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Soil-Geomorphic Relationships in the Vicinity of Niamey, Niger

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L. P. Wilding
Department of Soil and Crop Sciences
Texas A&M University
College Station, Texas

and

Ray Daniels
Department of Soil Science
North Carolina State University
Raleigh, North Carolina

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Contents

Introduction and Summary of Results 5

Soil-Geomorphic Relationships 7
- Stratigraphy 7
- Ironstone 7
- Geomorphology 9
- Geomorphic and Hydrologic Relationships 12

The ICRISAT Sahelian Center as a Base for Research Extension 14
- Morphology and Soil Classification 14
- Hydrology and Soil Erosion 18

Speculation and Questions 19
- Multiple Ironstone Sheets 19
- Plateaus 19
- Coversands 19
- Dallols 20

Log of Observations 21

References 33

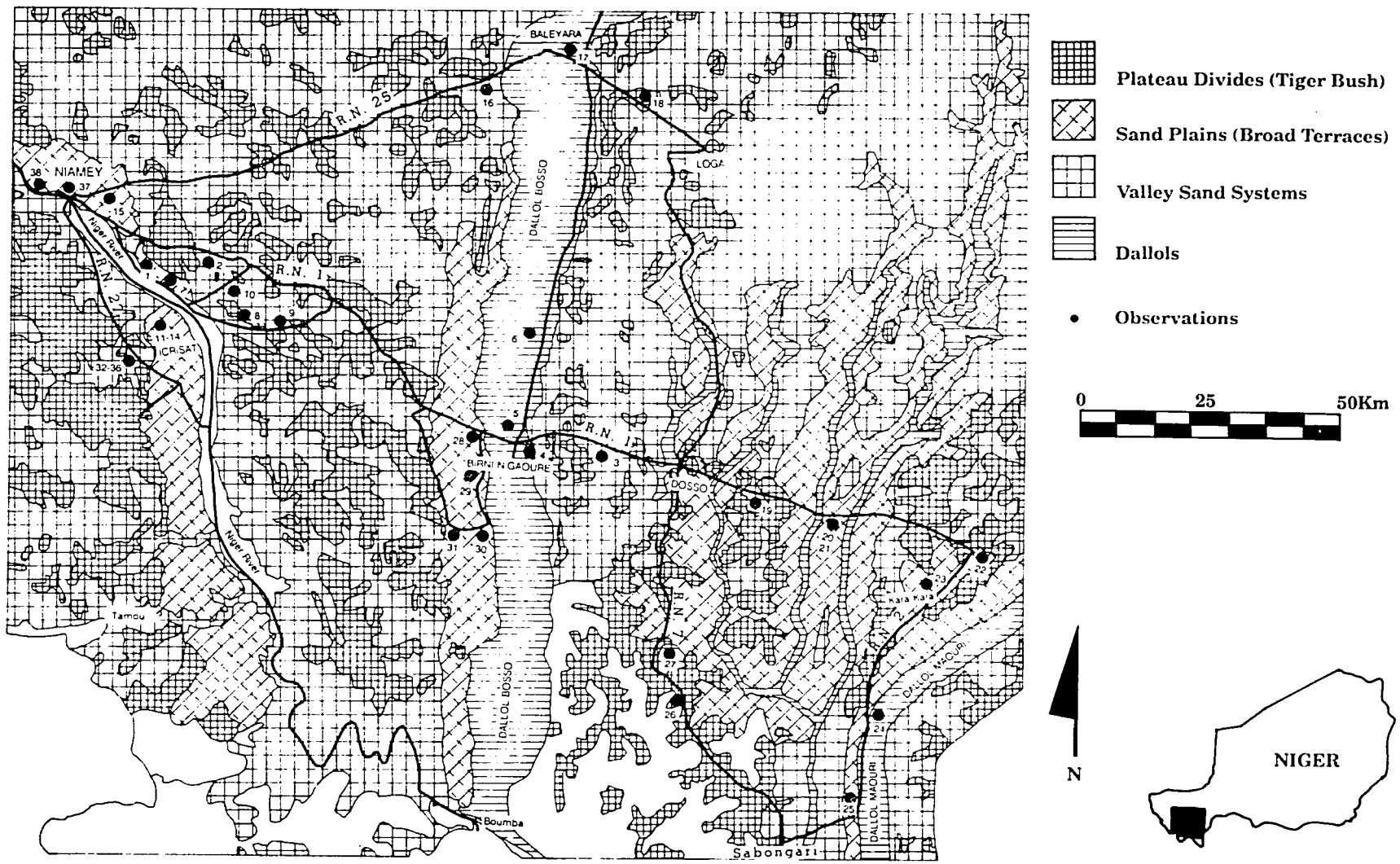


Figure 1. Location of field observations plotted on the Carte Pédologique de Reconnaissance de la République Niger-Niamey (l'ORSTOM, 1967).

Introduction and Summary of Results

The objective of this work was to determine the representativity of soils in the ICRISAT Sahelian Center to surrounding millet and cowpea production areas in southern Niger. A reconnaissance survey of the soil-geomorphic relationships in the vicinity of Niamey, Niger, was conducted from July 17 to August 2, 1983, to determine the applicability of research results on the ICRISAT Sahelian Center to the surrounding land resource areas. Travel routes and locations where observations were made are presented in Figure 1.

The surface deposits are a sequence of cover-sand materials over ironstone caps over loamy Miocene deposits (Continental Terminal). These units control the soils, geomorphology and hydrology in the area. The Miocene sediments are deeply weathered and exposed only in road cuts, seldom at the surface. Ironstone caps the Miocene deposits in most parts of the landscape and is exposed at escarpments or breakaways along multilevel plateaus and ledges within the Miocene sediments. The ironstone cap is a prominent landscape feature and is tens of centimeters to a meter or more thick as a continuous unit, sesquioxide blocks, or cemented ironstone gravels. The sandy cover materials are from a few centimeters to 8 m in thickness over an almost universal ironstone cap. This sandy cover is fine sand, fine loamy sand and, rarely, fine sandy loam in texture.

