Two loessic formations of Upper Quaternary age in the Brazilian Nordeste

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Abstract

Two sedimentary formations of eolian origin, composed of silt and loamy silt occur in the interior of the Brazilian Nordeste, several hundred kilometers to the west of the coast (Fig. 1). The area is semiarid, dominated by the trade winds and prone to severe dries in the present climate. Climatic conditions not very different to the present ones are postulated for the times of generations of both units. The older one is the Cariutaba Formation, red in colour, is massive, friable, porous and loose. Absolute ages from 21 ky BP to 8.5 ky BP were obtained by TL methods. The younger loess is gray in colour, powderish, loose and underwent subfussion processes. Late Holocene ages around 2.60 to 2.20 ky BP were found in this unit.

Introduction

Loose, porous earths, easily to excavate and to plow, have been identified centuries ago by all agricultural civilizations in the world. One of the main reasons of this preference was its practical value, because a high fertility was observed in these materials, besides the facility for

plowing. An interesting proof of such importance is the fact that this kind of earths received specific names in different societies of the pre-scientific world, in China as well in Perú, México and Europe.

Finally, the German term “loess” prevailed in the universal scientific literature, owing to the classical contributions of von Richthofen made in Germany and China, that established the basis of this branch of Sedimentology. Eventually, important advances were achieved in the last decades, although somewhat biased by the fact that most studies were made in the North Atlantic realm and Central Asia; that is, regions directly linked to the North Hemisphere glaciations, a relatively local phenomenon that only sporadically occured in the Earth’s history. For comparison, it can be noted that the 75 million square kilometers affected by the Quaternary glaciations hardly make a 15 % of the 510,000,000 Km2 of the Earth surface.

As a consequence of the historical advance of Science, the factic knowledge (and by attraction the theory) produced a blank that forget or dismiss most of the planet, the majority of the natural mechanisms producing silt-sized particles (not only the glacial ones) and the rest of the environments prone to loess genesis. The dry tropical belts of the Earth should be considered in the first place among such environments. Those dry belts are permanent systems, considerably larger than the episodically glaciated regions. Two loessic formations, generated in a semiarid tropical region, are analysed here; they possibly are typical cases of non-glacially-related loess (Iriondo and Krohling, 1997). Clasical, universally accepted principles and techniques of Sedimentology and Physical Stratigraphy, combined with Geochemistry and absolute datings were employed in the definition and analysis of both units.

Universal availability of fine sediments

The silt fraction of sediments and sedimentary rocks has been (and actually is) disregarded in comparison with either sand or clay. However, measurements of sediment transport in rivers indicate that between 90 and 95 % of the total load of the world channels is composed of silt and clay. Such figures is a clear indicator that the sediment dynamics is at present overwhelmingly dominated by fine particles. The oceanic bottom is also covered by mud in most of its extension, largely major than those areas represented by sand or other sediments; the only terigenous compoent in the abyssal plains is the "red clay" (King, 1962).

The general condition of clays in nature is a state of flocculation; observations in rivers and specially in estuaries and tide plains agree on this point. Natural aggregates are absolutely necessary for sedimentation in very small grain sizes. Hence, muds and "clays" are in fact silt-sized particles and aggregates under natural conditions. Measurements of descharge of silt/clay particles in the major rivers of South America produced the following figures (Meade, 1994):

- Amazon : 1200 x 1,000,000 ton/year
- Paraná : 200 x 1,000,000 ton/year
- Orinoco : 150 x 1,00,000 ton/year

The dominance of silt-sized clasts in the sedimentary bulk is not a particular event of present times. Rocks of all ages of the Phanerozoic Eon show a persistent dominance of fine sediments. Between 70 and 83 % of the computed sedimentary rocks are "lutites", versus 5-14 % of sandstones; the remainder correspond to limestones (Pettijohn et al., 1973). Mean values of thickness of sediments and sedimentary rocks are 3 km in the oceans and 1.5 km on the continents,

