Soils and Rocks
www.soilsandrocks.com
An International Journal of Geotechnical and Geoenvironmental Engineering
ISSN 1980-9743
ISSN-e 2675-5475

Typical geotechnical profiles of the main soil deposits found in the Maceio city, Alagoas, from SPT boreholes

Juciela Cristina dos Santos[1#], Roberto Quental Coutinho[2], Juliane Andréia Figueiredo Marques[3]

Article

Keywords
Barreiras formation
Typical profile
Limestone
Sandstone
Organic clay

Abstract

This work had as objective to carry out the construction of typical soil profiles of the main existing deposits in the city of Maceio from a database of SPT boreholes, built in GIS environment. In total, 1,686 records of drilling were specialized in sediments of the Barreiras Formation, Coastal Deposits, and lagoons-river, presenting the most frequent characteristics, exemplified through representative profiles. The Barreiras Formation, which covers about 75% of the urban area of the city, presented profiles with a predominance of clayey, without water level records. The deposits lagoons-river, located in the vicinity of Mundaú lagoon, were characterized by the significant presence of soft and organic clays, sometimes peat, it can reach large thicknesses and with the water table rising in certain regions. In the coastal plain, where the highest vertical construction indices in the city are concentrated, it presented an area with a predominance of fine to medium sand, with or without silt, and a water table varying between 1,00 m and 5,00 m. The analysis also allowed for the identification and mapping of the occurrence of limestone rock, sandstone rock, soft and organic clay rocks in the coastal plain, presenting a typical profile of their occurrence, helping to understand the geotechnical behavior of these materials in the studied region.

Introduction

It is consolidated in the middle of geoinformation technologies, the conception of systematized and processed data, used as raw material for the generation of information. It is for this purpose that this article aims to contribute to the understanding of the main geotechnical aspects of existing soil deposits in Maceio, Alagoas, through the construction of typical and representative profiles, created using simple recognition boreholes (SPT), systematized through Geographic Information System.

Bastos & Zuquette (2005) mention the development of a database from surveys in several European countries, such as Italy and England, and the survey database developed by Nathanail & Rosenbaum (1998), in addition to countries like France, Scotland among others.

The British Geological Survey (BGS, 2019) also performs the construction of geological maps through a Geology viewer of Great Britain, using a *GISweg*, featuring a simple tool, aimed at the public, which has a database with well sweep, earthquake timeline and 3D Visualization Models.

Chacón et al. (2006) cites the participation of scientists from 17 countries in the production of engineering geology maps through landslide databases using geographic information systems.

In Brazil, the geotechnical databases structured by Luiz & Guitierrez (2020) in Maringá, Bastos et al. (2007) and Miranda & Bressani (2007) in Rio Grande do Sul, Mafra Júnior (2007) and Cardoso & Medeiros (2011) in Santa Catarina, Wosniak & Wendler (2002) in Paraná, Augusto Filho (2005) in Minas Gerais, among others.

One of the most consolidated works for the Northeast, concerns the preparation of soft medium and organic clays database in Recife city, made by Coutinho et al. (1996). The information's contained included parameters of tests performed in the field and laboratory, in addition to SPT probes. The application of SPT data associated with Geographic Information Systems (GIS) for the construction of geotechnical maps it has been widely used for several applications, being widespread in some areas and gaining more and more space in geotechnics.

1. Characteristics of the study area

Maceio has approximately 511 km^2 and an estimated population of 1,025,360 inhabitants (IBGE, 2020), having

[#]Corresponding author. E-mail address: juciela.santos@ceca.ufal.br
[1]Universidade Federal de Alagoas, Campus de Engenharias e Ciências Agrárias, Rio Largo, AL, Brasil.
[2]Universidade Federal de Pernambuco, Centro de Tecnologia e Geociências, Recife, PE, Brasil.
[3]Universidade Federal de Alagoas, Centro de Tecnologia, Maceió, AL, Brasil.

Submitted on January 6, 2022; Final Acceptance on October 10, 2022; Discussion open until February 28, 2023.
https://doi.org/10.28927/SR.2022.000122

hot and humid climate, classified as type As' according to the Koppen classification. For the purposes of this article, the studied area is limited to the urban area of the Maceió city. Figure 1 presents a location map of the studied area.

In the geological aspect, Maceió has three main deposits: Barreiras Formation sediments, Coastal sediments and Lagoon-river sediments, near the Mundaú Lagoon.

The sediments of the Barreiras Formation cover approximately 75% of the urban area of Maceio and are considered the last deposits in the Alagoas Sedimentary Basin, with an average width of 20 km, forming a package between 60 and 130 m (Santos et al., 2004). It has poorly consolidated sediments characterized by sub-horizontal layers of different granulometry, associated with fluvial processes, being considered the most expressive geological unit on the Brazilian coast. The lithology is composed of clastic sediments of continental origin, which had their deposition associated with Cenozoic events of a climatic and/or tectonic nature, with Plio-Pleistocene (Tertium-Quaternary) age, presenting itself with bright color, ranging from orange, red, purple, yellow to white (Alheiros et al., 1988).

The coastal and lagoons-river deposits of the city of Maceio, have a quaternary origin, resulting from the marine, fluvial and wind action, which created a coastal and lagoon plain with marine and lacustrine terraces, sandy ridges and old drowned estuaries that give rise to the lakes (Mendes, 2017).