The area can be divided into four geomorphic elements. The landscape is dominated by broad, gently sloping plateaus with discontinuous sand cover, sand valley systems that slope gently from the ironstone-capped plateau toward a dry stream bed, broad sand plains (terrace-like), and dallols. Major plateaus several kilometers across are recognized at 220-, 240-, and 260-m elevations. They generally have thin, eolian cover sands with or without low dune forms. The valley systems begin just below the ironstone cap of the plateaus, have thick sands near the breakaway with discontinuous paleosols in the lower sand unit, and slope smoothly to the valley floor. The sandy surfaces are apparently a combination of fluvial and eolian processes.

The sand plains consist of thick (2-6 m) eolian sands over "stepped" surfaces or levels of laterite gravels that slope gently toward adjacent river or stream systems. The sand has well-expressed dunal relief, and some deflation depressions occur. The sand cover on all "stepped" levels is similar except for small differences in color, texture and pH. This cover abruptly overlies a cemented laterite gravel contact, which probably represents a constructional floor of fluvial gravels. The dallols are unique, sand-plugged fossil stream valleys. These nearly level landforms apparently were constructed both by fluvial and by eolian processes. Surfaces express marked dunal relief and activity. Depth of sands is unknown, but shallow water tables were observed at 2 to 3 m below the surface.

The ICRISAT Sahelian Center is situated on sand plains, and, from a pedo-morphological perspective, its soils are representative of extensive areas of major millet and cowpea production centers in the vicinity of Niamey, including the sand plains and upper reaches of valley sand systems. These areas comprise deep, red, sandy soils with weakly developed subsoils (Psammentic Paleustalfs, Psammentic Haplustalfs, and Ustoxic Quartzipsamments). Dallols also are extensively used for millet and cowpea production, but the soils of the Center are not representative of the dallols.

Likewise, soils of the Center do not adequately reflect soil resources on the nearly level, broad,

laterite-capped plateaus (tiger bush). These soils are quite acid, thin, and variable in texture and thickness of subsoils over a laterite gravel and sesquioxide sheet (petroferric) contact. Most of these soils are Ustoxic Dystropepts and Petroferric subgroups of Kanhaplustults, Kanhaplustalfs, and Dystropepts. They are generally loamy in texture rather than sandy. These plateaus are not extensively used for millet and cowpea production but are important forest and grazing lands, and may warrant satellite research centers that address soil resources not representative of the Center.

Hydrologically, soils of the ICRISAT Sahelian Center are representative of soil moisture and recharge conditions of the sand plains but less representative of soils on the valley sand, dallol or plateau systems. Soils at the Center, unlike those of the dallol and valley sand systems, receive little water from higher plateaus.

Wind-erosion results from the Center probably can be safely extrapolated to most other areas of the sand plains and valley systems because surface textures are similar. However, extension of such work to the dallols must be done with caution because they seem to be more fragile systems than other sandy areas. Water-erosion research cannot be effectively conducted on the Center because this work is most appropriate for the plateaus and sloping valley segments.

Windblown millet plants in test plots at the ICRISAT Sahelian Center.

Soil-Geomorphic Relationships

Only a few tentative relationships could be established from the limited amount of data collected, but a broad general description of the surface stratigraphy, geomorphology and soils can be made.

Stratigraphy

Miocene

The stratigraphy, or sequence of sediments in the surface few meters, controls the properties of soils, the geomorphology, and the hydrology of the area. The oldest exposed sediments belong to a complex Tertiary-age formation called the Continental Terminal (INRAN, 1980; Gavaud, 1966; Greigert, 1966). For the purposes of this study, it is assumed that the materials below the coversands are Miocene. However, Middle and Upper Eocene deposits are mapped on the southeastern border of Niger (Sombroek and Zonneveld, 1971). Greigert (1966) suggests the Continental Terminal is younger than Paleocene, probably Eocene or younger. Gavaud (1966) interprets the age of this formation(s) as Oligocene to Miocene.

The Miocene units are exposed only in road cuts, seldom at the surface. The Miocene sediments are deeply weathered and are largely sandy loam in texture except in some of the deeper exposed sections. Ironstone or laterite caps the Miocene in most parts of the landscape. The sediments immediately under the ironstone cap are weathered and have many characteristics of a soil.

The upper part of the Miocene is red to yellowish red and grades with depth to more yellow hues. When dry, the sediments are very hard to extremely hard. Examination of the sand fraction by hand lens suggests that most of the sand is quartz.

Ironstone

The landscape of West Africa is controlled (capped) by levels of ironstones; hence, it is not surprising that processes involving iron-oxide formation have fascinated geologists and soil scientists working there. Ironstone deposits, which once supplied iron ore for smelters, today provide roadbed materials. In Niger, the oldest existing ironstone deposits date from the late Cretaceous to the Tertiary. Their geologic history is discussed by Greigert (1966), Gavaud (1977) and Dubois (1979). According to these authors, they were deposited as oolitic sediments in a shallow Saharan sea connected to the Mediterranean Sea by the Straight of Gao after the worldwide eustatic rise in sea level during the late Cretaceous.

Ironstone sheets are interbedded in the Continental Terminal sandstone formation of the Iullemmeden basin and are estimated to be late Eocene to early Miocene in age. Equivalent deposits exist in Nigeria (Adetunji and Kogbe, 1987; Kogbe, 1978; Adeleye, 1973; Sombroek and Zonneveld, 1971). A recent study by Bui et al. (In press) suggests unique differences in iron-oxide forms and mineralogy between laterite deposits capping plateaus and petroferric materials formed in sandy soils of the Dallol Bosso. Sombroek and Zonneveld (1971) believe that ironstone deposits are from pedogenic formation of plinthite developed over extensive areas at the end of every sedimentation stage, or even every substage. This is in response to periods of relative landform stability and restricted drainage.