composed 75 % of silt and clay (Kuenen, 1941). As it can be seen, the dominance of silt particles in the sediment dynamics is clear and universal, and that was the case in the last 560 millon years. One example that clearly illustrates the non-glacial origin of most silt in the geological history is the case of the Jurassic rocks in southwest Argentina (Iriondo, 1999). The Jurassic was a warm Period of the Earth history, that began 40 million years after the Gondwana glaciation and was 45 million years long. No glacial occurrences are mentioned for that very long time span in the literature. However, the accumulation of fines was abundant and persistent in the whole Period (Digregorio, 1972; Lizuain, 1999); lutites, mudstones and siltites account for a thickness of 5,000 m, 85 % of the total stratigraphic column of the Neuquén basin, a figure that fits well with the gobal values. A dimensional comparison with the Upper Quaternary loess of the Pampa (Iriondo, 1999, silt...), resulting that the rates of accumulation (in volume per year) were similar for both systems, with and without glacial influence.

For clarifying the question of the origin of silt particles, it should be noted that an implicit belief among many naturalists involved in loess research states that silt particles are produced only in glacial and periglacial environments, which is an error. Several natural mechanisms produce massive volumes of silt-sized particles; the most spectacular one is explosive volcanism, which can eject almost instantaneously millions of cubic meters of ash into the atmosphere. Crystal growth of salt, pedogenesis, lixiviation, friction and other universal processes are effective silt “factories” (Iriondo, 1999). On the contrary, glaciations were very scarce and such events by no means can account for the dominant volume of silt along all the geological history. Glaciations were scarce and represented only short episodes, occurring on Earth at intervals of about 200 millon years. Glaciations were never really global; they covered only specific regions. Three glaciations have occurred in geological times since the Precambrian: the first one in the Sahara in the Ordovician; the second in the Permo-Carboniferous of Gondwana (the great southern continent) and the third in Antarctica during the Neozoic (Tarling, 1978). The later one provoked a series of short and unstable

cold pulses in the North Atlantic realm. That is the real dimension of our Quaternary glaciations in the whole geological framework. Glaciations represent only about 5 % of the geologic time since Precambrian, covering minor portions of the continental masses. When one thinks globally, it becomes evident that glacial processes are not responsible for the occurrence of most of the silt on Earth's crust.

Eolian dynamics in tropical South Atlantic

Tropical latitudes are marked by high atmospheric pressures. A belt of anticyclones occur over each ocean and over each continent, generating dry climates and developing the large deserts of the World. Regionally, the South Atlantic ocean is dominated by the general circulation of the atmosphere, which is characterized by the ITCZ (Inter-Tropical Convergency Zone) in equatorial latitudes, a high pressure belt around the Tropic of Capricorn, and the belt of Westerlies above 40/42° S latitudes (Fig. 2 and 3). The tropical belt is occupied by a semi-permanent atmospheric structure, the South Atlantic Anticyclone, which circulates in an anti-clockwise direction. Winds originated in this system reach the Brazilian Nordeste with low to median forces and rare cloudiness. The anti-cyclone does not dissapear in any season of the year, however, it is classified as "semi-permanent" because masses of equatorial air or polar waves sometimes cross thorugh it. In general, the anticyclone drives the major meteorological mechanisms between the latitudes of 15 and 40° S, migrating to the south in the austral winter (July) and northwards in summer (January) (Preston-White and Tyson, 1993)

The wind system in the Nordeste

The present wind regime in the Brazilian Nordeste can be considered similar to that of the Upper Quaternary, because it is dominated by the dynamics of the South Trade Wind (STW). Most of the year, the region is under the STW, which is relatively constant, stable and subsiding. Such characteristics hinder the ingress of ITCZ spells and other atmospheric humid perturbations. In consequence, the climate is semiarid. The South Atlantic Anticyclone itself is not a source of precipitation, because the lower levels of the air are warmed up by flowing into the continent. Consequently, the specific humidity diminishes, a phenomenon named "upper inversion" (Reis de Jesus, 1990) and rains do not occur.

Pluviometric data in jardim dos Angicos (5° 39' S and 36° 00' W) indicate a mean precipitation of 530 mm/year for the period 1911-1977, with 49 % of the years in the interval 250-500 mm/year and severe dries under 250 mm in seven years. The wind regime in Natal, at the coast, is the following (Costa, 1980):

- The percentage of stills is very low.

