Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-1718

Geotechnical spatial characterization of Buenos Aires City soils

Nicolás Tasso, Pedro Fernández
University of Buenos Aires, Buenos Aires, Argentina, ntasso@fi.uba.ar

Mauro Codevilla
AOSA SA, Buenos Aires, Argentina

ABSTRACT: This study provides an update of the geotechnical characterization of the soils in the City of Buenos Aires, with a focus on the Pampeano and Puelche formations, which underlie most of the city's infrastructure. The analysis is based on a comprehensive database of 1884 boreholes collected from 509 site investigations, including SPT data, index testing and descriptive logs. Stratigraphic classification was enhanced used binary segmentation techniques applied to borehole profiles. The results include spatial distribution maps of key parameters, analysis of stratigraphic boundaries, variability in index properties, and limited interpretation of ground behaviour. The findings contribute to a more robust understanding of the geotechnical conditions in Buenos Aires and support data-driven approaches to site characterization and design.

KEYWORDS: Buenos Aires city soils, Geotechnical database, stratigraphic clustering, soil variability.

1 INTRODUCTION

This study presents a comprehensive geotechnical characterization of the soils of Buenos Aires, based on an extensive and geographically distributed database of 1884 boreholes. The objective is to analyse key geotechnical variables and explore their spatial distribution and variability across the city. In addition to traditional analyses, a data-driven clustering algorithm is applied to support stratigraphic classification and identify consistent patterns within the subsurface profile.

The results contribute to a more detailed understanding of the soils in Buenos Aires and aim to complement previous geotechnical characterizations (Codevilla & Sfriso, 2011; Nuñez, 1986).

2 SUBSURFACE CONDITIONS IN BUENOS AIRES

The subsurface profile of Buenos Aires comprises three main geological formations: the Post-Pampeano, Pampeano and Puelchense. These units reflect a complex depositional and pedogenetic history involving fluvial, estuarine, eolian, and lacustrine environments (Núñez, 1986, Tófalo et al., 2011). Their distribution and properties are critical for geotechnical design. A conceptual stratigraphic profile is shown in Figure 1.

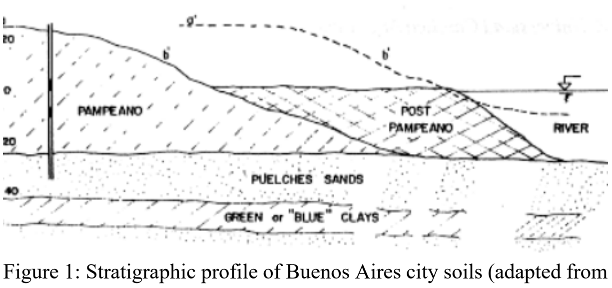

Figure 1: Stratigraphic profile of Buenos Aires city soils (adapted from Núñez, 1986).

The Post-Pampeano Formation is composed of Holocene-age fluvial and estuarine clays and silts. These soils are commonly found in low-lying areas such the Rio de la Plata floodplain and the Riachuelo valley. They are typically soft, normally consolidated to lightly overconsolidated, and highly compressible. Shallow layers include sandy silts with variable plasticity, while deeper marine clays tend to be more homogeneous and plastic (Leoni, 2009; Sfriso, 1997). These deposits developed in fine-grained sedimentary settings with limited post-depositional strength gain and often exhibit low structure or bonding. From a broader geological perspective, they belong to the uppermost Quaternary units of the Pampean plain and record the final phases of continental sedimentation in the region (Tófalo et al., 2011).

The Pampeano Formation, which is superficial in the central parts and underlies the Post-Pampeano in the lower parts of the city, consists of a modified loess deposited primarily during the late Pleistocene. This formation is strongly desiccation-consolidated and partially cemented with calcium and magnesium compounds. It typically spans from the surface to 35 m depth and presents a markedly overconsolidated behaviour, high shear strength, and low compressibility (Bolognesi & Moretto, 1957; Bolognesi, 1975; Núñez, 1986; Codevilla & Sfriso 2011). Its loessic nature has a volcanic-pyroclastic origin, with dust transported from the Andes and deposited across vast areas of the Pampas by wind and water (Tófalo et al., 2010). The frequent presence of paleosols and calcretes within this unit indicated episodic sedimentation and long periods of pedogenesis, which contributed to the high stiffness and cementation observed in the field.

