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THE SOILS AS PALAEOCLIMATIC INDICATORS. A FEW SEQUENCES OF PALEOSOLS IN THE FIUME SANTO AREA (SASSARI, SARDINIA). PRELIMINARY OBSERVATIONS

ABSTRACT: MADRAU S., *The soils as palaeoclimatic indicators. A few sequences of paleosols in the Fiume Santo area (Sassari, Sardinia). Preliminary observations*. (IT ISSN 1724-4757, 2004).

A number of paleosols that formed between the Late Miocene and the Pleistocene have been observed and described near the mouth of the rio d'Astimini - Fiume Santo (north-western Sardinia).

Buried under thick deposits of coarse sediments, these palesols have been preserved and have not been affected by climate conditions after the burial event, and therefore have not undergone pedogenetic evolution. Because of their properties reflect the existing environmental conditions at the time of formation, these soils represent an additional tool to reconstruct the climate and landscape of north- western Sardinia between the Late Miocene and the Pleistocene

KEY WORDS: Paleosols, Climatic changes, Sardinia (Italy).

RIASSUNTO: MADRAU S., *I suoli come indicatori climatici. Alcune sequenze di paleosuoli nell'area di Fiume Santo (Sassari, Sardegna). Osservazioni preliminari*. (IT ISSN 1724-4757, 2004).

Sono stati studiati e descritti alcuni paleosuoli formatisi alla fine del Terziario, tra il Tortoniano e il Pleistocene inferiore, nei pressi della foce del rio d'Astimini - Fiume Santo nella Sardegna nord occidentale.

Questi suoli, sepolti da una spessa copertura di depositi caotici, sono stati preservati dai successivi mutamenti imposti dall'evoluzione pedogenetica durante le successive fasi di cambiamento ambientale. Le loro caratteristiche chimico fisiche riflettono chiaramente le condizioni di equilibrio ambientale esistenti durante la loro formazione. Essi rappresentano un ulteriore tassello per la ricostruzione dei caratteri climatici e del paesaggio nella Sardegna nord occidentale tra il tardo Miocene ed il Pleistocene.

TERMINI CHIAVE: Paleosuoli, Cambiamenti climatici, Sardegna.

INTRODUCTION

The chemical and physical properties of soils reflect their steady state conditions with the environmental factors (substrate, morphology, climate, and vegetation) under wich the soils themselves developed. Any change in the surroundings, especially the climate, is reflected sooner or later in the pedogenesis, giving rise to pedologic types with new characteristics.

Based on these assumptions, Yaalon (1971) supports that the pedogenesis represents a condition of dynamic equlibrium. For this reason the soil characteristics are not stable in time, but tend to reach an equilibrium with the climatic conditions, possibly adapting to the changes that have occurred.

A set of soils, generically defined paleosols, escaped this condition of evolutionary dynamism, thus becoming of great importance for climatic reconstruction. Their only common property is the presence of characteristics that formed in the past (Yaalon, 1971) and that persist today either because the soil was buried at depths beyond the effect of soil forming processes including biologic activity (Fotakewa, quoted by Ruellan, 1971), or because these characteristics have reached such a level to be considered irreversible or self-sustaining (Ruellan, 1971). Table 1 shows a scheme of the time needed to form a few pedologic horizons and their period of persistence in paleosols.

The following pages will describe a few paleosols observed, between the mouth of rio d'Astimini - Fiume Santo and the Pilo lagoon (Nurra di Sassari), during studies carried out as part of the CNR MURST project *Atlante delle Spiagge Italiane (Atlas of Italian Beaches)*. Also this study is part of the EU MEDALUS acronym for Mediterranean Desertification and Land Use Project by the NRD acronym for Nucleo Ricerca Desertificazione (Research Center on Desertification) of the University of Sassari.

Thanks to these studies it has been possible to develop a first set of hypotheses on the climatic conditions between the late Miocene and the Pliocene. These hypotheses were comfirmed both by geomorphological studies and by several significant fossil findings in the past years (Cordy & Ginesu, 1993).