These Holocene marine terraces in which the lower part of the city developed, they form a long and extensive coastal plain, with a thickness of 25 m in the districts of Ponta Verde and 49 m in the district of Ponta da Barra, reaching up to 80 m in the district of Trapiche da Barra (Santos, 2004). In the geological chart of Brazil to the millionth (2004), these coverages were mapped as Holocene marine deposits (Q2li), classified as sand with seashells, clay and silt rich in organic matter and well selected fine sand dunes.

The river lagoon sediments are in the vicinity of Mundaú lagoon, which according to (Santos, 2004) they are located from the inland delta of the Mundau river to the end of Santa Rita Island. They are constituted by marine and lacustrine terraces, with occurrence of clays, clay and silt rich in organic matter and sands with fragments of crustaceans.

To better understand of the local geology and the various geological formations that make up the soil and subsoil of the region, a simplified geological profile was built (Figure 2).

2. Materials and methods

The geotechnical characterization of the soil deposits found in the city of Maceio was carried out through the identification and location of drilling records SPT in the study area, provided by the company AGM Geotechnical LTDA, between 2007 and 2017, containing drillhole execution reports, profiles and location sketches.

The survey bulletins were systematized through the creation of a database, based on the model produced and consolidated by the Slopes, Plains and Disasters Geotechnical Group (GEGEP/UFPE), built using the database manager system (DBMS) PostgreSQL and the extension for spacial data PostGIS. The choice for this system was because it is a free tool that already has embedded tools for analysis, processing and identification of spatial data and the facility of data integration with geographic information systems.

The *software* QGIS 3.10.7 was used as a geographic information system, performing geoprocessed data analysis, building maps of the deposits found and the spatial location

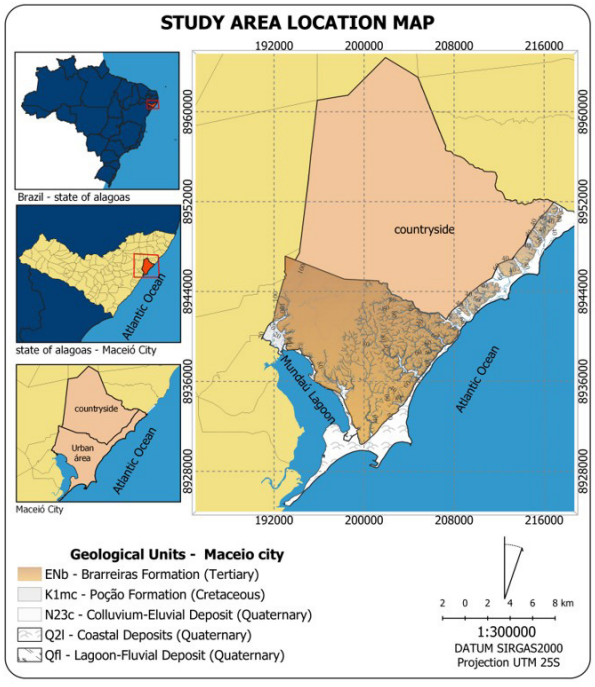

Figure 1. Study area location map.

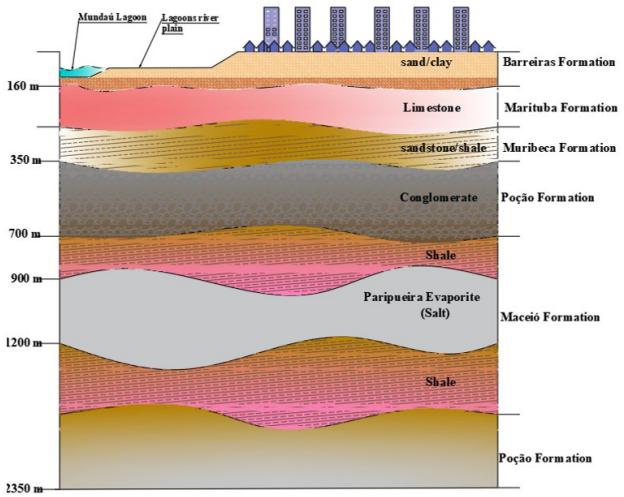

Figure 2. Simplified profile of geology in Maceio.

of drilling records, allowing the identification of the most frequent and representative soil layers of the main existing deposits in Maceio, highlighting the particularities and areas of occurrence.

3. Analysis and results

For the geotechnical characterization of the studied area, 1,686 drilling records SPT were used, distributed as shown in Figure 3.

Most of the drilling records are found under sediments from the Barreiras Formation. The high verticalization also brings several significant records in the coastal deposits, more specifically in the districts of Pajuçara, Ponta Verde and Jatiúca, however, leaving the regions of Pontal da Barra, Trapiche, Prado, Poço and Centro and most of the north coast neighborhoods uncovered. The same occurs in the lagoons-river deposits, where verticalization is less expressive.

The representative soil profiles used as an example for each type of deposit studied are spatially located and represented in Figure 4 as well as the area of occurrence of sandstone, limestone and soft and organic clays.