In practical geotechnical applications, the Pampeano Formation is typically subdivided into three distinct horizons, each of them with a characteristic geotechnical behaviour:

1. Upper Pampeano (~1–3 m to 8–12 m): consists of medium plasticity silts and clays. These soils are compact, with calcareous nodules embedded in a poorly cemented matrix. They are competent enough to support footings of high-rise buildings and, when not fissured, sustain unsupported excavations and trenches several meters deep.
2. Middle Pampeano (~8–12 m to 25–30 m): is composed of hard, fissured silts and clays of medium plasticity. This horizon shows moderate to strong cementation, contributing to its high stiffness and strength.
3. Lower Pampeano (~25–30 m to 36–40 m): comprises compact silt and clays with medium to high plasticity. Cementation is generally weak, and the material often shows signs of preshearing due to erosional decompression.

The Puelchense Formation underlies the Pampeano. It comprises clean, quartzitic Pliocene sands, generally between 15 m and 30 m thick. These deposits were formed in fluvial environments and now constitute a major regional aquifer (Bolognesi, 1975; Tófalo et al., 2011). The transition from the Pampeano to the Puelchense is typically gradual, with interbedded silts and sands. From a geotechnical perspective, the Puelchense sands are dense to very dense, highly permeable, and often used as bearing layers for deep foundations.

3 ANALYSIS OF GEOTECHNICAL INFORMATION

3.1 *Database*

A database was compiled using data from 1884 boreholes across Buenos Aires, grouped into 509 geotechnical site investigations. Figure 2 2 shows those locations. This database consolidates and expands upon earlier datasets published by Fernández et al (2023) and Codevilla et al (2024), which focused primarily on the Pampeano Formation. The current database includes boreholes performed by AOSA S.A. between 1997 and 2024, providing a broad and updated representation of the subsurface conditions the region.

The database includes 9398 particle size distributions, 12011 Atterberg limits, 30746 SPT blow counts, 10269 unit weights and 25457 natural moisture contents. Additional information is included, such as soil description at 1-meter intervals, groundwater depth when detected, and Unified Soil Classification System (USCS). This database allows for detailed statistical and geostatistical analysis of subsurface properties, enabling more reliable modelling of spatial variability and supporting risk-informed design approaches advocated by recent studies (Fernández et al., 2023; Fernández et al., 2025).

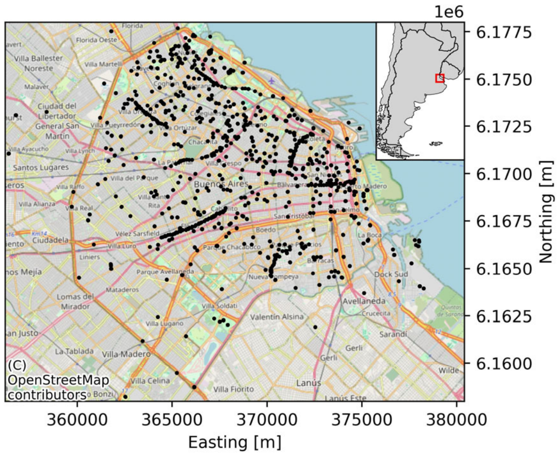

Figure 2: Location of the site investigations used in this study.

3.2 *Quantification of borehole descriptions*

The information typically included in borehole descriptions is useful for identifying stratigraphic units. Keywords such as brownish, greenish, cementation, nodules, and cemented matrix are commonly associated with the Pampeano Formation. In contrast, terms like sand, dense and yellowish are indicative of the Puelche Formation, while words such as clay, grey, soft, organic, black are often linked to the Post Pampeano deposits. These distinctive terms, which are strongly associated with specific formations, appear frequently in the borehole descriptions. Figure 3 presents the 20 most common Spanish words founded in the visual descriptions, along with their English translations. Figure 4 presents the most representative variables in the database as a function of elevation, including the most influential descriptive group terms. An increase in SPT N-value and unit weight with depth can be observed, along with a decrease in natural moisture content and fines content.