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TABLE 1 - Soil diagnostic features* and horizons grouped according their mode of origin and relative persistence in paleosols, o = occasionally, c = commonly, f = frequently, (from Yaalon, 1971). * horizons and features according to Soil Taxonomy USDA

altered easily generally < 1000 years to reach steady stade	*relatively persistent* slowly adjusting generally > 1000 years to reach steady stade	*persistent features*
properties acquired by reversibile, largely self-regulating processes	mostly steady-state near-equilibrium features or metastable state	features produced by essentially irreversibile self-terminating processes
mollic horizon (f) slickensides (c) salic horizon (c) gypsic horizon (o) mottles (c) gilgai (c) cambic horizon (o) spodic horizon (o)	cambic horizon (f) umbric horizon (f) spodic horizon (f) fragipan (f) mottles (o) argillic horizon (c) natric horizon (o) calcic horizon (f) gypsic horizon (c) histic horizon (c)	oxic horizon (f) placic horizon (f) plinthite (f) durinodes (f) petrocalcic horizon (f) gypsic crust (f) argillic horizon (c) natric horizon (c) albic horizon (o) fragipan (o) histic horizon (o)

THE STUDY AREA

For the study of the paleoclimatic characteristics of north-western Sardinia, between the Miocene and the Pliocene, we devoted our attention on Nurra di Sassari region, on the Mio-Pliocene alluvial deposits between the mouth of rio d'Astimini - Fiume Santo and the Pilo lagoon (Stagno di Pilo), figure 1. This is sizeable area with a weakly undulated morphologhy, subjected to clearly visible runoff-water erosion (locally even serious), for example at Sant'Osanna on the left of the river.

For the study area, the Geological Map of Italy, sheet no. 179 *Porto Torres*, shows the presence of pebbly alluvia with prevalently quartzose elements on the high plains and terraces, intercalated with variegated sands and clays.

Martelli (1953) indicates the presence of an *extended alluvial nappe, prevalently quartzose along the entire coastal arc. This nappe is a few metres thick… and it is covered by a mantle of eolian sediments that proceed westwards into small valleys, and cover their lowest slopes (Badde Su Laccu, Badde Guardia Secca, and Badde Lunga). These wind deposits are generally arranged along swampy areas. This is documented by alternating limestone travertinose levels in the eolian deposits. In this area, we can distinguish a number of ancient terraces which grade more or less uniformly towards the Pilo lagoon, the natural collector of local runoff waters.*

Based on new surveys Ginesu & *alii* (1995), reconstructed the relations between ancient alluvial formations and other landscapes features found in the area. Their work showed that alluvial deposits are made up of high-energy conglomerates with siliceous elements mixed with different grain-size sands, clay and carbonaceous horizons. These alluvial deposits cover, and the same time mark, the pre-existing paleosols of the middle stretch of the rio d'Astimini - Fiume Santo basin.

Thanks to the studies by Ginesu & *alii* (1995) and the studies by Baldaccini & *alii* (1995; 2002), it has been possible to identify the area involved by the presence of these deposits with great exactness. These deposits were spread over a vaster territory than postulated in the geological maps at 1:100.000 scale. It emerged therefore, that the Mio-Pliocenic alluvia link up with variously thick colluvial deposits partly made up of differently pedogenised materials widespread at the foot of the Mesozoic limestone reliefs which close the rio d'Astimini - Fiume Santo basin on the right. In the south, deposits can only be seen on the right of the rio and, as far as the mining village of Canaglia, where they are replaced by Palaeozoic metamorphic reliefs. Isolated margins of these ancient alluvia, a few areas in width, can be found almost as far as the outskirts of the village of Palmadula. Ginesu & *alii* (1995), postulate that the origin of these plates is related to the presence of ancient left tributaries of rio d'Astimini.

To the west and northwest, the ancient alluvia rest on the metamorphic reliefs that close the plain of Nurra separating it from sea. A few large Late Miocene fossil-bearing deposits discovered near the rio d'Astimini Fiume Santo mouth, inside the ENEL power stations, are related to these ancient alluvia (Cordy & Ginesu, 1993).