The differential gentle dips of the various laterite levels and the indications that a lower level may continue below a higher-level laterite at some multiple scarps and in geologic borings are evidence given for the pedogenic origin of the ironstone.

Since the uplift and dissection of the basin, these iron-rich deposits have been recycled several times in the landscape.

The ironstone cap commonly consists of angular to rounded recemented ironstone gravels a few tens of centimeters thick, or a massive ironstone layer that may be as much as a meter thick. The upper contact of the cap may be a laminar layer a few centimeters thick. The ironstone deposits cap all plateaus but are not confined to surface exposures alone. At the east edge of Birni-N-Gaouré, several meters of Miocene are exposed with at least six massive ironstone ledges at vertical intervals of two to several meters (Figure 2A). All ironstone ledges and the cap have a similar morphology. Multiple ledges of ironstone within the Miocene are not uncommon in the Niamey area (Figures 3A, 3B).

Between Niamey and Baleyara several exposures of Miocene sediments were examined. All exposures have a continuous ironstone cap in the form of either recemented ironstone gravels or massive, blocky, 50-cm-thick ironstone ledges (Figure 2B).

Overlying the ironstone cap on the plateau is a thin mantle of rounded to subangular ironstone gravel, which in turn is overlain by loamy sand to sandy loam sediments 0.25 to 1.5 m thick. The sand grains are rounded to subangular and the large ones are frosted. The ironstone gravels are partially recemented in many areas and have dark red to yellowish red or browner interiors. The above sediments are common in the tiger-bush areas.

Coversands

Overlying the Miocene sediments and the almost universal ironstone cap is a sandy mantle (coversands) whose texture is fine sand, fine loamy sand, or, rarely, fine sandy loam. The sand grains are subangular to rounded and most of the larger grains are frosted. The sand fraction is largely quartz (West et al., 1984; Bui, 1986). Except for color and texture differences in the Bt or Bw horizon, the sands are surprisingly similar at almost all upland sites. A stratigrapher could easily map the coversands as one formation. The concept of the morphostratigraphic unit (Frye et al., 1962) probably is a better approach than one following strict stratigraphic criteria. The use of morphostratigraphic units will allow separation of coversands based on form and lithology, allowing more emphasis on the evolution of the landscape.

In the dallols of Bosso and Maouri (dallols are sand-plugged fossil valleys—see section on dallols), medium and some coarse angular sands were

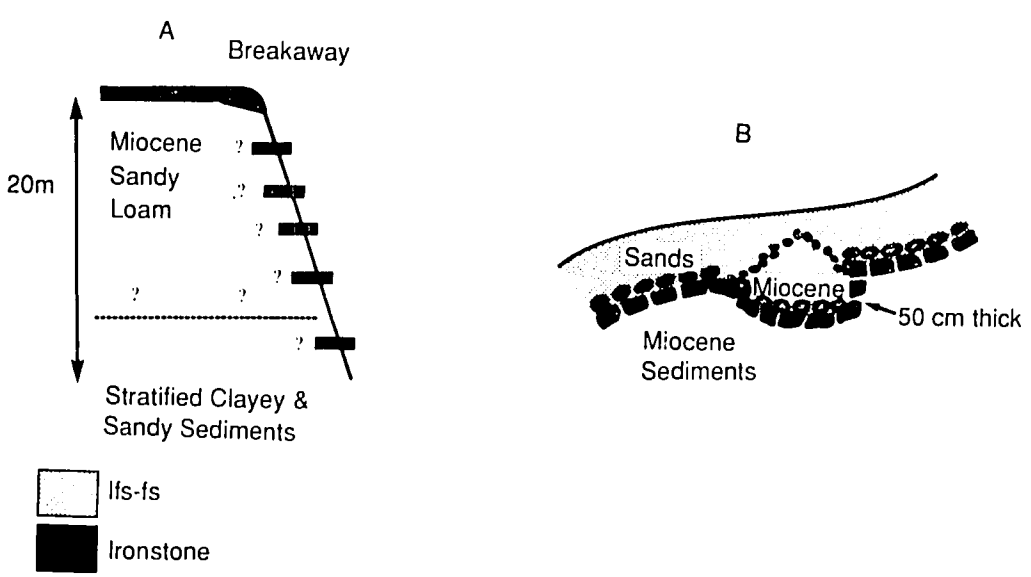


Figure 2. Schematic cross sections.