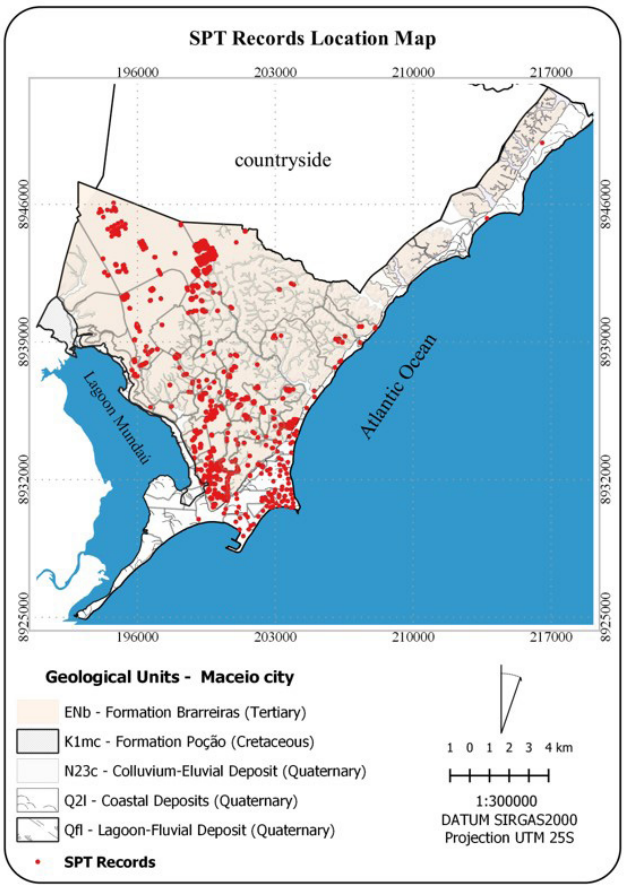

Figure 3. SPT records Location Map

3.1 Geotechnical characterization of Barreiras Formation sediments

To carry out the characterization of the sediments of the Barreiras Formation, approximately 1,500 records of drilling were used, distributed through 13 layers with depths that varied between 1.00 m and 37.00 m. Due to the degree of representativeness, the profiles were analyzed up to the 5th layer of soil. The probes were separated into four representative groups, taking into account the granulometry of the material obtained in the field:

a) Group 01: more sandy soils, composed of sands, silty sands and sandy silts;
b) Group 02: soils identified with finer granulometry, composed of clays, silty clays and clayey silts;
c) Group 03: soils identified as sands composed of clay and silt, such as clayey sands, clayey silty sands, clayey silt sand and sandy clay silts;
d) Group 04: soils identified as composite clays, such as sandy clays, silty sand clays, sandy silt clay and sandy clay silts.

It was found that the subsoil has about 55% of the SPT profiles presenting exclusively clayey layers and 43% presenting layers with intercalations between sand and clay.

The repetitions between sandy e clayey layers occur mostly with clayey predominance (81%), with only 19% having sandy predominance. This sand/clay intercalation pattern with vertical repetition may be associated with depositional cycles, common to sedimentary surface flat alluvial.

The highest incidence of occurrence is in groups with clayey predominance, with silt and sand (G02 e G04), that is, soils with finer granulometry, which together represent between 65% and 85% in all layers, with greater incidence for clays composed of sand and silt (G04). In these layers, the description of the presence of laterization and boulders (pebbles) is also frequent. Although less frequent, sandy layers

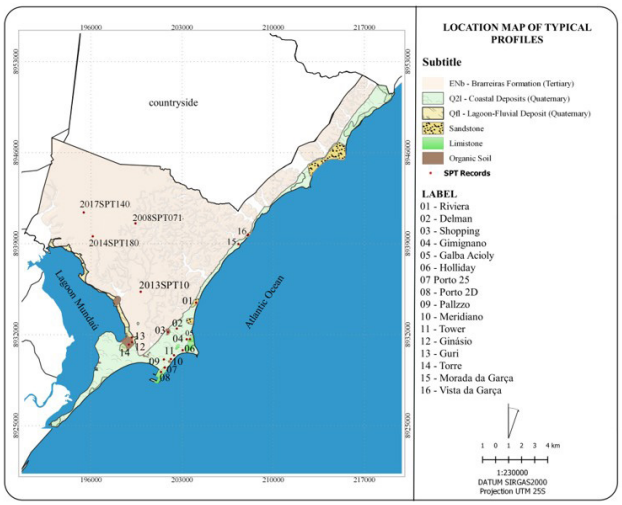

Figure 4. SPT records Location Map used as an example.

(G01 and G03) intersperse the clayey layers in depth, with a greater occurrence of sands composed of silt and clay, which represent between 15% and 35%. In these layers, laterization, boulders (pebbles) and clay nodules are also frequent.

Table 1 presents the most frequent characteristics found in the group of surveys studied, considering the particle size classification of materials.

In the analyzed SPT records, no groundwater levels were found, despite the existence of an aquifer in the Barreiras Formation in Maceió city, as its depth is greater than that reached by the studied drillings. According to Nobre et al. (2007), the underground waters of the Maceio city vary from 30 to 500 meters in thickness, passing through several geological formations, not being reached by the analyzed drillings.

Examples of representative profiles of SPT drillings inserted in the studied area are presented in Figure 5, which show two profiles with exclusively clayey layers, and Figure 6,

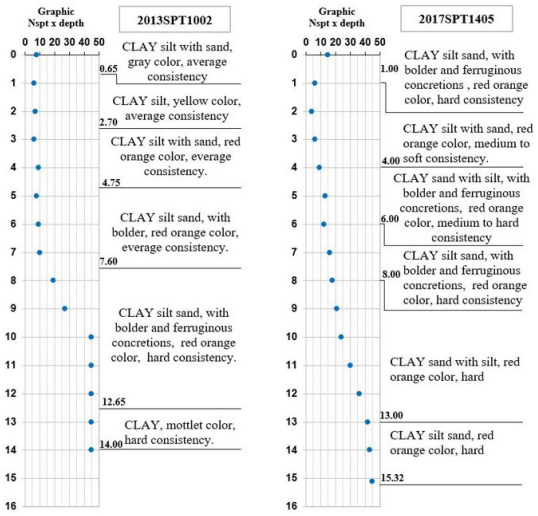

Figure 5. Example of profile with exclusively clayey layers.

