, p. 108117, 2023, doi: 10.1016/j.compag.2023.108117.
- [36] K. Sattar et al., "Soil texture analysis using controlled image processing," *Smart Agricultural Technology*, vol. 9, no. August, p. 100588, 2024, doi: 10.1016/j.atech.2024.100588.
- [37] S. Gharemahmudli, S. H. Sadeghi, V. S. Sadeghi, A. Najafinejad, and A. Jafarpoor, "Morphometrical analysis of cracks and crevices on a cyanobacterized soil surface subjected to a freeze-thaw cycle using image processing," *Catena (Amst)*, vol. 213, no. February, p. 106150, 2022, doi: 10.1016/j.catena.2022.106150.
- [38] D. Zuluaga, C. Slebi, and J. Ruge, "Correlation of Mechanical Parameters in Diatomaceous Soils Using Image Analysis and Digital Processing," *Journal of Posthumanism*, vol. 5, no. 7, pp. 1740–1754, 2025.
- [39] D. Zuluaga-Astudillo, J. C. Ruge, and B. Caicedo-Hormaza, "Micromechanical Characterization of Diatom Frustules of Multiple Origin," *applied sciences*, vol. 15, no. 749, pp. 1–24, 2025, doi: <https://doi.org/10.3390/app15020749>.
- [40] E. Mosquera and M. Del Valle, "Estudio del comportamiento bajo esfuerzo triaxial de un suelo fino, a partir de la adición de una muestra de diatomeas multiespecie," *Revista Ingenieros Militares*, vol. 17, pp. 1–21, 2022.