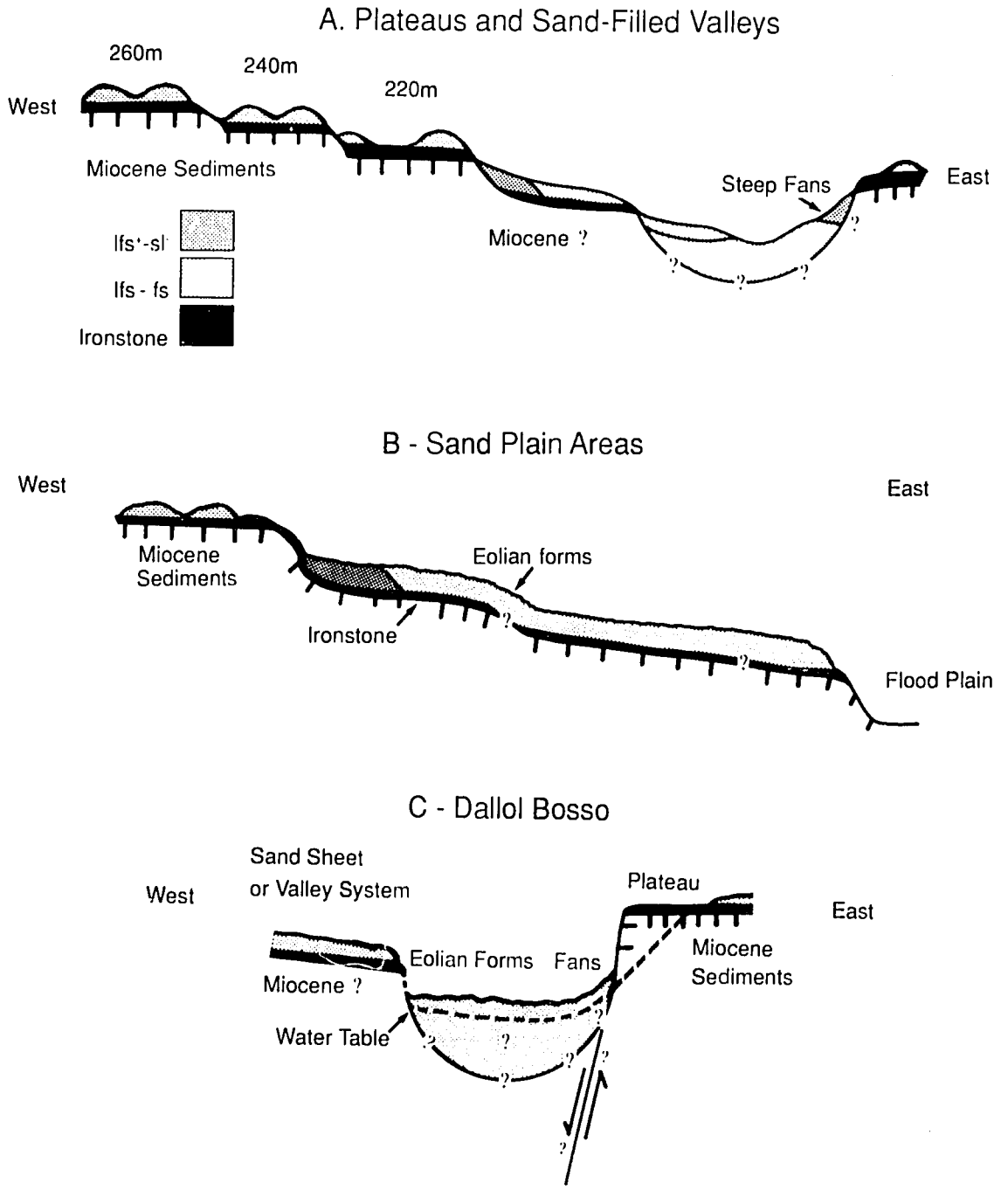


Figure 3. Schematic stratigraphic and geomorphic cross sections.

encountered at depth, and the surface and subsurface colors were more yellow and gray than the upland coversands. The fine sand grains were similar in shape and frosting to those of coversands.

Geomorphology

The area has four major geomorphic elements that are of direct interest in this study. The landscape is dominated by broad, gently sloping plateaus with discontinuous sand cover, sandy valley systems that

slope gently from the ironstone-capped plateaus toward dry stream beds, broad sand plains (terrace-like), and the dallols or sand-plugged fossil valleys.

Plateaus

The plateaus are several kilometers across, appear to be nearly level, but are believed to slope gently toward a local stream system or the Niger River. The plateaus may have a 2- to 4-m-thick discontinuous layer of coversands with or without low dune forms, or only a few centimeters of ironstone gravel or sandy loam over a fractured ironstone sheet. At the edge of the plateau or breakaway, a massive ironstone sheet a meter or more thick is exposed. Subrounded to subangular cobbles, blocks and pebbles of ironstone mantle the adjacent lower slopes. Major plateaus appear to occur at 220, 240, and 260 m (Figure 3A). Little is known about the gradients on each plateau, its areal distribution, and stratigraphic relationships to other plateaus. Topographic coverage does not allow a detailed examination of the plateaus.

Sand valley systems

The valley systems start just below the ironstone cap of the plateaus and slope gently toward a stream valley (Figure 3A). The slope near the breakaway is 4 to 6% but decreases to 1 to 2% toward the valley center. The slopes may be a few kilometers long before stepping down to a lower level. The coversands are thick near the breakaway, and apparently the buried erosional scarp next to the plateau is relatively steep (Figures 3A, 4B, 4C).

Buried soils within the 5- to 6-m-thick coversands appear to be common near the breakaway on southwest-facing exposures (Stop 16). The sandy sediments start just below the ironstone cap and appear to be finer-textured than materials farther out in the valley. Character of the sand grains appears similar, including size and surface frosting. The coversands are continuous except where the landscape steps down to a lower level and ironstone sheets are exposed (Figure 4C). The surfaces in these valleys are apparently a combination of smooth fluvial surfaces and dunes of low to moderate relief. Coppice dunes are common.

Water erosion is severe near the breakaway, and many shallow gullies or sand washes carry runoff to the lower parts of the valley. Two or three surface levels occur in the valley, and the lowest one receives sediment from the higher levels.

Sand plains

The sand plain system along the Niger River and other areas has a number of coversand "stepped" surfaces or levels (Figure 3B). Each surface slopes toward the adjacent river or stream system and has an apparently continuous ironstone sheet at the base of the sand. Ironstone is not exposed unless the breakaway or scarp to a lower level is sharp (Figure 3B). The coversands of each level have several irregularly shaped depressions and well-expressed dunal relief of about a meter. Some areas of the sand plains have both dunal and smooth, fluvial-like forms, especially on the west side of Dallol Bosso. Except for apparently slight differences in color, texture and depth of weathering, as expressed by soil thickness, the coversand on all levels is similar. However, each level may have its own major characteristics and should be separated initially as a morphostratigraphic unit. If later evidence does not support the separation, the levels can be combined.