Table 1. Most frequent characteristics of the soil layers of the Barreiras Formation.

Layers	Group	Occurrence	Material Classification
1st	G04	51% Clay + Sand + Silt	Gray, yellow, orange-red and variegated colours, medium consistency, occurring pebbles (pebbles).
	G02	30% Clay and Clay +Silt	Colours yellow, sometimes gray, orange-red and variegated, soft to hard with the occurrence of pebbles.
	G01	11% Sand and Sand +Silt	Gray, yellow, cream and orange-red colours, fluffy to medium compact, with gravel, pebble, and clay nodules.
	G03	8% Sand +Clay + Silt	Gray, yellow, and cream colours, fluffy to little compact, with gravel and clay nodules.
2nd	G02	59% Clay and Clay +Silt	Colours yellow, gray and orange-red, soft to hard, with little occurrence of gravel.
	G04	29% Sand +Clay + Silt	Orange-red and yellow colours, medium compact to hard, with the occurrence of gravel and rusty concretions.
	G03	10% Clay + Sand + Silt	Yellow and orange-red colours occurring gray, soft to hard, with gravel and ferruginous concretions.
	G01	3% Sand and Sand +Silt	Yellow, red-orange, cream, grey and mottled, medium compact to compact, with clay and gravel nodules.
3rd	G04	58% Clay + sand + Silt	Colours orange-red, yellow, gray and mottled, medium compact, with gravel (pebble) and ferruginous concretions.
	G02	26% Clay and Clay +Silt	Red-orange, yellow and variegated colours, medium to hard consistency, with gravel and ferruginous concretions.
	G03	13% Sand + Clay + Silt	Orange-red, yellow and gray colours, medium compact to compact, with gravel and ferruginous concretions
	G01	2% Sand and Sand +Silt	Yellow, grey, orange-red and cream, fluffy to very compact, with gravel and clay nodules occurring
4th	G04	42% Clay + Sand + Silt	Red-orange and variegated colours, occurring yellow and gray, hard to hard, occurring pebbles (pebbles) and ferruginous concretions.
	G02	32% Clay and Clay +Silt	Colours variegated, orange-red, yellow, and grey, soft to hard, with gravel and ferruginous concretions.
	G03	22% Sand +Clay + silt	Red-orange and yellow colours, medium compact to hard, with possible gravel (pebbles) and rusty concretions.
	G01	4% Sand and Sand +Silt	Yellow, gray and orange-red colours, medium compact to hard, clay nodules and little gravel may occur
5th	G04	43% Clay and Clay +Silt	Colours reddish orange variegated and yellow, hard, with gravel (pebbles) and ferruginous concretions.
	G02	41% Clay + Sand + Silt	Colours red orange, mottled and yellow, hard to hard, occurring pebbles (pebbles).
	G01	12% Sand +Clay + Silt	Red-orange and yellow colours, compact to very compact, with gravel.
	G03	4% Sand and Sand +Silt	Colours yellow and orange red, compact to very compact, with gravel.

which show two profiles with intercalation layers between sand and clay.

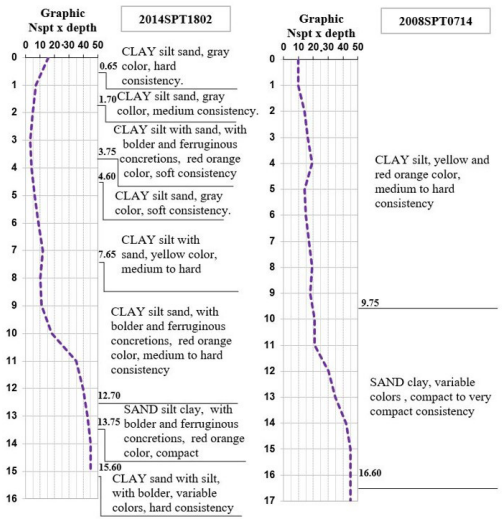

Figure 6. Example of profile with intercalation clay and sand layers.

3.2 Geotechnical characterization of coastal deposit

The drilling records located in the coastal deposits are distributed in the neighborhoods of Poço, Jaraguá, Ponta da Terra, Pajuçara, Jatiúca, Mangabeiras, Ponta Verde, Cruz das Almas, Jacarecica, Guaxuma, Garça Torta and Ipioca.

The surveys showed that the area has a water table varying at a depth between 1.00 m and 5.00 m. The most frequent soil layers are fine sand with silt and fine to medium sand, together representing a percentage of occurrence greater than 58%. The sandy silt starts from the second layer, with percentages that vary between 12% and 23%. Clays mixed with silt and sand occur less frequently, but are common in all layers, representing between 8% and 19% of the soils. In the studied area, calcareous rocks were found as an occurrence from the second layer onwards, at depths ranging from 1.00 m to 15.00 m. The most frequent soil layers and their characteristics are presented in table 2.

Representative profiles of the beach region are presented for the neighborhoods Pajuçara (Figure 7), Ponta Verde (Figure 8), and Jatiúca (Figure 9).