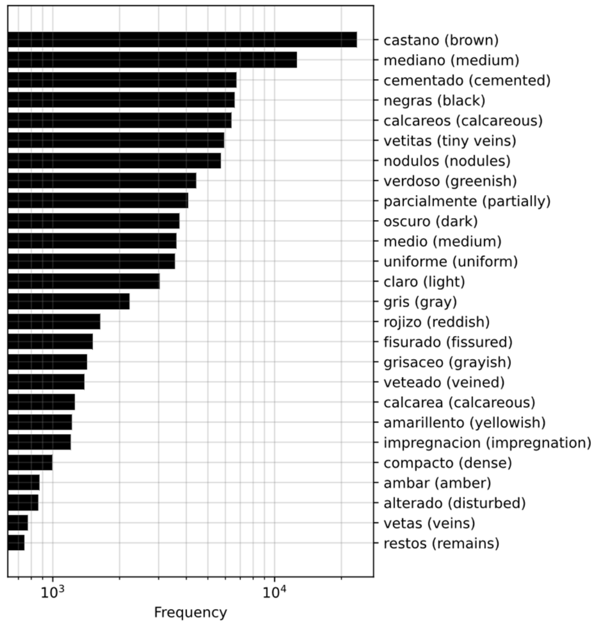

Figure 3: Most common words in soils visual description.

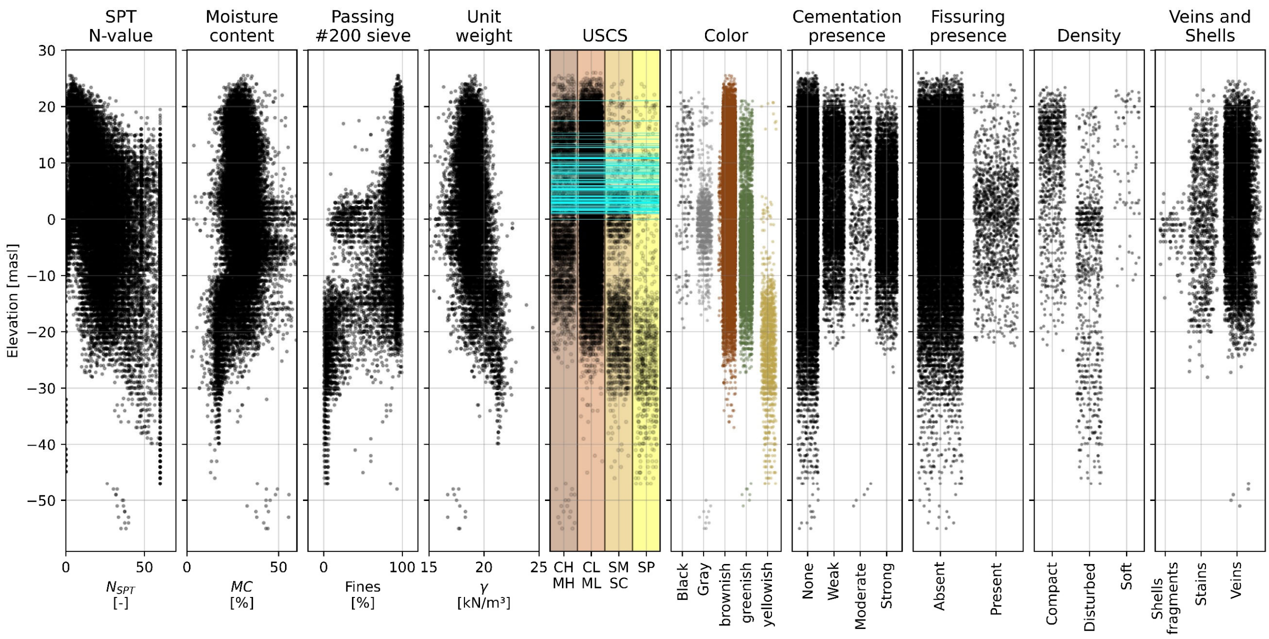

Figure 4: Elevation profiles of key geotechnical properties and text-based description from boreholes (cyan lines: water table elevations).

3.3 *Layer detection algorithm*

A clustering algorithm was implemented to automatically identify soil layers. The algorithm follows these steps:

1. Preprocessing: selected variables were normalized to ensure compatibility and equal influence. The variables considered include SPT N-values, fines content, plasticity index, cementation presence, fissuring presence, soil colour and USCS classification.
2. Segmentation: for each borehole, the variables were treated as a multivariate sequence ordered by depth. The binary segmentation (Binseg) algorithm from the Python library ruptures was applied to detect significant changes along the depth profile. The number of segments was limited to five, corresponding to the expected stratigraphic units
3. Cluster assignment: each segment was assigned an integer label in increasing order with depth, thereby preserving the expected stratigraphic sequence. The algorithm allows for the absence of any of the five formations in each borehole and does not assume uniform thicknesses across boreholes.