Dallols

A common feature of Sahelian Africa is the dallol, a fossil valley of mostly sandy alluvium that is wind-sculpted into low dunal terraces accompanied by depressed segments of abandoned channels (Bui, 1986; Bui and Wilding, 1988; Bui et al., 1989). In Niger, the word "dallol" refers to a wide, dry valley that is drained by intermittent streams only during the rainy season (Donaint, 1975). Smooth fluvial surfaces or fans occur as interfaces between adjacent plateaus or sand plains and dallols.

The dallols of Niger have been described as unique soil resources with the potential of supporting small-scale subsistence irrigation. One of the larger dallols, Dallol Bosso, is the fossil valley of the section of the ancient Azaouak River, which runs north-south in western Niger from 15° to 12° N latitude along 3° E longitude (Figure 1). The Dallol Bosso covers an area of about 3400 km^2 and is about 15 km wide; it may follow a reactivated pan-African

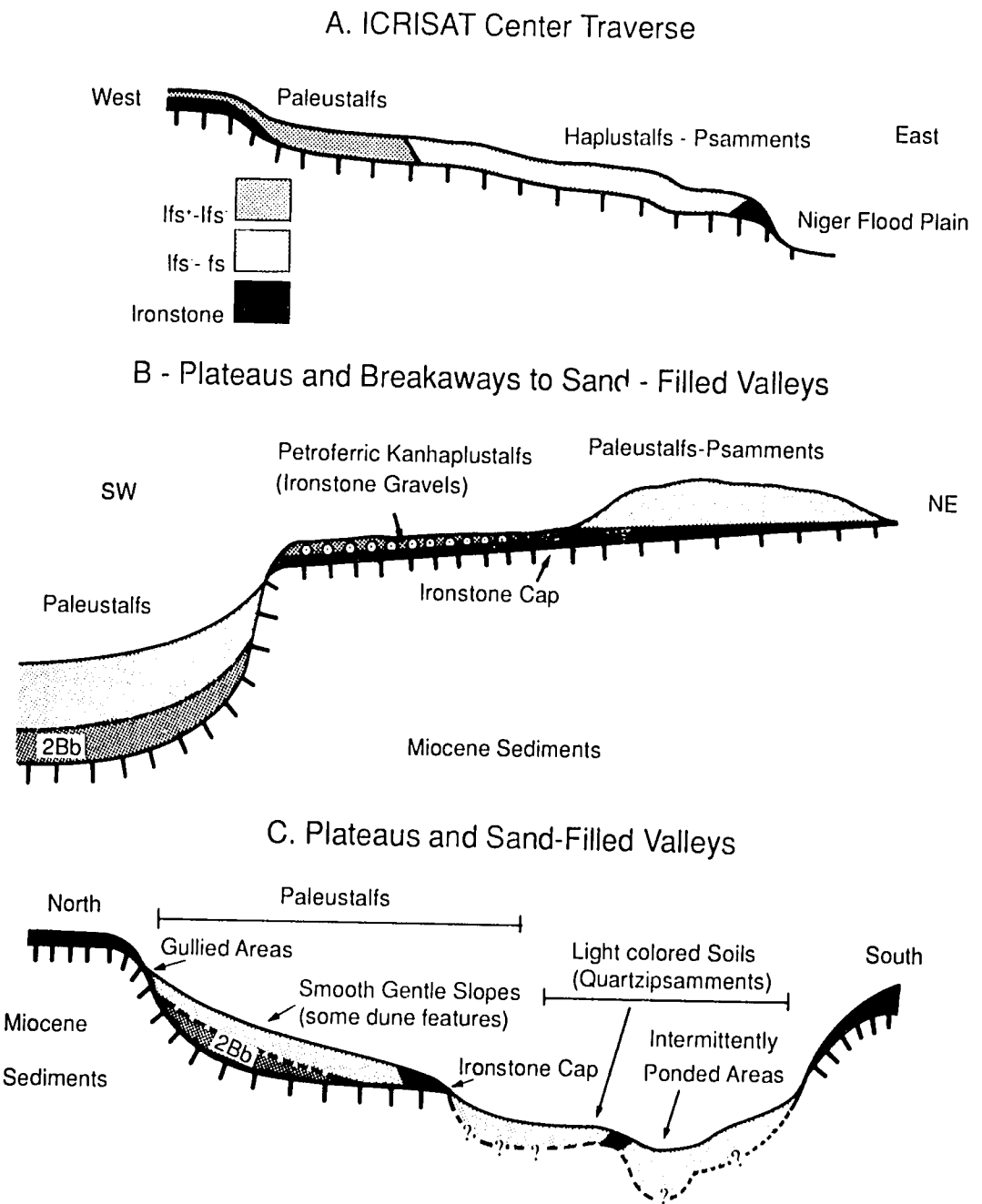


Figure 4. Schematic stratigraphic and geomorphic cross sections.

fault in the Precambrian basement. The incision of the valley is the product of a phase of downcutting throughout North Africa and the Sahel during the Pleistocene, and, thus, the alluvial deposits of the river are assumed to be Pleistocene or younger in age. The Azaouak/Dallol Bosso is a relict, anastomosing river system that developed from an earlier braided pattern as a result of the generally low gradient of the Dallol Bosso (SOGETHA, 1963).

Dunes cover an estimated 80% of the valley, while ancient channels occupy 20% (Bui et al., 1989). Quartz grain-size and -shape analysis have been used to distinguish between eolian and fluvial deposits in the Dallol Bosso (Bui et al., 1989). The medium to fine (and more angular-shaped) sand fractions are from eolian reworking of the fluvial deposits. Eolian materials are well sorted; fluvial deposits are poorly sorted in both size and shape.