Table 2. Frequent features of the layers found in coastal deposits.

Layers	Class	Occurrence	medium width (m)	Material Classification		
				color	consistency	note
1st	Sandy Silt	-	2.3	Yellow, ligth gray, dark gray, brown and red orange	Fluffy, medium compact	construction waste (26%), crustacean fragments (7%), clay nodules (2%), boulder (pebbles) (6%)
	Fine Sand with Silt	49%				
	Fine to Medium Sand	30%				
	Limestone Sand	-				
	Limestone	-				
	Clay and Clay+Silt+Sand	16%				
2nd	Sandy Silt	12%	3.4	Yellow, light gray, dark gray, cream and brown.	Fluffy, medium compact	Resíduos da construção (2%), fragmento de crustáceo (7%), pedregulho (seixo) (6%)
	Fine Sand with Silt	57%				
	Fine to Medium Sand	20%				
	Limestone Sand	3%				
	Limestone	2%				
	Clay and Clay+Silt+Sand	8%				
3rd	Sandy Silt	23%	3.4	Yellow, ligth gray, dark gray, cream.	Fluffy, medium compact	Resíduos da construção (2%), fragmento de crustáceo (33%), pedregulho (seixo) (10%).
	Fine Sand with Silt	38%				
	Fine to Medium Sand	26%				
	Limestone Sand	3%				
	Limestone	2%				
	Clay and Clay+Silt+Sand	9%				
4th	Sandy Silt	20%	3.4	Yellow, ligth gray, dark gray, cream.	Fluffy, medium compact	Fragmento de crustáceo (27%), pedregulho (seixo) (13%), nódulo de argila (3%)
	Fine Sand with Silt	54%				
	Fine to Medium Sand	14%				
	Limestone Sand	4%				
	Limestone	7%				
	Clay and Clay+Silt+Sand	8%				
5th	Sandy Silt	13%	3.62	Yellow, ligth gray, dark gray, cream.	medium to very compact	Fragmento de crustáceo (13%), pedregulho (seixo) (15%), nódulo de argila (6%)
	Fine Sand with Silt	30%				
	Fine to Medium Sand	30%				
	Limestone Sand	9%				
	Limestone	2%				
	Clay and Clay+Silt+Sand	19%				

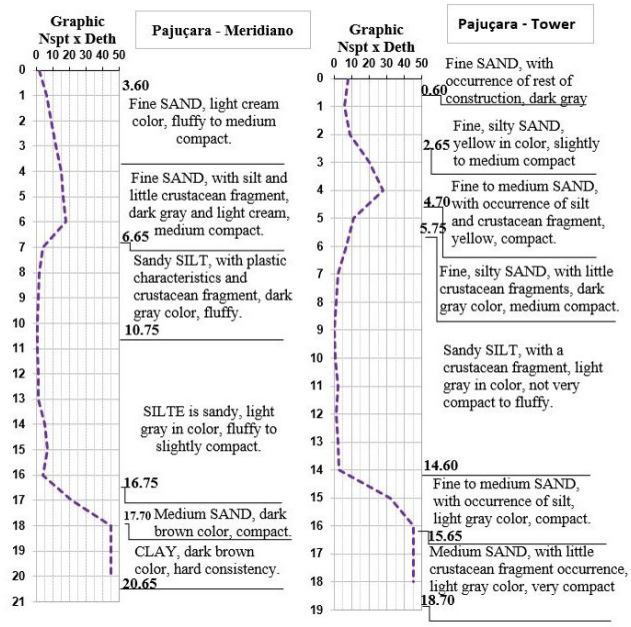

Figure 7. Example of profile located in the Pajuçara neighborhood.

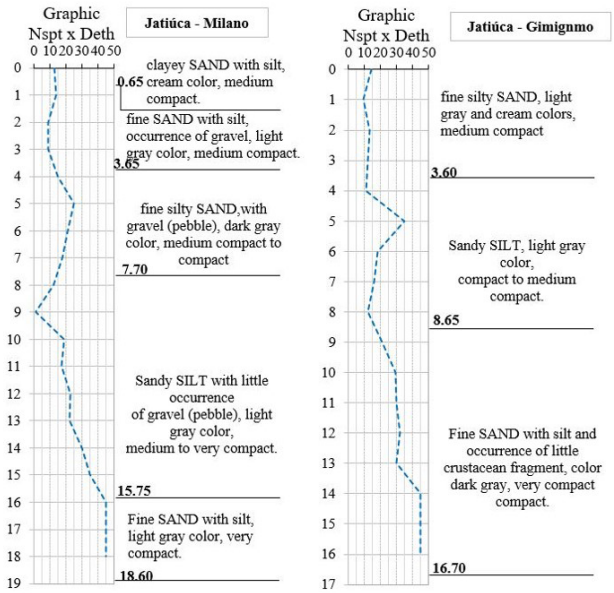

Figure 9. Example of profile located in the Jatiuca neighborhood.

