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Mineral distribution in soils of the coastal region of West-Central Senegal, West-Africa

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1 - Problem definition

Coastal plain soils of West Africa are generally saline and acid, due to seawater intrusions and pyrite oxidation, respectively. The according processes affect the mineral weathering in different ways. In addition to temperature and water saturation, clay mineral transformations in salt marshes can be driven by variations in acidity (pH) and salinity (ionic strength) (Velde and Church, 1999).

This work is an attempt to demonstrate that mineral characteristics formation and crystallinity in coastal plain soils are affected by the composition of the soil solution, as well as by the landscape position which determines the intensity of salinity and acidity through the water activity and redox cycles of Fe and S materials in soils. Topography directly influences the weathering intensity by controlling the dynamic of drainage which in turn determines the nature of the weathering products (Birkeland, 1999).

Only few studies involving coastal plain soils in Africa consider their mineralogical constitution. The most influential contribution was given by Marius and Lucas (1991) for mangrove ecosystems on the shoreline of western Africa (Souza-Júnior et al., 2008). The objectives of the present study are twofold: (1) investigate the mineral distribution in saline acid sulfate soils of the coastal plain of the Sine Saloum basin, West-central of Senegal, in order to (2) determine the incidence of the landscape position, soil salinity and acidity on their formation and cristallinity.

Keywords: Soil salinity, soil acidity, landscape position, mineral distribution, coastal plains

2 - Site characterization

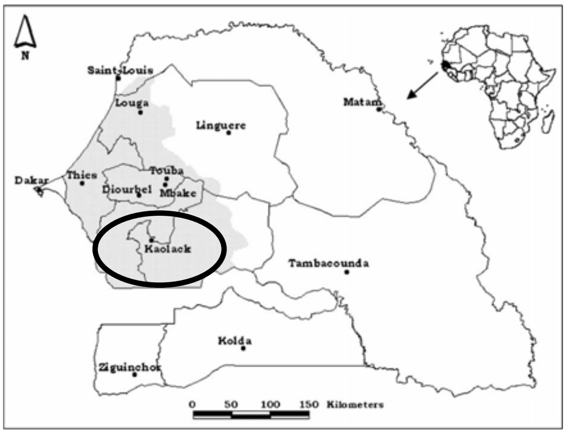

Figure 2-1. The Sine Saloum Basin in Senegal

Located between 13°35’ - 14°30’ N and 16°00’ – 16°50’ W, the Sine-Saloum Basin covers about 250,000 ha and is bounded to the west by the Atlantic Ocean, to the north by the Saloum River, to the south by Gambia frontier and to the east by the meridian passing Birkilane (Fig. 2-1). The climate is of “soudano-sahelian” type with high temperature (mean 29°C), high potential evapotranspiration (1500-2500 mm/year) and a mean annual rainfall between 600 and 800 mm/year, from north to south. Rainfall is limited to the rainy season (June-October). The hydrologic system of the region is characterised by the Saloum River, a tide influenced “inverse estuary”, with high salinities of more than 80‰resulting from seawater encroachment and evaporation (Faye et al., 2005).

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Our study area is located 20 km west of the town of Kaolack (190 km south of Dakar, Senegal), beside an estuary of the Saloum River.

3 - Materials and Methods

Four profiles located at two different landscape positions: floodplain (2) and low terrace (2) were investigated. The sampling transect was placed in such a way that influences of the landscape position could be reflected in soil properties.

Bulk and clay mineralogy were determined by X-ray diffraction. Clay minerals were determined semi-quantitatively using the computer package DIFFRAC AT V3.3 Siemens 1993. A Scanning Electron Microscope (SEM) LEO 420, equipped with a field emission cathode and coupled to an Energy Dispersive using X-ray (EDX), INCA 400 system, was used to confirm the mineralogy of some selected samples.

4 – Results

The bulk mineralogy is dominated by quartz; halite and feldspar are also present. Hematite and lepidocrocite are detected as main iron oxides, while pyrite and jarosite are low-contained in soils. The following trends are observed regarding the bulk mineral cristallinity and abundance, from the floodplain to the low terrace: quartz remains constant; it yields the most intense reflection in all samples; halite decreases; feldspar decreases; pyrite and jarosite decrease (Plate 4-2); hematite is only present in the low terrace; lepidocrocite increases (Fig. 4-1a and 4-1b).

The clay mineralogy is dominated by kaolinite, smectite, and illite in descending order (Tab. 4-1). Kaolinite increases in abundance with elevation (average of 72% of the clay mineral assemblage in the floodplain vs. 85% in the low terrace) but becomes less crystalline (Plate 4-1); smectite decreases (26% in the floodplain and 14% in the low terrace), illite is almost stable (2% in the floodplain, 1% in the low terrace, Tab. 4-1).