According to Ginesu & *alii* (1995), the thick deposits of Mio-Pliocenic clays, quarry fronts of thicknesses of over 50 m are visible in the Scala Erre quarry, with several intercalated levels of coarse material of various thicknesses originated as a result of the filling of a subsidence trough with Triassic clays and chalks at the end of Tertiary. This filling phase would have been prevalently of the continental type and would have involved a delta fluvial or fluvial environment conditioned by the presence of an action of coastal deposits by tidal processes when the Mediterranean Sea was more open than presently.

The Mio-Pliocenic levels underwent intense rework, mainly due to erosive processes related to the formation of present drainage patterns. These processes led to the formation of very gentle rounded forms that characterise the present landscape.

From the point of view of land use, apparently, the whole area of ancient alluvia is characterised by a large stretches of natural o quasi-natural conditions. Infact, grazing in rotation with fodder growing tend to predominate, while large stretches of maquis characterise the slopes, the non arable fluvial valleys, and the shores of the Pilo Lagoon. As witnessed by the numerous archaeological sites, from the Nuragic age to the late Empire (Basoli, 1989), and by numerous clay caves, this land has always been exposed to the intense modifying action of man. An action that reached its peak with the construction of two thermal and one wind power stations right in the middle of the study area, figure 1.

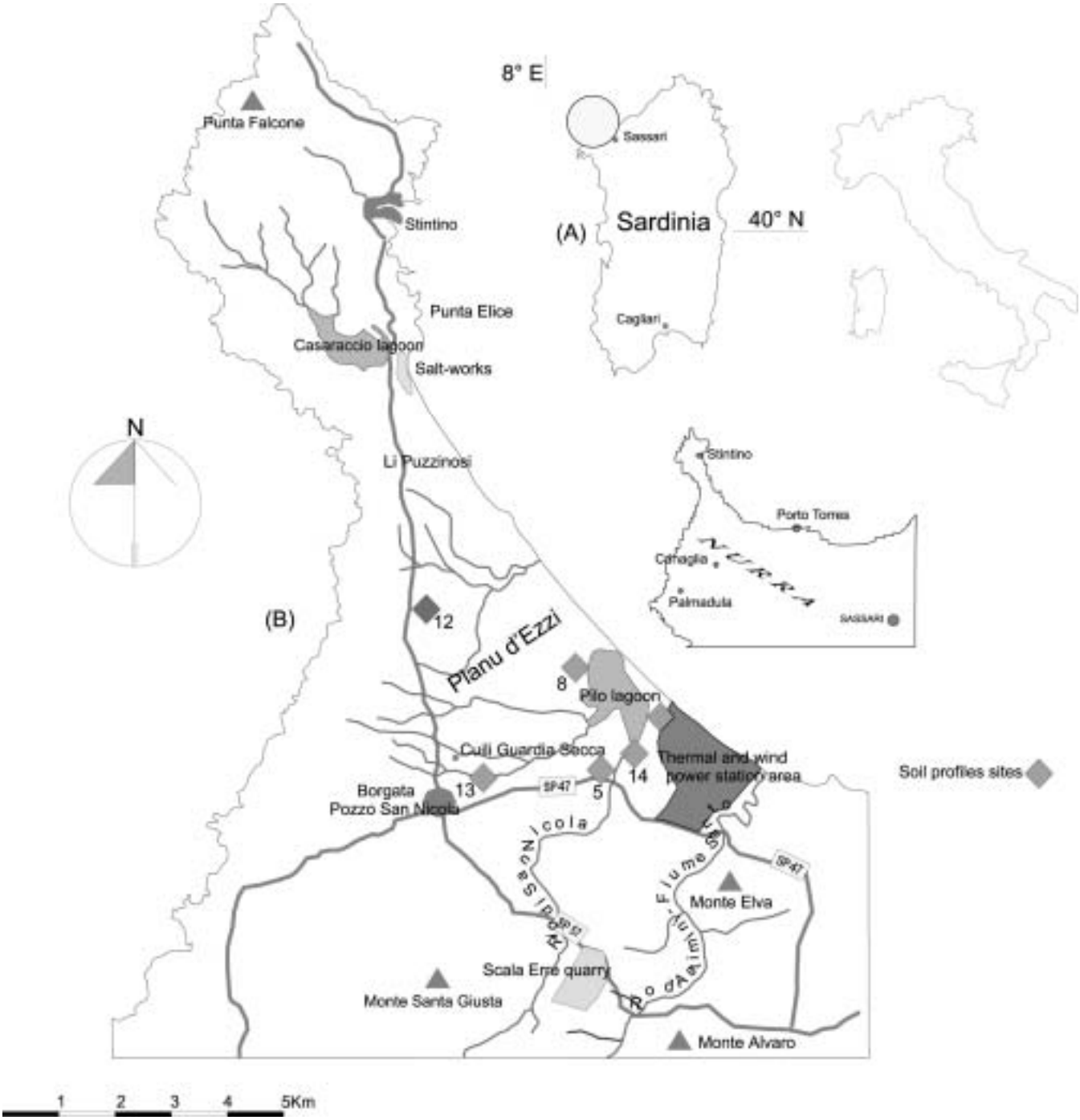

FIG. 1 - The Island of Sardina with the study area (A). Localities of the soil profiles (B).

THE SOILS

In this early phase of investigation, 6 pedological profiles have been located and described inside the study or in the immediately bordering areas. These observations have been verified and confirmed by others.

Descriptions of complete soil profiles are few in number, due to both the mixing caused by the massive excavations, earth moving work, and clay quarries, carried out on large areas for the constructions of the for power stations. Nevertheless, two pedogenetic sections have been located in the time frame considered. One refers to coarse alluvial, the other to wind deposits.