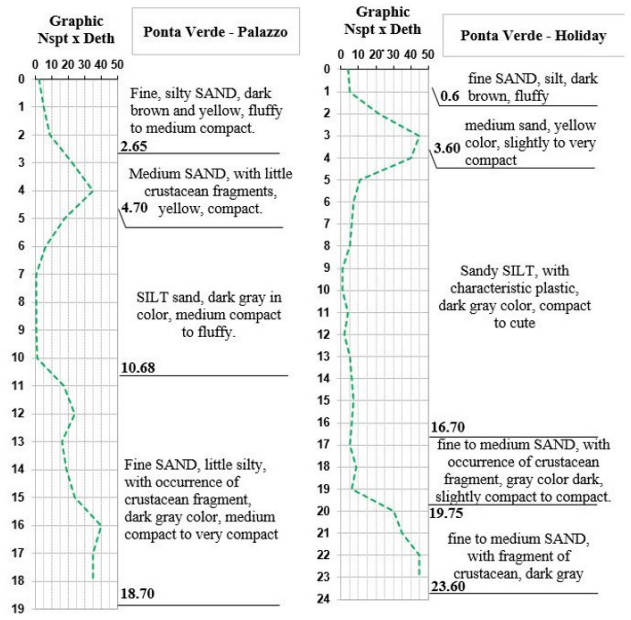

Figure 8. Example of profile located in the Ponta Verde neighborhood.

3.3 Geotechnical characterization lagoon river deposit

In Maceio, there are few records of drilling in the lagoons-river region, due to the low construction demand in the region, however, the analyzed SPT allowed the identification of 05 representative soil layers, described as per table 3.

The first layer is usually made up of fine sand, with or without the occurrence of silt, of consistency ranging from fluffy to medium compact, occurring soft clay/organic, with peat and crustacean fragments, starting near the surface (≈ 0.60 m), being able to reach large thicknesses (± 15.00 m), representing, in most cases, the second layer. The next layers represent silty sand, sandy clay and fine sand, medium compactness, and variable thickness. Marques e Marques (2005) found similar results. Figure 10 present example of profile located in lagoon river Deposit.

3.4 Limestone, sandstone, soft clay and organic deposits

A very special feature in the city of Maceio is the occurrence of limestone, sandstone and soft/organic clay deposits in the coastal region, and soft/organic clay in the lagoon region. In this article, based on studied SPT boreholes, areas of incidence of these deposits were mapped, shown in Figure 11.

3.4.1 Occurrence of limestone rocks

Limestone rocks are visible on the coast of the city of Maceio, especially at low tide, on the beaches of Pajuçara and Ponta Verde. Studies carried out by Mendes (2017) identified gray, yellow, and gray limestone deposits with bluish tones, constituting the occurrence of sedimentary limestone associated with Phanerozoic sediments from the Sergipe-Alagoas Basin.

The presence of limestone was evidenced in some of the surveys studied, occurring discontinuously in the horizontal direction, which in many situations brings the need for more detailed geotechnical studies in the area of incidence, limestone being identified in only part of the land of the same work, which can directly influence the applied foundation solutions.

Table 3. Frequent features of the layers found in Lagoon River Deposit.

Layer	W.L. (m)	Material Classification		Nspt medium
		Class	consistency	
1st	2.00	Fine Sand with or without silt	Fluffy to medium compact	1 – 10
2nd		Soft clay or Organic Soil (peat)	Very soft	0 – 1
3rd		Silt Sand, with or without clay	Medium compact to little compact	4 – 15
4th		Sand clay or Silt clay	Medium to hard	6 – 12
5th		Fine Sand with or without clay	Medium compact	15 – 18

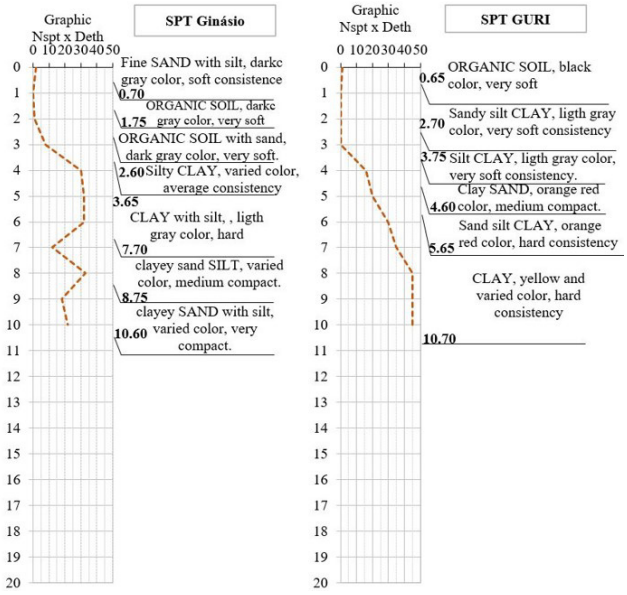

Figure 10. Example of profile located in Lagoon River Deposit.

Limestone was found more frequently in contact with soil classified as fine sand, with or without silt, and limestone, the latter with characteristics of residual soil. The analyzed boreholes tend not to exceed the limestone layer when found, as it is impenetrable to percussion.

Figure 12 shows three typical profiles of the coastal region with occurrence of limestone at a depth of approximately 5.00 m (a), an example where the drilling exceeded the limestone layer (b) and an example of occurrence of limestone rock at a depth of 10.00 m (c).

3.4.2 Occurrence of sandstone rocks

The occurrence of sandstone rocks was identified in the narrowest range of coastal sediments, more specifically in areas of the Jatiúca, Cruz das Almas, Garça Torta and Ipioca neighborhoods.

The layer where sandstone rock occurs has low strength, being penetrated through the SPT test. This characteristic may be related to the degree of weathering of the rock, requiring more detailed geotechnical studies to understand the physical properties of these materials. Figure 13 shows examples of profiles with appearance of sandstone rock.