This method produces a stratum label for each data point, which can be post-processed to compute the minimum and maximum depth of each of them. The use of unsupervised segmentation allows data-driven stratification even in the absence of clear visual boundaries, aligning with recent advances in geotechnical site characterization. Recent studies advocate similar approaches for stratigraphic modelling. For instance, Phoon et al. (2021) reviewed data-driven subsurface characterization methods, highlighting the value of unsupervised clustering classification.

4 RESULTS

4.1 *Data uncertainty*

The variability is assessed for each site investigation by plotting the mean value (μ) and the Coefficient of Variation (COV). Figure 5 presents these statistics for moisture content (MC), liquid limit (LL), plastic limit (PL), and unit weight (γ), along with reference values from bibliography ISSMGE-TC304 (2021) for data corresponding to the Pampeano Formation. This figure is an updated version of the chart previously published by Codevilla et al. (2024).

The variability is generally of the same order of magnitude as the values reported in the literature. Notably, the COV of moisture content is relatively high in some site investigations, likely due to the presence of organic soils or highly plastic clays, particularly in areas near Rio de la Plata low basin (east Buenos Aires) or Riachuelo watercourse (south Buenos Aires). In contrast, the COV of unit weight is consistently low, suggesting that these parameters exhibit limited variability in the available geotechnical campaigns.

4.2 *Maps of spatial distribution*

Figure 6 shows spatial distribution maps of ground level, depth to the Puelche Formation, elevation of the Puelche Formation, elevation of the groundwater table, and average SPT N-values $(N_1)_{60}$ in the upper 5 meters, corrected for energy input (Leoni et al., 2008) and depth (Liao & Whitman, 1986). Historical watercourses, most of which are now culverted beneath the city, are also shown. A Gaussian blur was applied to the variables to provide a smoother surface representation. Both ground level and depth to top of Puelche sands decrease near watercourses; however, the areas of lowest Puelche sands elevation do not necessarily coincide with the location of these watercourses.

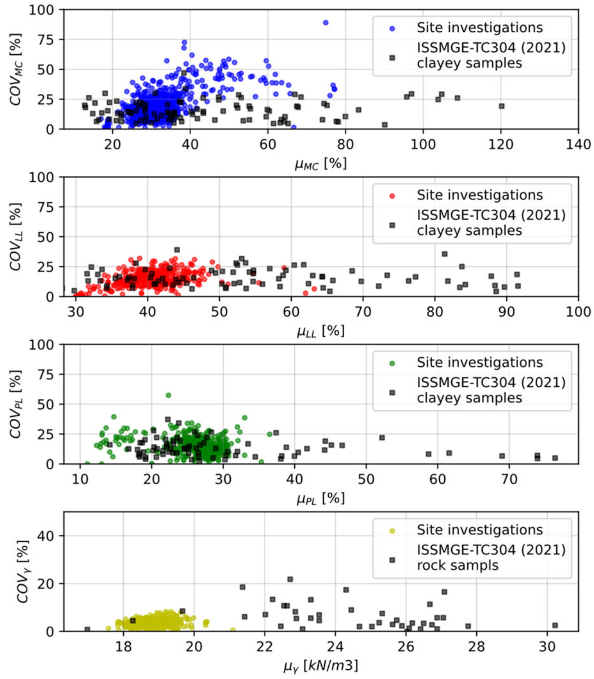

Figure 5: Mean and Coefficient of Variation (COV) of physical parameters for each site investigations.

4.3 *Analysis*

These findings are consistent with the geological description of the geodynamics proposed by Fidalgo (1973): the Lower Pampeano was deposited underwater and never exposed to atmosphere, thus explaining its greenish colour in contrasts with the brownish colour of the oxidized Middle Pampeano. Streams and creeks carved into the Middle Pampeano sediments created high heterogeneity within the Middle, and sometimes the Lower Pampeano, but without eroding or otherwise affecting the sands of the Puelche Formation.

Caution should be taken when interpreting the contour maps of groundwater, as the water levels were measured along a very extended period between 1997 and 2024 and do not represent a consistent seasonal snapshot. Moreover, it was difficult to maintain stabilization periods during the measurements for each site investigation. However, the groundwater surface appears to be coherent, rising progressively away from the Rio de la Plata and showing a slight decline near historical watercourses, most of them now buried, backfilled and running within the drainage system of the city.