- The most frequent weather state is a weak breeze (2 degrees Beaufort: 6-11 Km/h) from the ocean, in the morning.

- In the afternoon, the wind force frequently increases to category 4 (20-28 Km/h). In this class, sand begins to move.

- The frenquency of stronger winds increases in the second half of the year. Wind velocity augments with higher atmospheric pressure and low relative humidity of the air.

- Winds of degree 6 (strong breeze, 39-49 Km/h) are rare.

Coastal dunes

Coastal dunes cover long sectors in the Brazilian Nordeste, from Sao Luis do Maranhao to Maceió, a 1200 Km long segment of the coast. They form an irregular sequence of dune fields entering several kilometers into the continent (Fig. 4). A typical area is locate around the city of Natal.

There, two generations of dunes were described by Costa (1980). The older one is yellow ochre in colour, is formed by longitudinal dunes 15 to 22 m high and 150 to 200 m long and covered by vegetation. The sediment is fine to median sand, dominantly composed of quartz with zircon and tourmaline in the heavy mineral fraction. The age is estimated in Late Pleistocene to lower Holocene.

The younger dunes are pale gray in colour; they are formed by fine sand (mode 177 microns) and basically irregular, with microforms of erosion and sedimentation in a rather chaotic pattern. That suggest a wind regime less regular than the former one. Most microforms are 10 to 15 m long. Major dunes are also longitudinal, but with irregularities and ramifications; transversal profiles are asymmetrical. 100 to 200 m wide deflation corridors are carved inter-dunes. The proposed age ofthis system is late Holocene.

Below both dune systems lays a red silty sand, forming a sheet, also with eolian origin. The dominant clay mineral in that sediment is kaolinite.

The Cariutaba Formation

The Cariutaba Formation is a dark red, friable, porous, powderish, massive tropical loess (Fig. 5). Thickness varies between 1 m and 6 m. It occurs in numerous localities in the State of Ceará, particularly in Chapada do Apodí and in the Farías Brito area. TL dates indicate agres of 21.39 + 0.03 ky B.P. at the base and 8.75 + 0.01 at the top. It is composed of 95 to 99 % of quartz in the very fine sand fraction. Such percentages diminishe somewhat in the coarser sand fractions. Minor components are potasic felspars, lithics and heavy minerals. Kaolinite is the clay mineral present in the sediment (Fig. 6). In spite of the strong red color, the content of Fe2O3 is only between 3.6 and 4.2 %. The red color indicates the postdepositional evolution of the sediment under a savanna climate, that is a minimum of 20 °C of temperature and 1,000 mm/year precipitation.

The mineralogical composition of the fine fractions is dominantly quartzose, with subordinate plagioclase and kaolinite. According to XRD the rate quartz/plagioclase is near 5 and the rate quartz/kaolinite results 3. It can be noted a considerable percentage of ill-cristalized material (proto-clay) with chemical composition similar to kaolinite, and a similarly disorganized smaller proportion with gibbsitic chemistry. In the sand fraction, quartz varies between 98 % in the very fine- and 79 % in the fine sand fraction. Near 10 % of gramineae cells (in the very fine fraction) and a similar precentage of lithics (in the fine fraction) were counted in the microscopic loose-grain method. The granulometric composition belongs to a loam, with 36 % silt, 34 % sand and 28 % clay; the resting 2 % accounts for gravel-size concretions (Fig. 7). The mode is located in the coarse silt fraction (phi 5).

Cariutaba Fm covers mountain chains in the region, as the Chapada do Apodí (divisory between the Jaguaribe and Apodí fluvial basins) in an extension of several kilometers. It forms a mantle on a buried landscape of irregular hills carved in Proterozoic schists (Fig. 8). Other important occurrence in the same position appears in the area located between Crato and Nova

Olinda, there, Cariutaba covers the landscape as a mantle, smoothing the irregularities of the subjacent Proterozoic rocks.

In the Farías Brito area, this formation covers with a 4-5 m thickness the upper terrace of the Cariús river; it lays there on alluvial deposits. The type profile was described in a quarry located at the town of Cariutaba. The formation is there 3.80 m thick, composed of red loam to silty loam, massive, friable, powderish, containing scarce ferric concretions. Slopes are vertical to subvertical, with vertical disjunction.