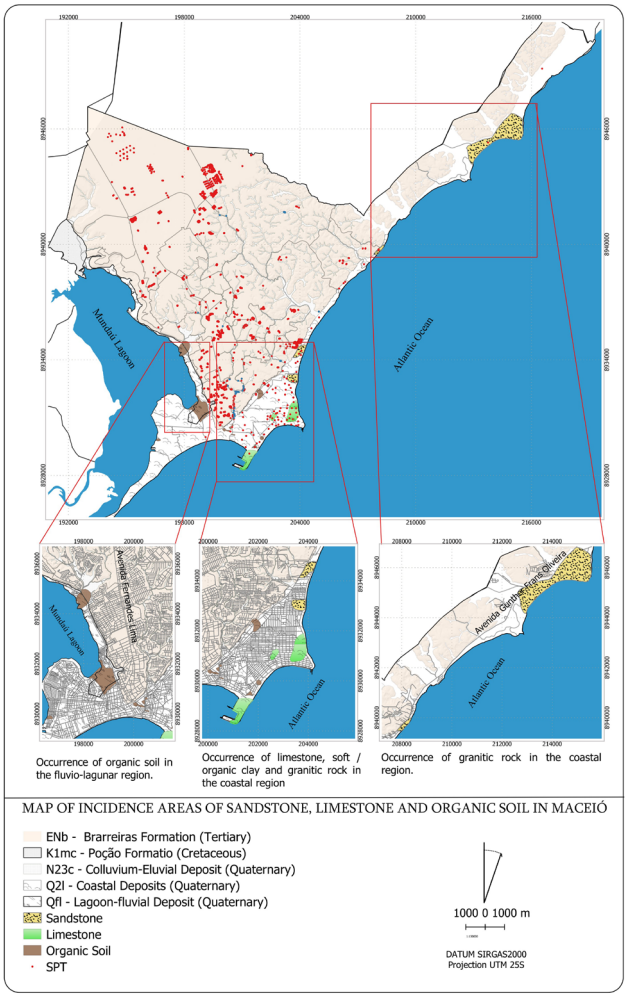

Figure 11. Map localization areas of incidence the rocks and soil.

3.4.3 Occurrence of organic soil

On the coastal plain, deposits of the organic soil were found between Dona Constança de Góes Monteiro and Comendador Gustavo Paiva avenues, located near the Maceio shopping mall, in the Mangabeiras district, near the harbor of Maceio, in the Jaraguá district, and around the Salgadinho stream in the Poço district. The layers of soft/ organic clays are less thick in this region, varying between 1.00 m and 3.00 m. Figure 14 presents two examples of

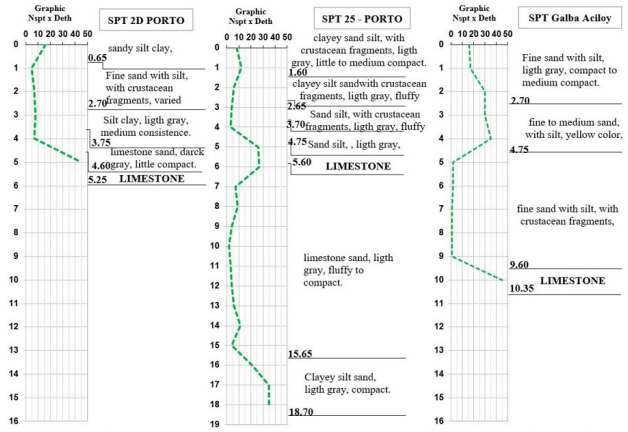

Figure 12. Example of profile with occurrence of limestone layer.

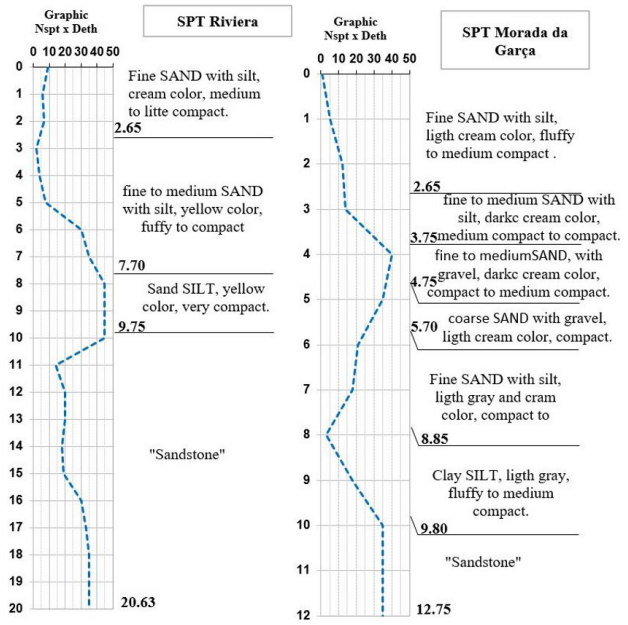

Figure 13. Example of profile with occurrence of Sandstone layer.