a - The soils of coarse alluvia

i - Profile no. 5. This profile was observed along the edge of road cut at km 7 on provincial road no. 47, between Porto Torres and Stintino (fig. 1), in a terrace on the left of rio San Nicola, a tributary of Pilo lagoon.

The profile presents the following sequence of horizons, A-Bt-C-2Bkqb-3Btb-3Btvb [1] with a total thickness over 5 m (fig. 2).

The mean feature of profile 5 is the presence of C horizon, which has a total thickness of over 160-180 cm and it is made of lenses of prevalently quartzose pebbles and gravels cemented by limes and very fine clays, the latter one make up 51% of the fine earth fraction and by a small percentage of carbonates. Immediately below it, there is a 2Bkqb horizon, 60-80 cm thick, whose fine fraction appears cemented by silica, and to a lesser extent, by carbonates (5,2%).

At the bottom of the section there is a 3Btvb horizon, which ranges from about 330 cm, where plinthite predominates, making up as much as 28% in volume of the first 70 cm of the horizon.

The presence in C horizon of a chaotic succession of a number of lenses of materials different only in their grain size, both in this and in many other profiles, suggests that the origin of this horizons is due to the succession of a number of alluvial episodes in a delta fan type (foreset beds) of environment that have occurred in a short time span.

ii - Profile no. 12. This profile is observed in road cuts along the provincial road no. 57, near La Pergola restaurant, in a terrace that weakly grades from Planu d'Ezzi towards the reclaimed plain Li Puzzinosi, separating the complex of Mio-Pliocenic alluvia from the Casaraccio lagoon and the Stintino salt works.

The profile sequence includes: A-Bt-Bkm-C-2Bkqb-2Btb-2Btvb. The sequence thicknesses is greater than 320 cm. The Bkm horizon has an average thickness about 65 cm and it is made up of very fine, strongly cemented materials. This is followed by C horizon, a chaotic succession of lenses of strongly cemented gravels and pebbles.

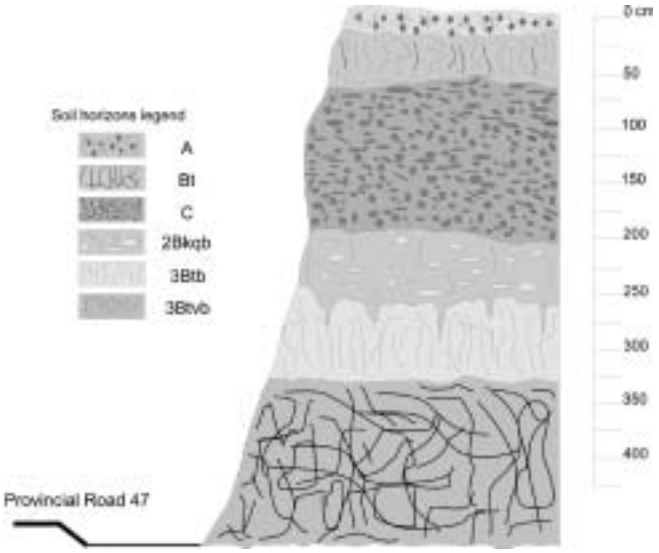

FIG. 2 - Soil profile n. 5.

