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## SOILS AND GEOMORPHOLOGICAL DEVELOPMENT OF THE HAFF DELTA OF THE VOUGA RIVER (PORTUGAL) (\*\*\*)

**Abstract:** PERDIGÃO A.M.M. & ROGADO N.J.Q., *Soils and Geomorphological development of the Haff Delta of the Vouga River (Portugal)* (ISSN 0084-8948, 1989).

The Vouga basin is situated in the western part of Portugal, in the Iberian Peninsula. Owing to the Mediterranean influence, both the rainfall and the river flow are very irregular. For the most part of its course, the Vouga flows through the Old Iberian Meseta. Near the sea, it crosses a lagoon containing modern alluvium. The lagoon is enclosed by sand dunes-partly levelled by human action or otherwise-and its greatest extent is along the coast, forming a haff delta.

Most of the soils of the area are Humic Cambisols; in the western part, Regosols, Podzols, Fluvisols and Gleysols can also be found, as well as Gleyic Salic Fluvisols.

In the beginning of the Holocene (or Flandrian) the coastline was situated much more to the inland. Afterwards the Vouga outlet began to form a delta and some small transgressions and regressions seem to have taken place. The development of the zone must have been influenced by the coastal lagoon, with its microtidal characteristics. The hydrological variation of the Vouga River and its tributaries seems to have been very important to the distribution of the sediments. The type of sediments appears to be closely related to the rocks that occur on the river-basin.

**KEY-WORDS:** Soils, Geomorphology, Haff Delta, Holocene, Vouga Basin (Portugal).

**Riassunto:** PERDIGÃO A.M.M. & ROGADO N.J.Q., *Suoli ed evoluzione geomorfologica del delta del F. Vouga (Portogallo)* (ISSN 0084-8948, 1989).

Il bacino del Vouga è situato nella parte occidentale del Portogallo. Sottoposti all'influenza del Mediterraneo, sia le precipitazioni che il regime del fiume sono molto irregolari. Per la maggior parte del suo corso, il fiume solca la vecchia *meseta* iberica, poi in vicinanza del mare attraversa una laguna di origine recente. La laguna è chiusa da dune sabbiose, parzialmente livellate dall'uomo, che si estendono lungo la costa, formando nell'insieme un delta a *haff*. I suoli sono per la maggior parte Humic Cambisols; si possono anche trovare Regosuoli, Podsol, Fluvisols e Gleysols, così come Gleyic Salic Fluvisols.

All'inizio dell'Olocene la linea di costa era posta molto più all'interno. In seguito il Vouga iniziò a formare un delta nell'ambito di alcune modeste ingressioni e regressioni marine. L'evoluzione dell'area

è stata condizionata dalla laguna, con le sue caratteristiche microtidali, ma anche le variazioni idrologiche del Vouga e dei suoi affluenti hanno giocato un importante ruolo nella distribuzione dei sedimenti.

**TERMINI CHIAVE:** Suoli, Geomorfologia, Delta a Haff, Olocene, Fiume Vouga (Portogallo).

The Vouga basin is situated in the western part of Portugal, in the Iberian peninsula, between latitudes 40° 15' and 40° 55' North and longitudes 7° 33' and 8° 15' West. The River Vouga has its sources in a mountainous area (Serra da Lapa 953 m high) and its mouth through a lagoon, near Aveiro, on the Atlantic shore running with a East West direction.

Its main tributaries are the rivers Agueda, Cértima, Alfusqueiro and Caima. The Vouga area contacts North with the Douro basin and South with Mondego.

Owing to Mediterranean influence, the summers are long and virtually rainless. However, in the zone of Aveiro, some Atlantic influence is also apparent: temperature is mild (18.4 °C mean temperature of the warmest month) and atmospheric moisture is relatively high. The winters are also mild (9.9 °C mean temperature of the coldest month) and most of the rain occurs between October and April. The rainfall is irregular and so is the flow of the Vouga River: 3780 m<sup>3</sup>/s to 0.5 m<sup>3</sup>/s in the downstream area.

For the most part of its course, the River Vouga flows through Precambrian shales and schists and Paleozoic granites of the old Iberian Meseta. Between Albergaria and Aveiro, the river goes across Triassic and Cretaceous sandstones, often covered by terraces of marine or fluvial origin and dated from the Pliocene and the Pleistocene.

Downstream of Aveiro, the river enters a coastal lagoon with modern alluvium, which is enclosed by sand spits partly levelled by human action or otherwise. The greatest extent of the coastal lagoon is along the shoreline, thus forming a haff delta 38 km long and 1 to 4 km wide, approximately.

Modern alluvium and sandy areas of the Holocene lie upon Cretaceous sandstones or Precambrian shales: the

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deposits can be 20-30 m thick in the deltaic zone to more than 60 m near the mouth of the lagoon.

## SOILS

Most of the soils of the area are Humic (or Umbric) Cambisols, with Rankers derived from granites and shales, in the eastern part, as well as Luvisols derived from shales.

The Cambisols also occur on sandstones and on the terraces. These are formed by unconsolidated deposits, generally middle-textured but sometimes presenting a lighter texture. Such deposits are largely widespread, covering Triassic and Cretaceous sandstones and even Precambrian shales, in certain areas. Their thickness is variable: from only some centimetres to several meters.

In the sandy areas around the lagoon, Regosols occur on the most recent sands and Podzols in the older ones.

Fluvisols and Gleysols are the predominant soils in the alluvial plains of the Vouga River and its tributaries, with Gleyic Salic Fluvisols in the salt marshes, inside or near the lagoon the «Ria de Aveiro» (ROGADO & PERDIGÃO, 1986).