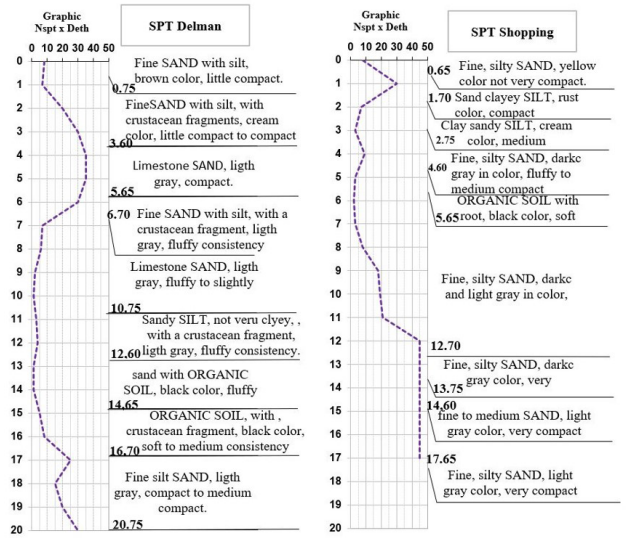

Figure 14. Example of profile with occurrence of soft clays in coastal deposits.

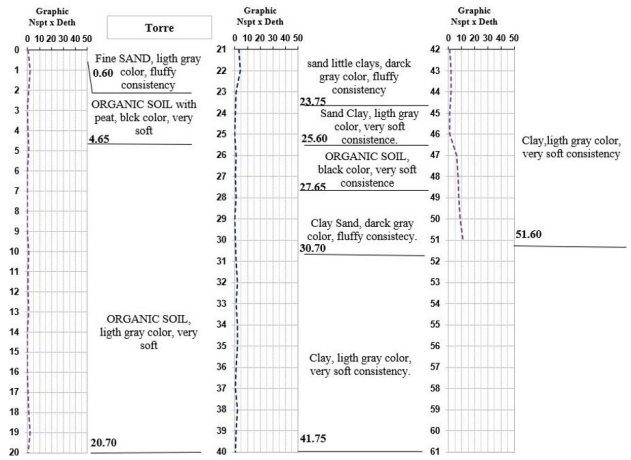

Figure 15. Example of profile with occurrence with occurrence of thick layer of soft clay.

profiles that record the occurrence of soft clays in an area covered by coastal deposits.

In the lagoons-river plain, on the banks of the Mundaú lagoon, the soft/organic clays were identified between the Levada, Bom Parto and Bebedouro neighborhoods, as well as portions in the Trapiche da Barra neighborhood, highlighting the regions along the banks of Frog e village Brejal stream, Ceasa and the production market, where the thickest layers are found, with the occurrence of peat starting at depths less than 1.00 m from the surface and reaching a thickness of 15.0 m. This region is characterized by the occurrence of anthropogenic grounding actions for the construction of dwellings, where previously there were floodplains and mangroves and outcrops of the water table. Figure 15 shows an example of a profile located in the Levada neighborhood where the soft/organic clay layer presents a significant thickness.

In this example, the layers of organic soil are already noticeable at a depth of 0.60 m, very close to the surface to a depth of 20.00 m. Another very thick layer occurs from 30.00 m onwards, presenting a clay with a very soft consistency, until reaching a depth of 51.60 m.

4. Conclusion

The design of typical and representative profiles of the main soil deposits found in Maceio constitutes an important tool to aid in the execution of engineering projects in the region.

Analyzing the drilling records arranged under the sediments of the Barreiras Formation, it was possible to identify the existence of layers with a clayey predominance (between 69% and 84%) with frequent occurrence of

laterization in depth, with no water levels being registered in the analyzed profiles. The coastal deposits, in turn, have layers with a predominance of fine sand, with and without silt, and a water table ranging from 1.00-5.00 m.

The SPT records enabled the spatial location of areas where there are deposits of limestone, sandstone and soft clays, inserted in the coastal plain, in contact with layers of fine sand and/or medium sand, with or without silt, or calcic sand.

In the studied region, it was observed that Limestone has a characteristic of discontinuity in the horizontal direction, which can be evidenced only in parts of the land, with occurrences being registered at a depth of up to 15.00 m. The analyzed boreholes tend not to go beyond the Limestone layer, as it is impenetrable to percussion, however, when exceeded, a limestone layer was found, with a significant loss of resistance. It is important to emphasize the need for more detailed geotechnical investigations in areas with this type of occurrence since the existence of voids in carbonate rocks is common and may be associated with its geological process or dissolution processes.

Sandstone rocks were also identified, more commonly in parts of the city's north coast neighborhoods, with friable rock characteristics, penetration being possible through the SPT test, which may be related to the degree of weathering of the rock, requiring more detailed geotechnical studies for the knowledge of the physical properties of these materials.

Soft and organic clays also occur in the coastal plain, having a small thickness (between 1-3m), and may occur at variable depths.

In the lagoons-river deposit, the water table was found at an average depth of 2.00 m, and it may outcrop on the surface. These deposits are characterized by the occurrence of soft and organic clays from the second layer onwards, which can reach a thickness of up to 15 m. The other layers are made up of fine sands, silty sands and sandy clays of varying thickness.

Acknowledgements

To the Geotechnical Engineering Group for Slopes, Plains and Disasters (GEGEP) of the Federal University of Alagoas and to AGM geotechnical for providing the survey information.

Declaration of interest

The authors have no conflicts of interest to declare. All co-authors have observed and affirmed the contents of the paper and there is no financial interest to report.

Authors' contributions

Juciela Cristina dos Santos: conceptualization, data curation, methodology, visualization, writing – original draft. Roberto Quental Coutinho: conceptualization, methodology, supervision, validation. Juliane Andréia Figueiredo Marques: validation, review & editing.

List of symbols

BGS	British Geological Survey
DBMS	British Geological Survey
GIS	Geographic Information System
Nspt	SPT number
SPT	Standard Penetration Test
W.L.	Water Level

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