The Puelche Formation is a confined aquifer. Several interceptions with boreholes and bored piles built at the bottom of deep excavations have led to sudden inflows of water and, sometimes, eroded sand, including flooding of the excavations in some cases. The elevation maps shown in Figure 6 may serve as a preliminary tool to estimate the top level and water head of the Puelche aquifer. The resolution is not enough, however, to employ these maps as a final decision-making tool. Detailed site-specific investigations are mandatory prior to excavation activities.

The average SPT $(N_1)_{60}$-value within the upper 5 meters is also plotted and can provide a useful starting point for estimating near-surface soil strength. Lower average N-values are observed along Riachuelo river (southern boundary), while no clear reduction was noted along the Río de la Plata (eastern boundary). This contrast may be attributed to the presence of man-made fill soils near the Río de la Plata, whereas soils along the Riachuelo are predominantly natural deposits.

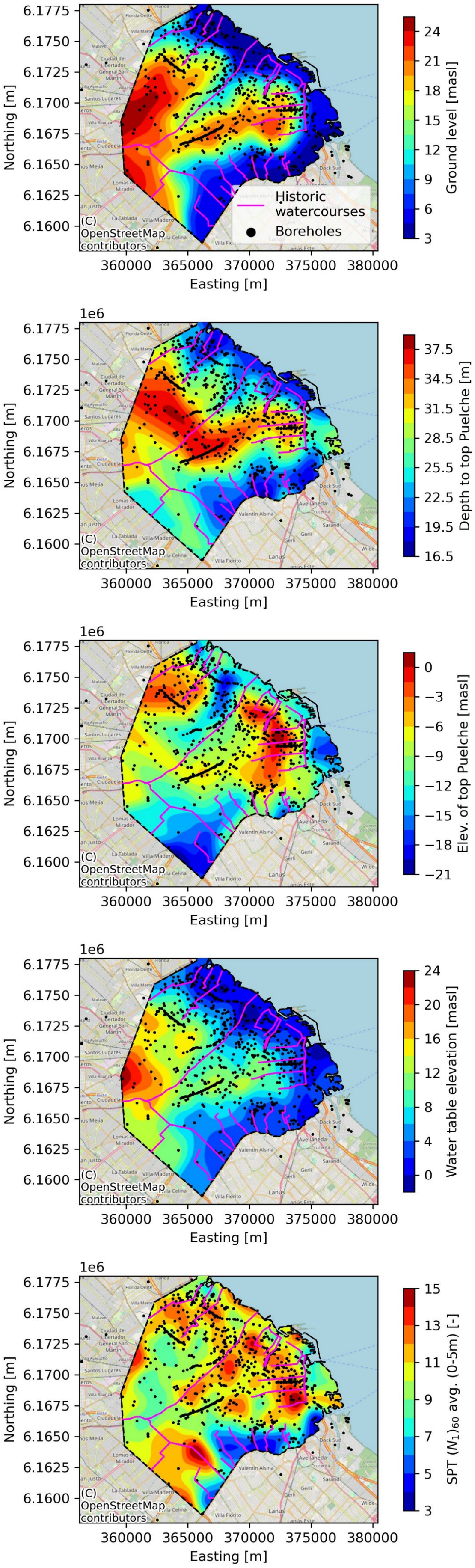

Figure 6: Spatial distribution maps of key parameters.

4.4 *Plasticity chart*

Liquid limit and plasticity index values for the Pampeano Formation were plotted on the plasticity chart show in Figure 7. Historical data reported by Bolognesi (1975) are also included for comparison. The results generally follow the trend described by Casagrande, where data points from a given soil type tend to align parallel to the A-line (Casagrande, 1932).

Some untypical samples exhibit very high liquid limit and plasticity index values, which likely correspond to soils located in the southern sector of the city and may belong to superficial fill materials. This suggests that the clustering algorithm may not be accurately delineating the boundary between superficial fill and the upper Pampeano Formation.

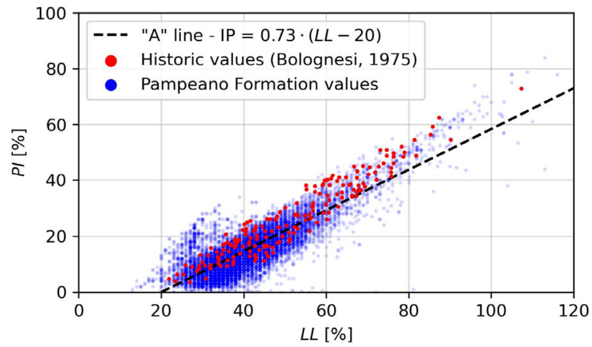

Figure 7: Plasticity chart with Pampeano Formation data and historical values from Bolognesi (1975).