East of Nova Olinda, Cariutaba Fm is composed of a 1.20 m thick basal agglomerate and a main body of loess 4 m thick. The unit lays on Jurassic-Cretacic siltites and sandstones that include dinosaur tracks. In the Pombal area (Paraíba State), which is characterized by a large granitic batholite, Cariutaba forms patches several square kilometers in area, frequently covered by the Porteiras Formation.

The Porteiras Formation

The Porteiras Formation is a tropical loess, composed of loam to sandy loam, massive, powderish, friable, characterized by vertical disjunction, that occurs in association with patches of loose fine eolian sand. In the type profile, locate near the town of Brejo Santo (Fig. 9), subfussion processes are frequent. The age of this deposit is Lower Holocene, with TL dates of 2.59+0.01, 2.20+0.01 and 2.38+0.01 in different localities. Quartz percentages in Portera Fm is not so high as in Cariutaba Fm. Felspars and mica are also present in considerable proportions. Clay minerals (kaolinite, montmorillonite and interestratified) have low cristalinity. Porteiras is a sediment less mature than Cariutaba Fm (Fig. 10). It was formed in a dry climate, which allowed the preservation of felspars and mica and hindered the oxidation of iron minerals. Note that the iron content is here between 4.2 and 7.3 %, higher than in Cariutaba Fm. The general scenario points to a climate

similar to the present one, with precipitations below the limit of generalized oxidation and mobilization of iron (one thousand milimeters per year).

The granulometric composition of the formation is 31-41 % sand, 26-34 % silt and 33-35 % clay (Fig. 11). XRD analysis of the total sample indicate a dominance of quartz, with minor proportions of plagioclase, kaolinite, illite, ortoclase and montmorilonite. Plagioclase, kaolinite and illite appear in all outcrops, whereas ortoclase and montmorillonite appear only sporadically. The rate quartz/felspars varies between 2.3 and 5; the rate quartz clay minerals between 1.4 and 1.7. The loose grain analysis of the very fine sand fraction indicate 85 % quartz, 4 % ortoclase, 3 % lithics and only 1.7 plagioclase. The percentage of heavy minerals is high: 5.6 %. Coarser sand fractions have similar mineralogical composition.

The type profile is located in a small bridge crossing the Porteiras channel, a tributary of the Jenipapeiro stream, which ends in a major river named Porcos, the main fluvial collector of the State Ceará. It is 3.30 m thick and lays in neat contact on fluvial sand. The general colour is gray. The base of the formation is a gravelly median sand, which passes in transition to the loess. The loess is massive, powderish, friable, loose, with vertical slopes, vertical disjunction and piping holes.

This formation also appears in the neighboring State of Paraíba, in the Pombal area, forming a few kilometer long patches on a large granite batholit; in parts it covers the lower terrace of the Peixe river, in other localities it discordantly lays on the Cariutaba Formation. The thickness rarely reaches 1 meter, but a record figure of 8 m thickness was observed near the locality of Pombal.

Geochemistry

The geochemical composition of both loessic formations shows some interesting points (Fig. 12). The rate Sio2/Al2O3 is lower in Cariutaba Fm than in Porteiras, a characteristic that appears as inverse to the results observed in the set of minerals found by XRD and loose grain analysis. The reason for that apparent contradiction is the existence of a considerable amount of coloidal

substances (with composition similar to clay) detected in the diffractograms. Other usual indicators of maturity, such as CaO, Na2O and K2O, have values coherent with the mineralogy, that is a higher maturity in Cariutaba.

Discussion and conclusions

A short discussion on the information contributed by this paper points to the following general scope of the interesting issue that can be named “non-glacial loess”. Main points are:

REGIONAL CERTAINTY OF WIND TRANSPORT

Wind has been (and is today) a major agent of sediment transport in the Brazilian Nordeste:

Coastal dunes developed during the Pleistocene and Holocene in numerous localities. Those in Natal are particularly extensive.

Pre-Quaternary rocks are frequently eolian in origin.