Gross shape characteristics indicate a common source rock for all sands.

Summary

Although there are several distinct surfaces within the area, it will be difficult to date most of them. The plateaus have discontinuous coversands with or without eolian forms that are similar to coversands in the other systems. Age of the plateaus may have little chronologic relationship to the present soil if the sands are later eolian deposits or other deposits that have been extensively reworked by wind. We found no evidence of fluvial sediments in the sand sheet system, and the dunal surface forms seem to mantle each level (Figure 3B). Yet, there are changes in depth of weathering, texture and color across these levels. There are three possible explanations for these differences: (1) the higher levels are actually older dunes that have been stabilized; (2) the parent sediments become finer away from the source area; or (3) the lower levels are wind-reworked fluvial deposits.

The relationships among the sand plains, valley system, and dallols are not clear, but the excellent reconnaissance soils map of the Niamey area provides a solid base from which to fill in the necessary details (Figure 1).

Geomorphic and Hydrologic Relationships

The soils of the sand plains and elsewhere are interesting because they are so similar across several geomorphic levels and over wide areas. There are some generalizations that appear to be true but should be tested. In the sand plains, such as those at the ICRISAT Sahelian Center, there is little or no change in soil horizon thickness, texture, color or sequence from the crest of a dune to the bottom of an adjacent dunal trough. Small coppice dunes are prevalent in many areas, yet the A horizon has nearly the same properties anywhere in the local landscape. A recent study by Pfordresher et al. (1989), however, suggests that even subtle differences in soil texture, surface horizon thickness, microtopography, pH, and exchangeable Al status may be important to millet productivity.

At the ICRISAT Center, in parts of the high sand plains, and on upper and middle backslopes of valley sand areas, the soils have thick red Bt horizons that are Psammentic Paleustalfs (Stops 11, 28, 32, 33; West et al., 1984). However, on some of the higher and lower step levels, the B horizons are thinner and less red (Stops 12, 13, 14); here soils are Psammentic Haplustalfs (Figures 3A, 3B, 4A). On a low surface on the north side of the Niger River at the Ndounga Tarey (INRAN Center, Stop 7), a high-pH Quartzipsamment was found.

On the plateaus several soil conditions prevail. At and close to the breakaways, the soils are shallow, crust badly, and most have a horizon with 40 to 60% ironstone gravels (Stops 8, 18, 26, 34). From 20 to 50% of the area represented by these soils has no vegetation, is subject to considerable wind and water erosion, and is a major source of runoff to adjacent lower areas. The coversands on the plateaus usually rise abruptly 2 to 4 m above the shallow ironstone soils (Figure 3B, 4B). The ironstone cap at the top of the Miocene passes under the coversands. Paleustalfs and Psamments have formed in thick sands, while Petroferric Kanhaplustalfs and Petroferric Kanhaplustults occur in shallow, finer-textured material. The Petroferric subgroups are common in tiger-bush vegetative communities.

Downslope from the plateau breakaways, several conditions are encountered. Most of the soils are Paleustalfs with B horizons of fine loamy sand overlying buried soils, especially on the southwest exposure (Stop 16, Figures 4B, 4C). The soils below breakaways, both in valley systems and on sand sheets, receive considerable run-on from the shallow soils upslope. Gullies and shallow sand washes are common. Crusting is prevalent in many of these areas where the Bt horizon has been exposed.

Investigations in the valley systems are incomplete, but there appears to be a change in color and possibly texture of the B horizon from the higher surfaces to the lower (Figure 3A). Near the center of these valley systems, the sandy surfaces are almost white and suggest considerable wind reworking—conditions similar to those of the dallols.

Many of these valley systems contain ponded water at lower reaches during the rainy season. The valleys are dissected by a number of inset dry washes leading down from the plateau or in-valley breakaways to wetter toeslope positions. There are

short periods of saturation. These soil characteristics appear to be related to geomorphic surface in the valley (Figure 4).

Hydrology

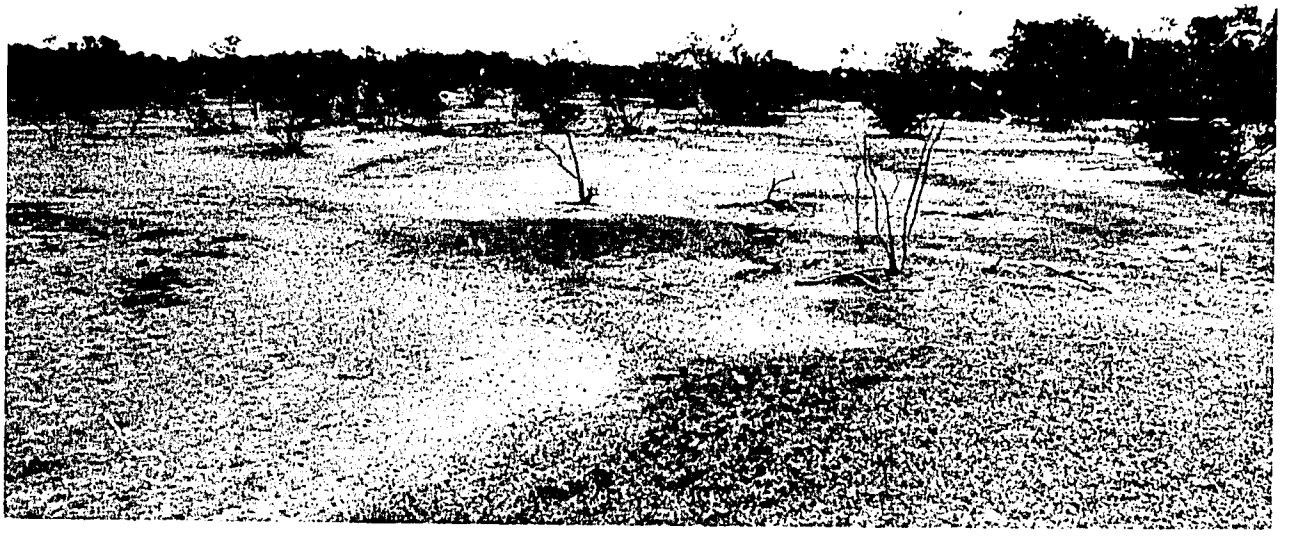
The hydrology of the major systems differs somewhat and may be important when soils are intensively managed. The sandy plateaus seldom receive water from higher areas, whereas the valley systems and dallols have run-on areas and possibly may store considerable amounts of ground water. The tiger-bush areas of the plateaus are large runoff positions that have limited ground-water recharge. The sand plains seldom receive much run-on from higher areas, and their potential for water storage appears to be low.