4.5 *Cross-sections*

Figure 8 presents the same data integrated in a typical cross section running parallel to, and 2500 m away from, the Rio de la Plata coastline. Boreholes located 500 m or less from the cross-section were included and an interpolation scheme was adopted for SPT blow count, presence of fissures, colour, degree of cementation and the stratigraphic classification derived from the clustering algorithm.

$(N_1)_{60}$ values are highly variable due to the erratic cementation. They however increase with depth, with a jump in the contact zone between the Upper and Middle Pampeano. Refusal values are reached within the highly cemented zones of the Middle Pampeano Formation and systematically in the Puelche Formation. SPT refusal is rare in the Lower Pampeano due to its lower cementation.

Apart from the division into Upper, Middle and Lower Pampeano, no clear pattern was observed in the degree of cementation. A similar observation can be made with respect to the occurrence of fissures, which appears to be erratic throughout the Middle and Upper Pampeano Formation, and less frequent in the Lower Pampeano. In fact, fissures are predominantly reported in the historic centre of Buenos Aires (southeastern), where the highest level ground is found, and where the historical city was founded.

Soil colour appears to be a good indicator of stratigraphy. Yellowish tones are predominant within the Puelche Formation, whereas brown hues dominate in the Pampeano Formation, with greenish shades becoming more common at greater depths.

The clustering algorithm appears to perform well, successfully identifying superficial fill materials within the upper 5 meters and the Puelche Formation.

In areas near the Río de la Plata and within the Maldonado basin the model finds the contact of Middle and Lower Pampeano strata at lower elevations, compared with the rest of the city. This probably reflects erosional processes associated with the two biggest watercourses shaping the landscape and creating spots of higher accumulation of softer sediments.