The buried soil is similar to horizon 2Bkqb described in profile no. 5. In profile no. 12 it is about 35 cm thick and it is strongly cemented. It is followed by a argillic horizon and by one rich in plinthite, 2Btvb, which is observed from about 290 cm downward.

iii - Profile no. 13. This profile was found at Cuili Guardia Secca (fig. 1) in a valley dug by a small watercourse that flows into Pilo lagoon. It is located at about half way its west shore. The width of the valley varies from a few tens of metres, as at the point of observation of the profile, to about a hundred in its middle an terminal part. The height of the incised face varies from slightly above two metres in the first tract to a maximum of 5 m in the central tract.

The profile has been described on the left face of the incision, at about 500 m from the provincial road no. 57. The sequence of the horizons is the following: Ap-Bt-C-2Btb-2Btgb. A water table, probabily under the river bed, is a dept of 190 cm.

The present surface consists of a heavily eroded soil that is developed on ancient alluvia with a total thickness of about 90 cm. As in the case of the previous profiles, the C horizon is made up of gravels and pebbles cemented by fine materials with a thickness of only 20 cm. Since the buried soil is characterized by a texture particularly rich in sands, it could be related to the soils that developed on ancient eolian sands deposits described in the following profile 3, 8 and 14.

b - The soils of sandy deposits

i - Profile no. 14. This profile was observed at Cabu Aspru at a few tens of metres from the Pilo lagoon, at the edges

[1] For designation of horizons and layers, see Keys to Soil Taxonomy, USDA, 8th ed. 1998.

of an incision which at variable width and height limits the outflow of rio San Nicola into the lagoon (fig. 3).

The horizons sequence shows: Ap-Bkm-2Btb-3Btb-3C1b-3C2b, the total thickness is greater than 400 cm.

A particurarly important feature in this profile is the presence of a petrocalcic horizon, Bkm, 120 cm thick. Based on different content of coarse materials and grain size of sands, it has been possible to distinguish three sub-horizons. The petrocalcic horizon is followed by a sequence of buried Bt horizons, whose recognition in the field has been based on colour, on the clayey texture, and on the larger skeleton content of the 2Btb compared to 3Btb. At the base of this profile, horizons 3C1b and 3C2b are made up of variegated deposits consisting of loose sands poorly or not pedogenized at all.

At the mouth of rio San Nicola, these deposits represents possibly the bottom members, subsequently covered by eolian and alluvial materials.

ii - Profile no. 3. This profile is present at Cuile Cabu d'Aspru in a recently opened quarry. Morphologically the site represents an old terrace that before the excavations for the construction of the thermal power stations, graded, with a slight inclination, both towards the sea to the north, and towards the distal part of rio San Nicola to the west. The terrace partly rests on small limestone reliefs incised by the river itself.

The profile has the following sequence of horizons: A-Bt-C-2Btb and a total thickness of more than 400 cm. The present soil is classificable, according to USDA Soil Taxonomy (1999), as a typical Palexeralfs developed on Mio-