Continental dune fields were formed in the interior during the Upper Quaternary. The largest one, linked to the Sao Francisco river, coveers a surface of 7,000 square kilometers (Barreto et al., 1998). Cariutaba and Porteiras Formations are correlative to these sands.

Disruption and reactivation of dunes by human activity are frequent in many localities of the region.

LOCAL AND INTRINSIC EVIDENCES OF EOLIAN ORIGIN

Both Cariutaba and Porteiras Formations have characteristics which have been attributed to loess.

A silt-loamy granulometric composition.

A general shape of mantle covering older formations of different age and composition.

A discordant relationship with the underlying formations.

A torrential gravel with tractive structures in most sites.

Evidences of accumulation - Absolute ages measured in one point are always younger than the lower ones and older than those located in upper levels.

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Figure captions

1 – Localization of the study area.

2 – General circulation of the Atmosphere.

3 – Localisation of the tropical anticyclones.

4 – Coastal dunes in NE Brazil.

5 – Type profile of Cariutaba Formation.

6 - Mineralogy of Cariutaba Formation.

7 – Granulometry fo Cariutaba formation.

8 – Basal discordance of Cariutaba formation.

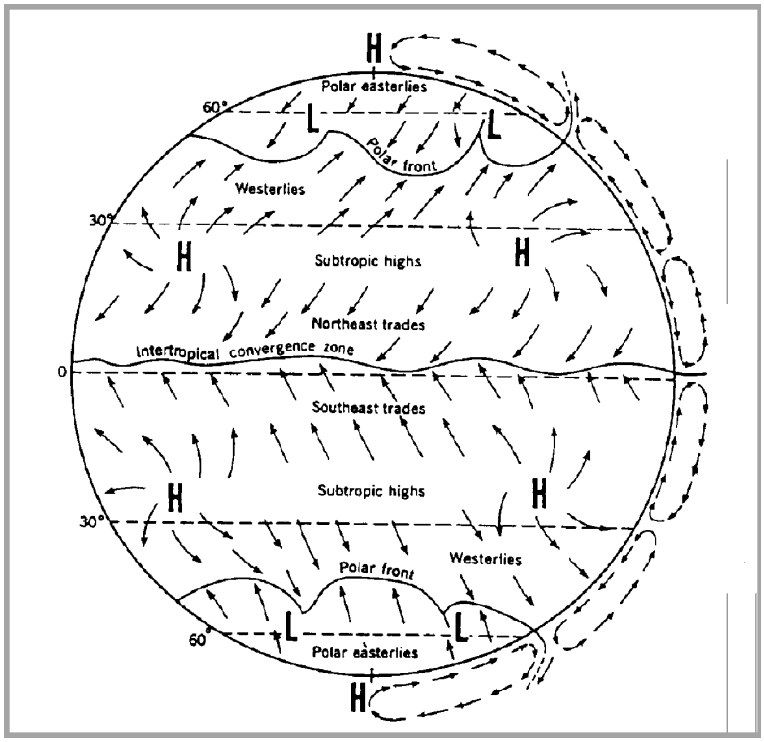
9 - Type profile of Porteiras Formation.

10 – Mineralogy of Porteiras formation.

11- Granulometry of Porteiras formation.

12 – Geochemical composition of both formations.