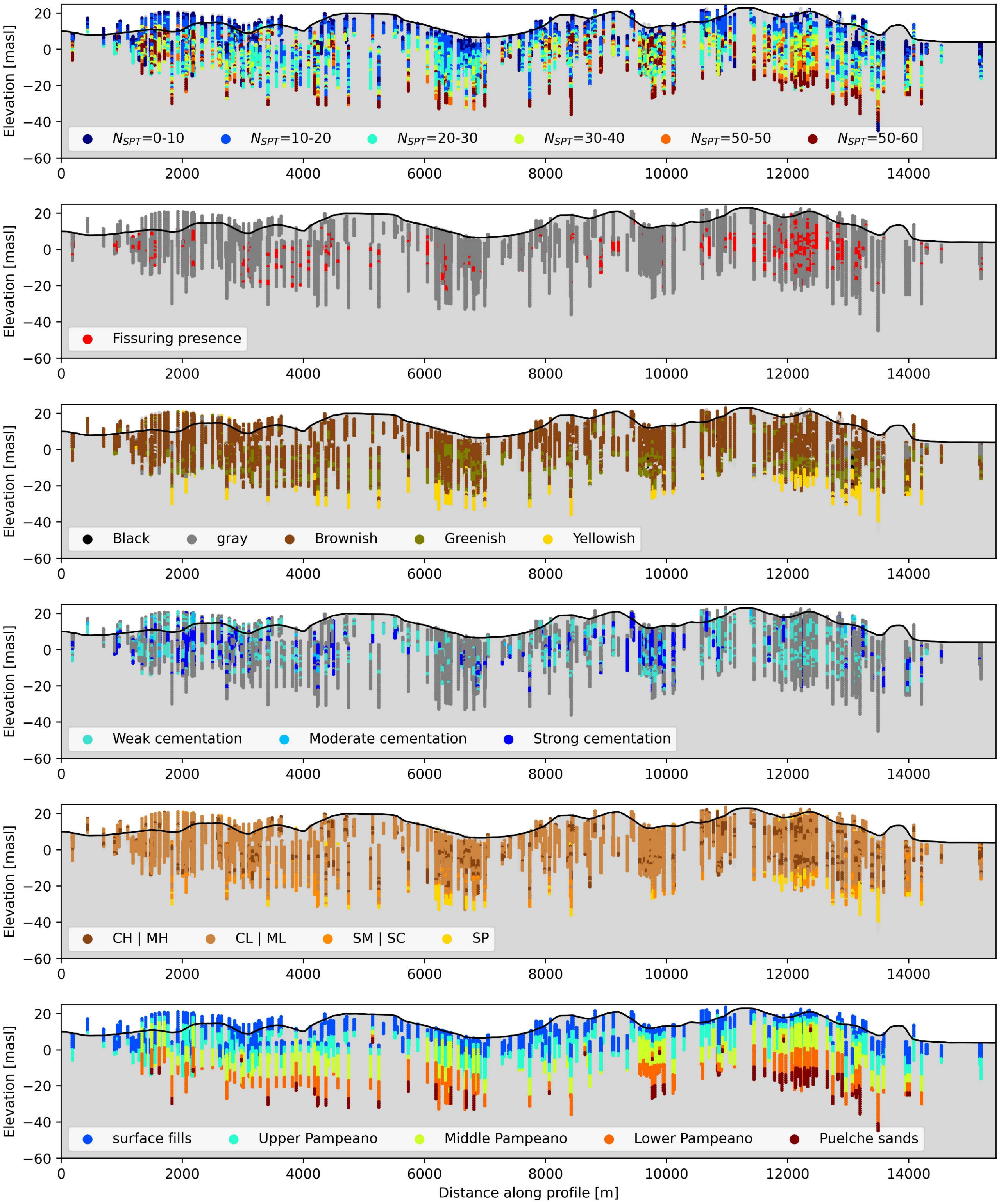

Figure 8: Spatial distribution of $(N_1)_{60}$ values, fissuring presence, soil colour, degree of cementation, USCS classification and clustering-based classification for boreholes closer than 500 m from a selected cross-section running parallel to and 2500 m away from the Rio de la Plata coastline.

5 CONCLUSIONS

This study presents a comprehensive geotechnical database for the City of Buenos Aires, integrating 1884 boreholes across 509 site investigations (1997-2024 period) provided by only one geotechnical laboratory company. The dataset comprises stratigraphic descriptions, in situ and laboratory test results. All data was analysed using an unsupervised clustering algorithm to generate contour maps and representative cross-sections.

Textual information extracted from borehole logs proved highly valuable for stratigraphic interpretation. As expected from the literature, soil colour showed a strong correspondence with formation boundaries: yellowish tones are typically associated with the Puelche Formation, while brown and greenish hues predominate in the Pampeano Formation. These colour transitions, together with depositional mode, remain robust criteria for distinguishing stratigraphic units in the region.

Although the classic subdivision of the Pampeano Formation into upper, middle, and lower sub-units is well established in geological studies—primarily based on colour (brownish versus greenish), depositional environment (aeolian versus fluvial), and degree and style of cementation—the present analysis did not consistently resolve these boundaries across the geotechnical database. Fissuring and cementation appeared irregular, with no systematic relationship to depth, and fissures were mainly concentrated in the southeastern sector of the city. However, the inability of the data-driven clustering method to delineate the traditional sub-units does not undermine their geological or engineering significance. Rather, it underscores the limitations of this clustering algorithm—particularly their tendency to identify abrupt transitions—when applied to complex, gradational stratigraphy, as well as the constraints imposed by data heterogeneity and resolution. It is therefore recommended that future work integrates additional sources of information such as geological mapping, sedimentological data, and other higher-resolution laboratory strength tests like triaxial tests.

The elevation of the upper surface of the Puelche Formation is one of the most valuable outcomes of this work, providing a first-order approximation for anticipating potential encounters with the confined aquifer during urban excavations. Similarly, the reconstructed groundwater table surface exhibits spatial trends consistent with regional hydrogeology, although it must be interpreted with caution given the broad time span of data collection (1997–2024), the absence of a uniform seasonal reference and the lack of a strict stabilization period during measurement on each site.

Statistical analysis of the physical properties shows that the coefficient of variation for moisture content, liquid limit, and plastic limit is generally in line with values reported in international guidelines (e.g., ISSMGE-TC304, 2021). Higher variability of moisture content in certain areas, particularly in the south of the city, likely reflects the presence of unstructured silty soils, while the low variability of unit weight indicates good overall consistency in the site investigations.

The clustering algorithm reliably identified superficial fill within the upper 5 meters and the Puelche Formation but struggled to consistently detect the expected internal boundary between the Pampeano Formation and superficial fills. Moreover, its inherent limitation in representing gradual changes means that sharp stratigraphic boundaries may be over-emphasised, and subtle transitions underrepresented. The issue is further compounded by the lower spatial density of geotechnical data in the south-west portion of the study area, where special caution should be exercised when using the information for preliminary designs.