Erosion

The tiger-bush areas of the plateaus appear to be modern erosion and transport surfaces. Slope is toward the breakaway, and discontinuous cover-sands rise sharply above the tiger bush. The profile is a classic pediment surface. The tiger-bush areas have very low permeability, crust severely, and are seldom moist more than a few centimeters below the surface (Stops 8, 34). Runoff from these areas produces considerable gullying on the backslopes of the valley systems near the breakaways.

Wind erosion is a problem in most, if not all, agricultural areas. The clay contents of surface horizons in soils classified as Ustalfs may be slightly higher than those of the Psamments in the dallols. This may result in less chance of erosion on the Ustalfs. However, most of the clay in surface and subsurface horizons is water-dispersible (West et al., 1987). These weakly structured systems have few water-stable aggregates. Under intense rainfall, the clays slake from the sands, decreasing the cohesive strength of the aggregates. As a result, water erosion increases with soil crusting and declining infiltration rates; wind erosion increases as loose sand grains are exposed to saltation processes.

The dallols seldom have wide expanses of clean-cultivated land even though subirrigation may make them very productive areas. Agroforestry, as alley-cropping between tree windbreaks, may help conserve soil from wind and water erosion, benefiting crops in the dallols.



Soil crusting in a "tiger-bush" area of Niger.

The ICRISAT Sahelian Center as a Base for Research Extension

Morphology and Soil Classification

A detailed log of site descriptions and soil classification is given in the section entitled "Log of Observations" (pp. 21–31). Placement and thickness of sand over laterite gravels or Miocene sediments, and soil series representative of the ICRISAT Sahelian Center are summarized in Table 1 (pp. 15–16).

From a pedo-morphological perspective, soils on the ICRISAT Center are representative of extensive areas of the sand plains and valley sand systems. These soil areas are major millet and cowpea production centers in the vicinity of Niamey. Another major land resource, the dallols, is also used extensively for millet and cowpea production, but soils on the Center are not representative of the dallols. Neither do the soils of the Center adequately reflect the conditions of the plateaus. Research at satellite sites is warranted.

Sand plains

The ICRISAT Center is situated on sand plains (sand sheets or sand terraces), and most of the soils are placed as Psammentic Paleustalfs, sandy, siliceous, isohyperthermic (West et al., 1984). The Labucheri series is representative of these soils on the Center. Very similar soils occur throughout other areas mapped as sand plains (Table 1 and Log of Observations). The reconnaissance soils map of the Niamey region (ORSTOM, 1967) provides an excellent geographical distribution of these soil associations. Soils within the sand plains include, in addition to Labucheri, those with thinner, more weakly expressed argillic horizons, those that lack argillic horizons, and those that have a laterite (petroferric) contact within 1 to 2 m of the surface (Psammentic Haplustalfs, Ustoxic Quartzipsamments, and Psammentic Paleustalfs, respectively, [Table 1]). Soils of the Center representative of the latter two conditions are Dayobu and Zogoti; no equivalent was mapped for the Psammentic Haplustalfs on the Center.

While all of the above soil conditions are similar, with the exception of minor variations in color, pH and texture, it is apparent from this study that the soils of the ICRISAT Center have thicker and more strongly expressed argillic horizons than most other soils on sand plains, on lower backslopes and toe slopes of valley sand systems, and on the dallols. This may have important implications for the amount of water available for plant use, especially when subsoils become less than 1 m thick or lack sufficient clay or argillic horizons. In effect, the rooting volume of the millet and other deep-rooting crops will be closely correlated with thickness, available water content, and clay content of the subsoils. Clay content is the single soil property most closely correlated with available water content in these soils (West et al., 1984).

Valley sand systems

The ICRISAT Center is also quite representative of the soils of the valley sand system, especially those on the upper backslope just below the breakaway laterite-capped escarpments. These soils are either Labucheri or closely allied series (Table 1 and Log of Observations). On middle to lower backslope and footslope positions of the valley toposequence, soils have less strongly developed argillic horizons, are less red, and tend to be slightly coarser in texture. No equivalent condition exists for such Psammentic Haplustalfs or Haplustults on the

Table 1. Classification and depth of soils in study area.