Site	Depth (cm)	Kaolinite	Smectite	Illite	Total (%)
Topsoil					
Floodplain	0-8	78	18	4	100
Low terrace	0-16	84	14	2	100
Central Horizons					
Floodplain	8-30	66	33	1	100
Low terrace	16-51	93	6	1	100
Subsoil					
Floodplain	30-60	71	28	1	100
Low terrace	51-100	77	22	1	100

Table 4-1. Abundance values (average) of clay minerals on the two landscape positions and at three different depths

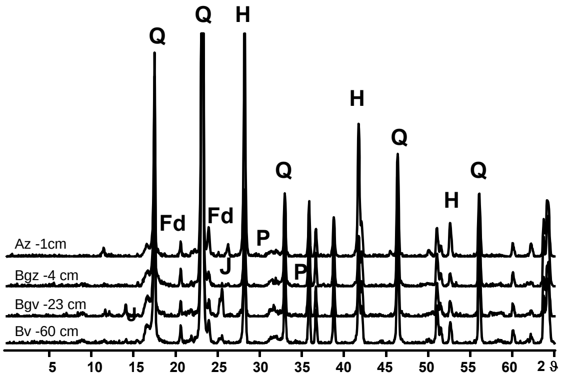

Figure 4-1a. Mineral assemblage in the floodplain soils. Q: quartz; H: halite; Fd: feldspar; P: pyrite; J: jarosite

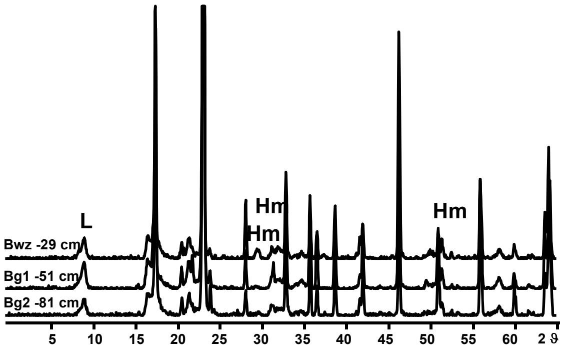

Figure 4-1b. Iron oxides in the central horizons of low terrace soils Hm: hematite; L: lepidocrocite

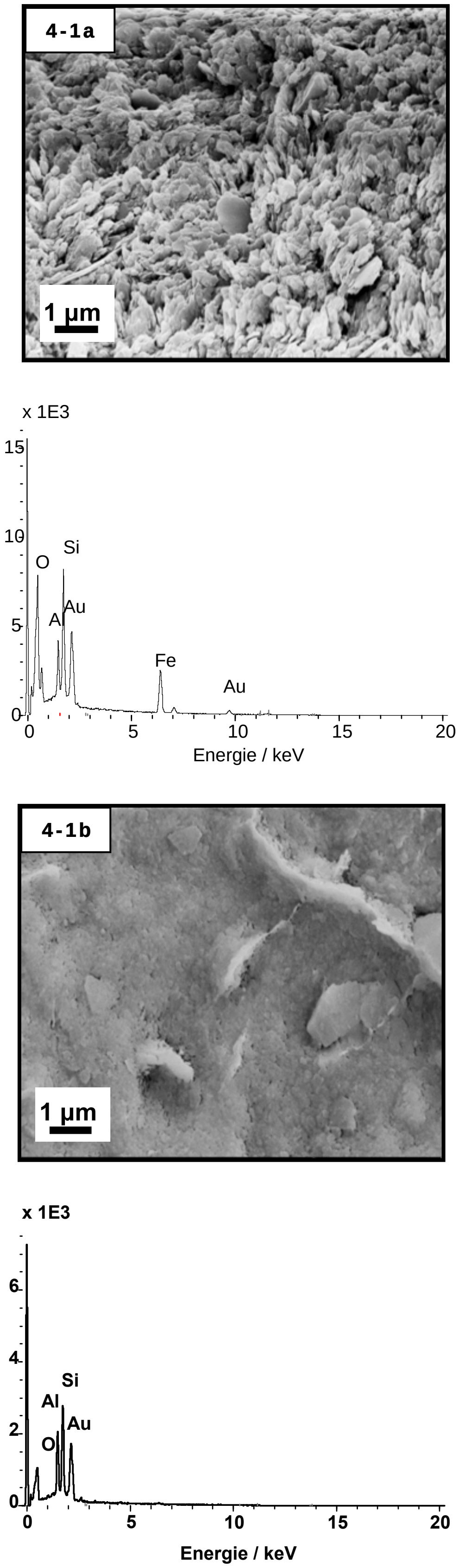

Plate 4-1. SEM and EDX showing kaolinite crystals with different forms and structures in the floodplain (4-1a) and low terrace (4-1b)