Figures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Polar easterlies
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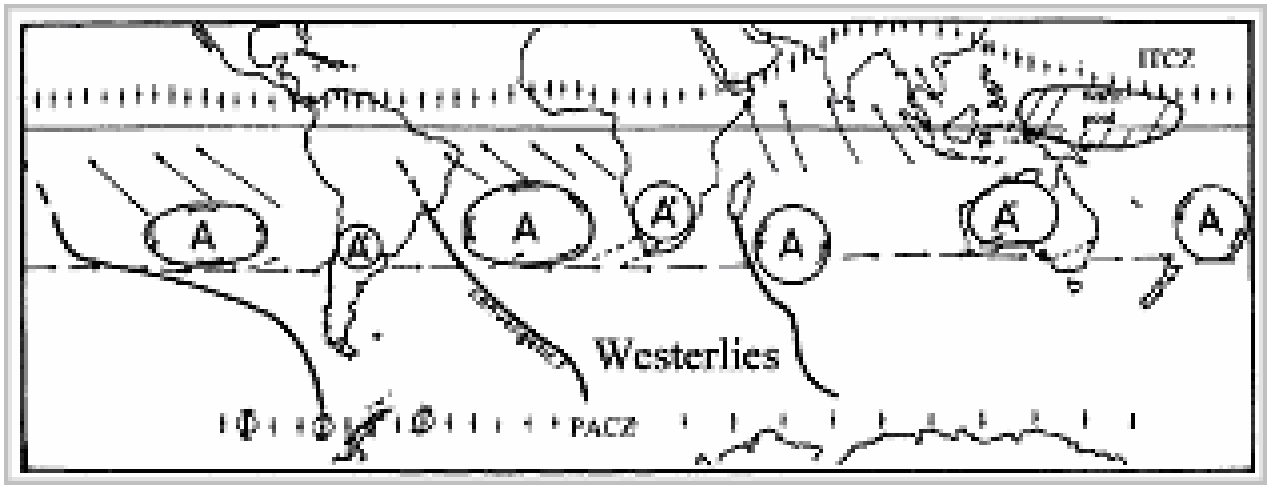
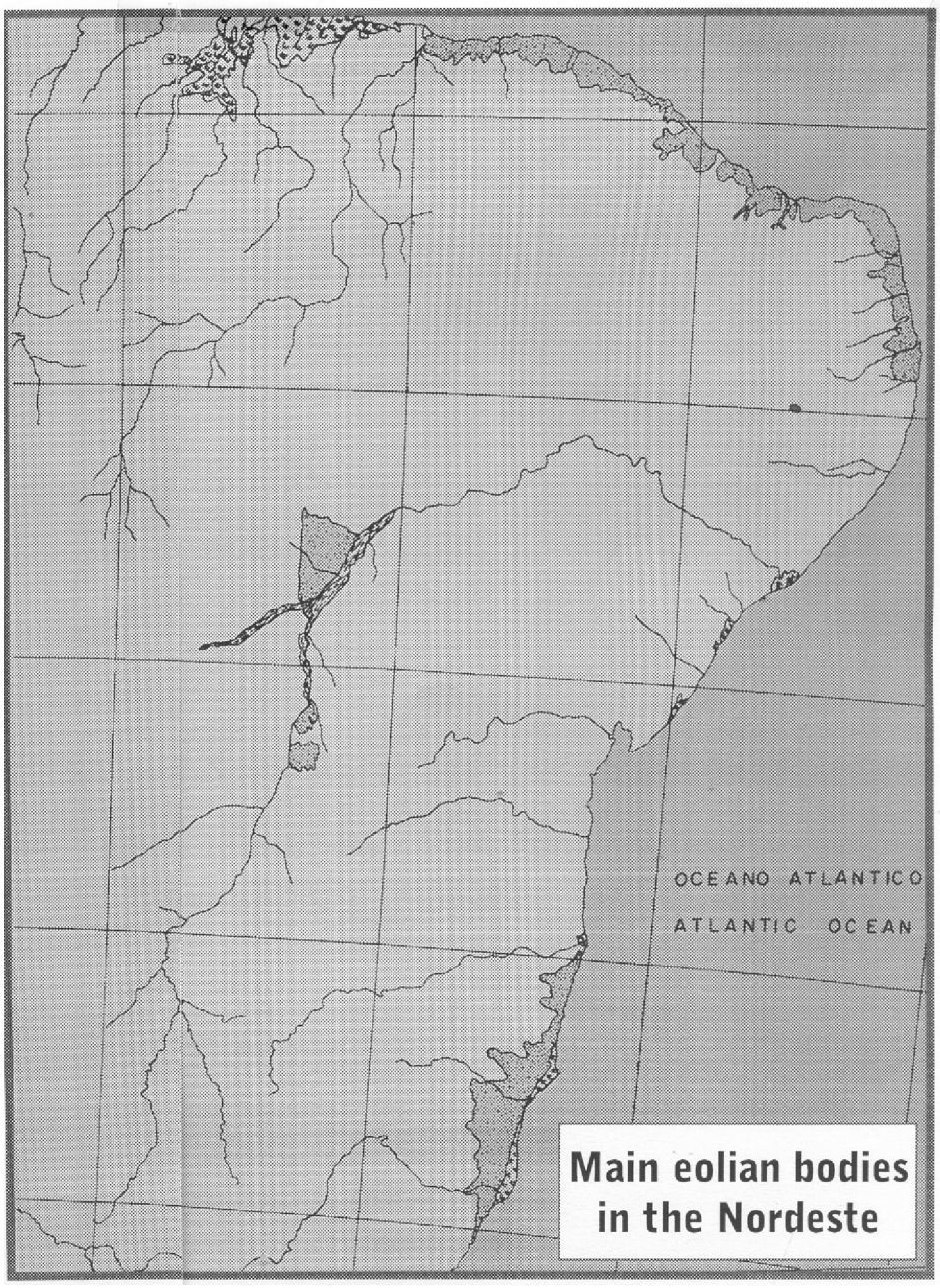
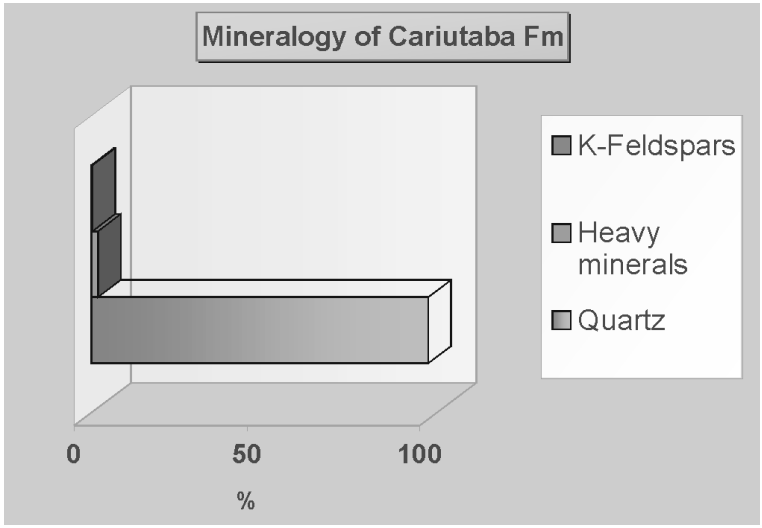