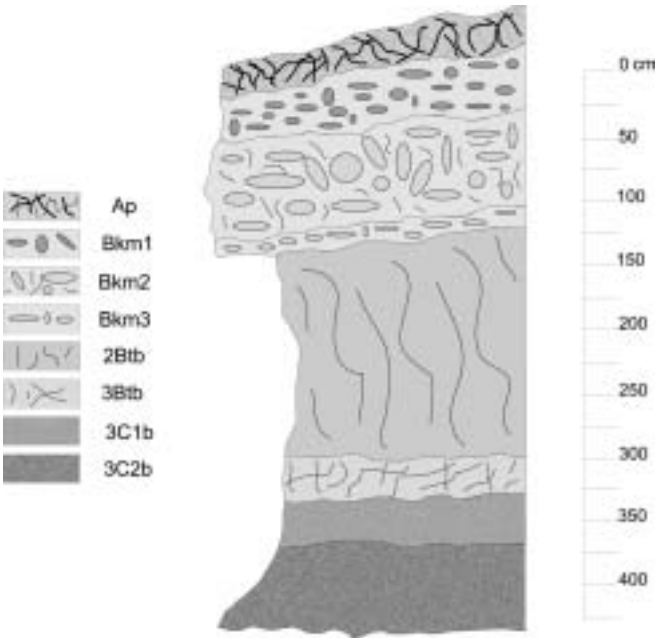

FIG. 3 - Soil profile n. 14.

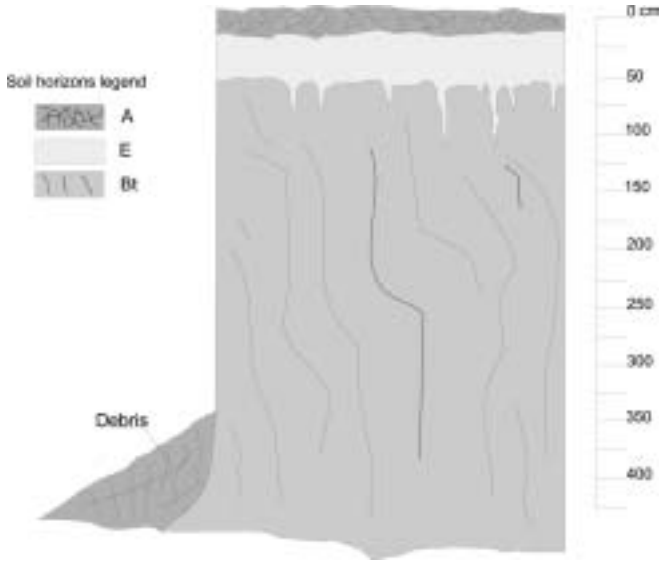

FIG. 4 - Soil profile n. 8.

Piocenic alluvium. In its essential characteristics it does not appear different from those soils that rest on analogous substrates that are commonly found in the study area, (Baldaccini & *alii*, 2002).

The C horizon is made up of a series of lenses of small quartzose gravels with rounded clasts of a total thickness of about 220-250 cm, overlying a 2Btb illuvial horizon made up of quartzose sands. This series of gravelly lenses was observed discontinuosly, along the entire western edge of the terrace at an altitudine ranging from 30 to 35 a.s.l., exposed by the excavations for the ENEL thermal power stations. The sand is covered with thick illuvial coatings of very fine clay and lime bridges of characteristics dark red (2,5 YR 3/8 wet and 2,5 YR 3/6 dry), clearly visible to the naked eye. The sand grains are very rounded and the coarse elements (less than 1% in volume), show some flatness.

It has been possible to follow the 2Btb horizons for about a hundred metres along the quarry face. From these observations it has been possible ot estabilish that, in spite of the variations in grain size composition, the horizons persists well over 500 cm.

iii - Profile no. 8. This profile was observed at Case Murineddu at about 250 m from the west shore of the Pilo lagoon at an altitude of about 10 m, in an old dune that was used as a sand querry in the past, now it is only a few metres above the present surface (fig. 4).

Morphologically the site is located at the SE edge of the vaste terrace of Planu d'Ezzi (fig. 1), in an area where the Mio-Pliocenic alluvia that make up its main formations were replaced by eolian deposits of equal age. These deposits advanced inland from the present lagoon in the shape of many irregular tongues.

Profile 8 shows the following horizons A-E-Bt, with a total thickness of over 400 cm.

In the horizon A the skeleton is made up of a few rounded quartzose gravels. Because of, these gravels may be observed in the entire area around the station point, it is postulated that A horizon derives entirely or partly from a Mio-Pliocenic alluvial episode. It was, probably, not exceptionally important, perhaps, marginal compared to those observed previously, and at any rate subjected to strong erosive processes.

In support of this hypothesis, it is pointed out that in the entire coast, in the areas covered by Mio-Pliocenic alluvia, the total thickness of the horizons A and Bt of the present soil is, hardly ever, more than 50 cm.