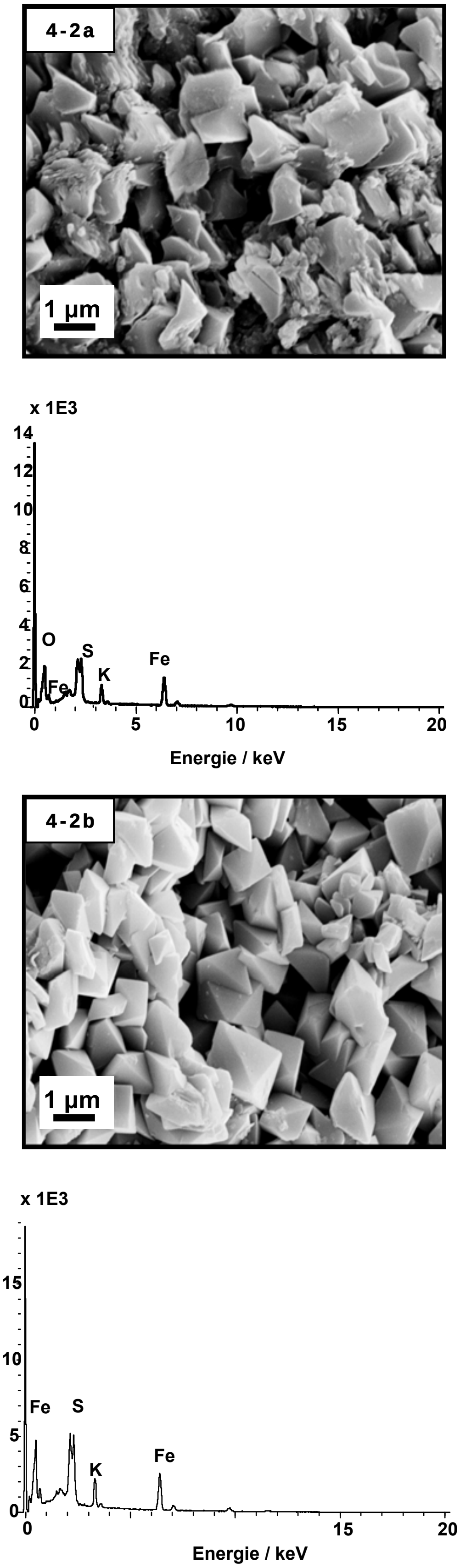

Plate 4-2. SEM and EDX showing jarosite crystals with different forms and structures in the floodplain (4-2a) and low terrace (4-2b)

5 - Discussion

Kaolinite is predominant in low terrace soils (Tab. 4-1). Soils on this elevated landscape position undergo marine (tidal inundations) and terrestrial (eolian dust inputs) influences. This supports the view that kaolinite is partly inherited (from feldspars in the parent material) and partly detrital (descended from the surrounding hinterland). Floodplain soils contain inherited kaolinite (from feldspar), diagenetic kaolinite (alteration of smectite), and detrital kaolinite. Also the low pH (between 3 and 5) in low terrace soils promotes kaolinite formation over smectite which becomes unstable under such acid conditions because of removal of bases and/or silica and usually decreased pH. The vicinity to the estuary explains the higher amounts of halite and feldspar (mainly albite, $NaAlSi_3O_8$) in the floodplain soils, compared to the low terrace ones.

The oxidation of pyrite and the distribution of the main oxidation products (Fe^{2+} and SO_4^{2-}) appear to be the most important processes in the formation of iron oxides (hematite, lepidocrocite) and jarosite in the studied soils. This is supported by an absence of Fe-bearing silicate minerals or a Fe-rich parent material in the bulk mineral suite. The Fe^{2+} produced migrate towards the soil surface and then becomes immobile by the formation of jarosite after combination with SO_4^{2-} in presence of K^+ ions from the seawater. The Fe^{2+} may also diffuse upward and accumulate in the oxidized layers where it is now in the form of immobile iron (III) oxides. This explains the presence of hematite in the mottled horizons starting at about 20 cm below the surface in low terrace profiles (Fig. 2.b). Lepidocrocite is also known to form from precipitated Fe^{2+} hydroxides (Van Breemen and Buurman, 1998).

6 - Conclusions

Soil acidity explains partly the prevalence of kaolinite in the low terrace soils, while the effect of soil salinity is only reflected by the presence of albite, precursor mineral of kaolinite in studied soils. The landscape position appears the more determining parameter of mineral distribution in this coastal area. A lower landscape position supports higher water saturation, stronger redox processes, lower cristallinity of jarosite and iron oxides, and less eolian inputs from the continental hinterland. A dominance of diagenetic clay minerals on the floodplain and detrital clay minerals on the low terrace corroborates this statement. Terrigenous inputs exert, thus, ultimately the major influence on the clay minerals in these coastal plain soils.

7 - Acknowledgment

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