Main eolian bodies in the Nordeste


Mineralogy of Cariutaba Fm
K-Feldspars
Heavy minerals
Quartz
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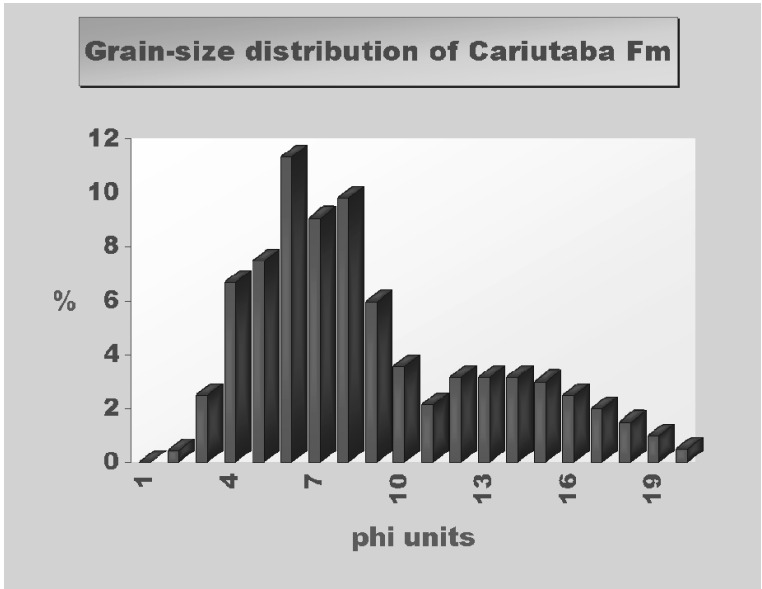
%