The thickness of the E horizon is moderate, 30-40 cm, and is clearly visible only in the parts of the dune that have not been affected in the past by a deep tillage. Thanks to a number of observations in the vicinity of the station area, it has been possible to establish that the eluvial horizon is present, discontinuously and with a thickness not more than 20 cm, only in the relict of another dune about of 300 m SE of the studied one.

The Bt horizon is characterised by a sandy texture and accumulations of illuvial clays well visible even to the naked eye. In the first few cm the illuvial clay acquires the morphology of tongues or spherical nodules with a diameter of 10-15 mm. With increasing depth, the illuvial clay is deposited as bridges between individual grains of sand, cementing them and giving to the horizon, in the dry state, a very strong consistence. Although the road cut is about 50 m long and displays a height of about 500 cm, it was not possible to observe anywhere a C horizon because covered by debris.

CONCLUSIONS

Based on these preliminary observations in the Pilo Lagoon - Fiume Santo mouth area (Sardinia), it can be hypothesised that from the Late Miocene onwards, the following processes have occurred following a chronological sequence. These events may be regional, however they have not as yet observed:

i - Plinthite formation: plinthite formed by localized separation and accumulation processes of iron oxides in horizons that have been satured with water at some time during the year (Duchafour, 1977; Giordano, 1999; Yaalon, 1971). The iron probably has been added from other horizons or from the higher adjacent soils, (Soil Taxonomy, 2nd ed., 1999), strongly eroded during the continental conditions in the Late Miocene (Ginesu & *alii*, 1995).

ii - Illuviation processes on eolian sands of various grain size that led to the formation of red or dark red Bt horizons. In terms of relative chronology, the processes should be older and are probably related to leaching processes of Pleistocene soils (profiles 5 and 12).

iii - Lateral and in depth leaching processes of carbonaceous material and subsequent re-deposition in flat or morphologically depressed areas led to the formation of horizons of strongly cemented sands and gravels (profiles 12 and 14). The carbonaceous material could come from the crystalline limestone hills nearby, (reliefs of Monte Elva, Monte Alvaro, etc.), which close the basin of the rio d'Astimini - Fiume Santo in the left, figure 1. To varying extents the deposition of secondary carbonates affected the entire study area. At the present state of knowledge, the subsequent origin of the petrocalcic horizons appears localised on a few areas, though with greatly varying thickness.

iv - On these soils, the erosion has eliminated any possible A and E horizons. These horizons are in fact absent in all the observed buried soils. These erosive processes are probably coeval with or immediately before the alluvia mentioned under the previous item.

v - The Bt and petrocalcic horizons were covered in relatively short times by a succession of several Plio-Pleistocenic deposits (Ginesu & *alii*, 1995) of coarse alluvial deposits partly mixed with finer, strongly pedogenised fractions. The coarser materials come from the metamorphics hills nearby, while the finer is likely to derive mostly from chalky materials of the Trias and of the Jura, wich can still be observed in the sedimentary landscape in the rio d'Astimini - Fiume Santo basin. These alluvial materials have mostly made up the parent material for the present soils.

The present knowledge on the clay illuviation processes, the formation of petrocalcic horizons and of plinthite, as well as the geomorphological and paleontological confirmation suggests that between the end of Miocene and the early Pliocene, the entire study area displayed a level or gently undulating morphology. Such morphology is typical of fluvial or deltaic environments, with a good vegetation cover and with climatic conditions characterized by high temperatures associated with abundant rainfall distribuited in one or more rainy seasons alternated with dry seasonal periods.

These are favorable climatic and morphologic conditions for the formations of plinthite, clayey, and carbonaceous horizons. This relatively stable morphological and climatic situations was followed by strong changes in the precipitation cycle, both in quantitative terms and in its distribution over the year. Climatic change first triggered erosive processes and subsequently, probably in very short times, it led to the covering of eroded soils with alluvial deposits.

These hypotheses represent a first contribution to the reconstruction of the pedological and morphological landscape of a region of north - west Sardinia. They are still to be verified and compared by researchers from other disciplines such as paleoclimatology, polinology, geomorphology, etc. Without the contribution of these disciplines the attempt at reconstructing landscapes, based only on pedological evidences would remain incomplete.

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