## GEOMORPHOLOGY

In the areas of granites and shales the valleys of the Vouga River and its tributaries are, as a rule, deeply dissected by erosion, with steep slopes, often corresponding to tectonic faults.

Immediately downstream, there is a transitional area of Triassic and Cretaceous sandstones and also Precambrian shales, presenting less steep slopes. This zone is partly covered by old terraces, of marine or fluvial origin, at several heights: 5-8 m, 15-20 m, 30-40 m, 45-50 m, 60-70 m, 80-90 m, 100-110 m and 120-130 m.

The highest terraces are the oldest ones; 100-110 m and 120-130 m terraces must have been formed during the Pliocene. All the others are probably dated from the Pleistocene. The texture of the deposits is generally loam or sandy loam; the main exception is the 30-40 m terrace. Wich presents a coarser texture, loamy sand with plenty of gravel, and some pebbles and stones.

An intensive continental erosion is supposed to have occurred during the Pleistocene and it was over that eroded substratum that the alluvial sediments of the area must have been deposited. The alluvial plain occupies an old bay now silted up with sediments; in the beginning of the Holocene, the coastline was situated much more to the inland along Ovar, Estarreja and Aveiro. The River Vouga and some of its present tributaries flowed into that bay, independently from each other, and developed the present marshes of Fermentelos, Frossos and Tabueira, which represent the remnants of the old bay. Alluvial aggradation must have permitted the capture of the River Cértima by the Agueda and of this one by the Vouga, which thus became the main river (GIRÃO, 1951).

After this phase of estuary, the river mouth began to present some deltaic characteristics. Two sand spits seem

to have been formed north and south of the mouth causing an accumulation of sediments and inducing a braided-stream pattern (SOUTO, 1923). Some small transgressions and regressions seem to have taken place contributing to the diversions of the branches of the streams.

Finally, the lagoon must have been formed owing to the advance of an offshore sand spit since the 10th till the 18th century, when the old bay was closed (ABECASSIS, 1955).

The bar showed a trend to wander southwards until it was artificially opened in 1808, fixing the place of the mouth and, at the same time, providing an entrance to the harbour of Aveiro. The dominant winds blow from the Northwest and, as the coast runs North-South, the waves break obliquely, which must have contributed to the formation of the offshore bar (LEEDER, 1985); in fact, as it is well known, the cumulative action of the winds, the currents and the waves favours the longshore drift. However that offshore sandy bar is quite fragile: the sea has broken through it several times, during violent storms.

The lower Vouga zone is according to HAYES (1975) a river delta influenced by the development of the coastal barriers. Owing to the deceleration of the discharge regime, the sediment yield of the river (caused by the mixing of riverine and marine waters), resulted in sand filled river channels according to the increased eustatic sea level during the Holocene.

This area is influenced by a coastal lagoon with microtidal characteristics. It was an old estuarium influenced by the development of caostal barriers, broken along one or more bursts, promoting the free contact of the estuarine environment with the ocean.

The natural flow line of Vouga River, formerly through Laranjo Lagoon, has been changed with the construction of an artificial drainage channel (see map 1). The variation of the flow of Vouga river and tributaries, together with tidal variation related with melting of riverine and salt water, had an important effect on the distribution of sediment yield of the river, as well as with waves, climate of the basin, coastal wind regime and direction of coastal currents. The upstream sediment load due to tidal influence can be the reason for a cyclic sequence on the layer found in the area (Vouga Deltaic Basin) according to 3 m deep augerings.

Differences in the geological origin of the sediment yield, must have occurred, changing from the granite zone to the shale.

## RELATIONSHIPS SOIL-GEOMORPHOLOGY

The higher and middle courses of the Vouga and its tributaries cross zones of shales and granites and these rocks seem to have originated most of the sediments found in the lower course. Triassic and Cretaceous sandstones must have contributed only moderately as well as the clays of Cretaceous; more important is probably the influence of the River Antuã which flows directly in the lagoon after crossing area of Precambrian gneisses and mica-schists.

The origin of the sediments must be predominantly fluvial, although in the lagoon a marine influence seems to be apparent; sandy aeolian deposits also occur in the area near the sea. The sediments lie on a substratum of Precambrian shales and Cretaceous sandstone sloping to the Atlantic Ocean.

The size of the particles seems to show a downstream fining. In the alluvial plains of the lower Vouga, Agueda and Cértima, the dominant fractions of the surface layers are silt (0.02-0.002 mm) and very fine sand (0.063-0.02 mm). The sediments are rich in muscovite which can be seen with the naked eye chiefly in samples of the layers at or below 78-80 cm depth.

In lower Vouga and Agueda, the natural levees and backswamps of the alluvial plain are clearly seen, the levee soils being, as a rule, lighter textured than the basin soils. In the Vouga delta plain and in the Cértima such differences are not so clear, due probably to the rice culture which has modified the landscape along the time. In the case of the Vouga delta plain, the intricate channel network must have also contributed to reduce differences between natural levees and basin soils.

In the moderately well drained areas, the soils can be classified as Fluvisols, normally Umbric or Dystric. Where

the soils are poorly drained, the Gleysols (Fluviombric, as a rule) predominate. In the zones of the lagoon that are affected by salt water, the soils present characteristics of the Gleyic Salic-Fluvisols. The coastal dune area is formed by Dystric-sometimes Calcic-Regosols, where the material has been recently deposited. In the somewhat older sandy deposits, the Podzols are the predominant soils.

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