Grain-size distribution of Cariutaba Fm
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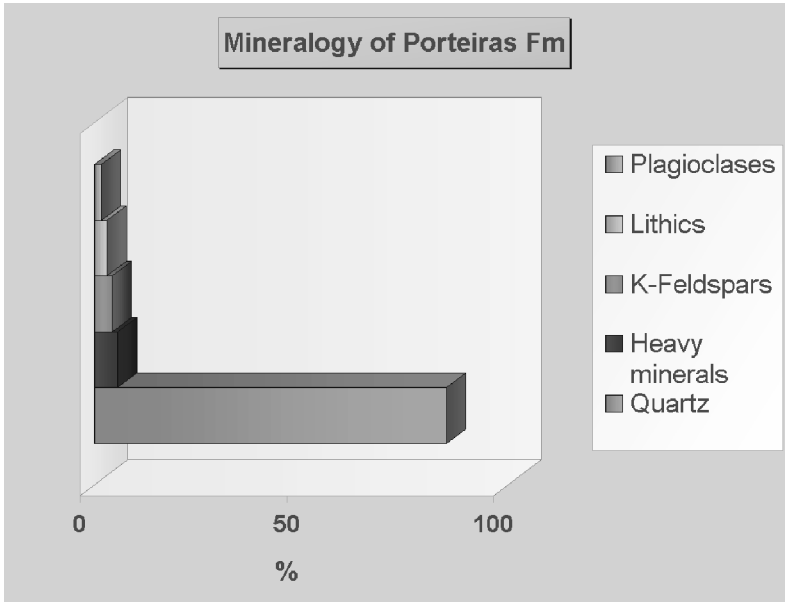
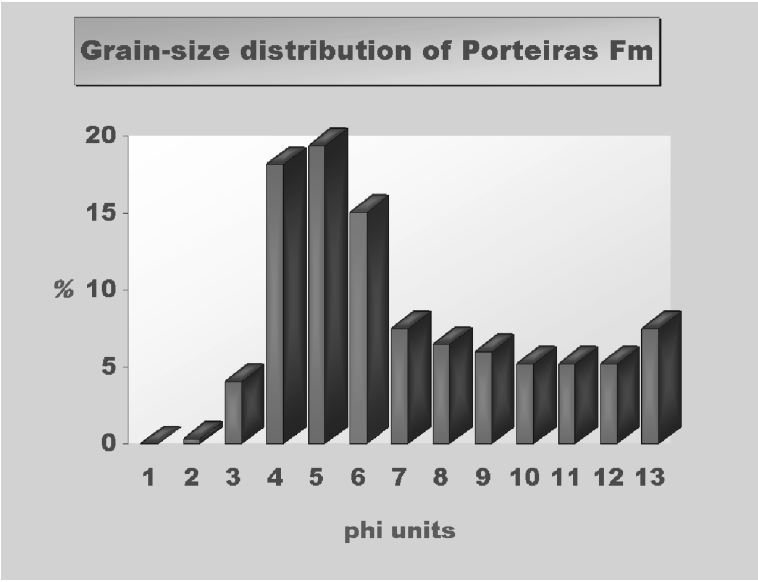
%
1
4
7
10
13
16
19
phi units


Mineralogy of Porteiras Fm
Plagioclases
Lithics
K-Feldspars
Heavy minerals
Quartz
0
50
100
%



Chemical Data

Unit	SiO2	Al2O3	CaO	MgO	Na2O	K2O	Fe2O3	MnO	TiO2	P2O5	Cr2O3	LOI
Lower Cariutaba	62.7	22.1	0.04	0.10	0.10	1.75	4.17	0.02	0.46	0.03	0.02	8.10
Upper Cariutaba	65.7	19.3	0.01	0.10	0.10	2.06	3.61	0.02	0.43	0.02	0.02	7.05
Porteiras 1	70.8	13.0	0.68	0.99	0.19	1.76	4.22	0.07	0.50	0.13	0.04	6.25
Porteiras 2	68.5	14.0	1.55	1.35	2.13	2.61	4.99	0.09	0.81	0.01	0.03	2.80
Porteiras 3	59.5	17.5	1.41	2.22	2.85	2.79	7.29	0.22	1.10	0.05	0.02	4.65