In summary, the approach adopted in this study provides a robust, data-driven framework for spatial geotechnical characterization in Buenos Aires City but also highlights the need for integrative methodologies that combine quantitative algorithms with geological and engineering expertise. Continuous or probabilistic stratigraphic models, such as those based on Gaussian processes, may provide more nuanced representations of subsurface variability and uncertainty in future work.

6 ACKNOWLEDGEMENTS

The authors wish to express their sincere gratitude to Prof. Alejo O. Sfriso for continuous academic's guidance and inspiration. Many of the boreholes included in the database were carried out under his supervision. Special recognition is also due to Prof. Eduardo Nuñez, who laid the foundations for geotechnical understanding in the region with one of the earliest publications of characterization of Buenos Aires soils four decades ago. This work stands on the shoulders of their contributions.

7 REFERENCES

Bolognesi, A. 1975. Compresibilidad de los suelos de la formación pampeano. *V Pan Am. Conf. On Soil Mechanics and Foundation Eng,* Buenos Aires, (5) 255-302.

Bolognesi, A., and Moretto, O. 1957. Properties and Behaviour of silty soils originated from loess formations. *IV Intl. Conf. on Soil Mechanics and Foundation Eng.* London, (1) 9-12.

Casagrande, A. 1932. Research on the Atterberg Limits of Soils. *Public Roads*, (13) 121-136.

Codevilla, M., Fernández, P., and Tasso, N. 2024. Incertidumbre en los parámetros físicos y mecánicos de los suelos de la Formación Pampeano en la Ciudad de Buenos Aires. *Proc. 17th Pan-American Conf. on Soil Mechanics and Geotechnical Eng.* La Serena, (1-10).

Codevilla, M. and Sfriso, A. 2011. Actualización de la información geotécnica de los suelos de la Ciudad de Buenos Aires. XIV *Pan-am CGS Geotechnical Conference.* Toronto.

ISSMGE-TC304 2021. State-of-art review of inherent variability and uncertainty in geotechnical properties and models. *ISSMGE – TC304 'Engineering Practice of Risk Assessment and Management'.*

Fernández, P., and Codevilla, M. 2023. Incertidumbre en los parámetros físicos de los suelos de la Formacion Pampeano. *XXVI Congreso Argentino de Mecánica de Suelos e Ingenieria Geotecnica,* Comodoro Rivadavia, 117-121.

Fernández, P., and Sfriso, A. 2025. Elements for the reliability-based design of shallow foundation in Buenos Aires, Argentina. 9th International Symposium for Geotechnical Safety and Risk. Oslo, Norway.

Fidalgo, F., Francesco, F., and Colado, U. 1973. Geología superficial de las hojas Castelli, J.M. Cobo y Monasterio (Provincia de Buenos Aires). *Proc. 5th Congreso Geológico Argentino*. Córdoba, (4) 27-39.

Leoni, A. 2009. Characterization of post pampean clays. *Proc. 17th International Conference on Soil Mechanics and Geotechnical Engineering*, Alexandria, 56-59.

Leoni, A. Guaraglia, D., Bielecki, A., and Cánchero, J. 2008. Medición de la energía entregada por el impacto del pisón en la ejecución de los ensayos SPT ejecutados en la República Argentina. XIX Congreso Argentino de Mecánica de Suelos e Ingeniería Geotécnica. La Plata.

Liao, S., and Whitman, R. 1986. Overburden Correction Factors for SPT in Sand. *Journal of Geotechnical Engineering, ASCE.* (112) 373-377.

Nuñez, E. 1986. Panel report: Geotechnical conditions in Buenos Aires City. *Proc. 5th IAEG Congress,* Buenos Aires, (4) 2623-2630.

Tófalo O., Orgeira, M., Compagnucci, R., Alonso, M., and Ramos, A. 2011. Characterization of a loess-paleosols section including a new record of the last interglacial stage in Pampean plain, Argentina. *Journal of South American Earth Sciences* (31), 81-92.

Phoon, K., Ching, J., and Shuku, T. 2021. Challenges in data-driven site characterization. *Georisk Assessment and Management of Risk for Engineered Systems and Geohazards*, (12) 1-13.

Sfriso, A. 1997. Formación Postpampeano: Predicción de su comportamiento mecánico. *III Conferencia Latinoamericana de Ingenieros Geotécnicos Jóvenes.* Caracas, 1-10.