Stop #	Placement (Soil Taxonomy)[1]	Series Represented on ICRISAT Center	Depth to Laterite or Miocene Sediments
			(cm)
Plateau Divides			
8	Ustoxic Dystropepts sandy	none (Tondi-like but lacks argillic and is skeletal)	51
18	Petroferric Kanhaplustults, coarse loamy	none (Tondi-like but finer argillic horizon)	85
26	Petroferric[2] Dystropepts, loamy skeletal	none (Gagani-like but lacks argillic and is skeletal)	26
34	Petroferric Kanhaplustalfs, loamy skeletal	none (Gagani-like but base saturation higher and is skeletal)	33
Sand Plains (Terraces)			
7	Psammentic Paleustalfs, sandy	Labucheri	558
11	Psammentic Paleustalfs, sandy	Labucheri	410
12	Psammentic Haplustalfs, sandy (borderline to Ustoxic Quartzipsamment)	none (Dayobu-like but with better argillic)	100+
13	Psammentic Haplustalfs sandy (borderline to Ustoxic Quartzipsamment)	none (Dayobu-like but with better argillic)	100+
14	Psammentic Haplustalfs sandy (borderline to Ustoxic Quartzipsamment)	none (Dayobu-like but with better argillic)	855
15	Psammentic Paleustalfs, sandy	Zogoti	150-200
20	Psammentic Haplustalfs, sandy (borderline to Ustoxic Quartzipsamment)	none (Dayobu-like but with better argillic)	100+
21	Psammentic Haplustalfs, sandy (borderline to Ustoxic Quartzipsamment)	none (Dayobu-like but with better argillic)	160+
22	Psammentic Haplustalfs, sandy (borderline to Ustoxic Quartzipsamment)	none (Dayobu-like but with better argillic)	160+

[1]Official placement according to current classes. The mineralogy and temperature placements are all siliceous and isohyperthermic. Many of the soils in sand plains (terraces) and valley sand systems are borderline Kandiustalfs or Kanhaplustalfs.

[2]Proposed class placement in Soil Taxonomy; current placement would be Lithic Dystrochrepts.

Table 1 (continued).

Stop #	Placement (Soil Taxonomy)[1]	Series Represented on ICRISAT Center	Depth to Laterite or Miocene Sediments
			(cm)
23	Psammentic Haplustalfs, sandy (borderline to Ustoxic Quartzipsamment)	none (Dayobu-like but with better argillic)	160+
25	Psammentic Haplustalfs, sandy (borderline to Ustoxic Quartzipsamment)	Labucheri (borderline to Dayobu)	160+
28	Psammentic Paleustalfs, sandy	Labucheri (borderline to Zogoti)	210
29	Psammentic Paleustalfs, sandy	Labucheri	440
30	Psammentic Paleustalfs, sandy	Labucheri	375
31	Psammentic Paleustalfs, sandy	Labucheri (borderline to Dayobu)	350
37	Psammentic Paleustalfs, loamy	Zogoti-like but finer-textured argillic	100-200
38	Psammentic Paleustalfs, sandy	Labucheri	340
Valley Sand Systems			
2	Psammentic Haplustalfs, sandy	none	120
9	Psammentic Haplustults, sandy	none (Labucheri-like but more acid and thinner solum)	270
10	Psammentic Paleustalfs, sandy	Labucheri	555
16	Psammentic Haplustalfs, sandy	none (Labucheri-like but with thinner solum)	680
19	Psammentic Haplustalfs,	Zogoti but finer-textured solum and more acid	128
27	Ustoxic Quartzipsamments	Dayobu	160+
32	Psammentic Paleustalfs, sandy	Labucheri	265
33	Psammentic Paleustalfs, sandy	Labucheri	265
35	Ustoxic Quartzipsamments	Dayobu	435
36	Typic Ustifluvents	none	160+
Dallols			
5	Typic Ustipsamments	none	190+
6	Typic Ustipsamments	none	190+
17	Typic Ustipsamments	none	290+
24	Typic Ustipsamments	none	250+

ICRISAT Center, but the Dayobu series would be the closest analogue. Morphologically, the Psammentic Haplustalfs on the valley sand systems and those of the sand plains are equivalent, but hydrologically and geomorphically, they are quite different; those soils on the valley sand systems are much more susceptible to water erosion and water recharge via run-on from adjacent higher landscape positions.

In flood plains along dry stream bottoms, the alluvial soils are Typic (Psammentic) Ustifluvents. Bordering these drainageways and in the footslope positions of the valley segments, soils are lighter colored on the surface and appear to be dominantly Quartzipsamments, though no observations were made to confirm this relationship.

Plateau divides

The soils of plateau divides are quite variable in depth to the petroferric contact, in pH, and in development of subsoils. In general, these soils exhibit between 25 and 85 cm of sandy or gravelly loam cover materials over impermeable, cemented sesquioxide sheets or ironstone gravels. The effective rooting volume is confined to the cover materials. Available water is low because subsoils are shallow and infrequently wet.

Soils of the plateau are commonly armored with a fine mantle of ironstone pebbles (desert pavement) over a thin, massive or weakly platy surface horizon that effectively serves as a crust. These areas shed water because surfaces have very slow infiltration, subsoils are thin and have low water-holding capacities, and restrictive petroferric layers (aquitards) occur at shallow depths. Both wind and water erosion are effective in truncating shallow cover materials; this is evidenced by deflation basins, desert pavement, and fluvial-cut rills and channels. The area has sparse vegetation that may be correlated with areas of thicker cover materials, and hence to the stippled tiger-bush pattern, but this postulate has not been tested.

Major soils consist of Ustoxic Dystropepts and Petroferric subgroups of Kanhaplustults, Kanhaplustalfs, and Dystropepts. Most of the soils belong to loamy or loamy skeletal families and are siliceous in mineralogy; however, sandy subsoils also were observed (Table 1 and Log of Observations). Most of the soils that are shallow to the petroferric contact are more acid than soils with thick sands, but exceptions to this generalization can also be found (Stop 34, Table 1). Soils of the ICRISAT Center that serve as analogues to the soils observed on the plateau divides are Tondi and Gagani. Both of these soils of the Center have argillic horizons with base saturations less than 35% in the lower solum, while many of the soils of the broad plateaus appear to have less strongly developed subsoils, in spite of their finer textures. In general, soils of the Center are not representative of the plateaus, and this should be considered in the selection of research sites to expand experimental conditions of the Center.

Dallols

Soils of the dallols are uniquely different from any represented on the ICRISAT Center. All soils observed on the dallols were Typic Ustipsamments. A more comprehensive study of soils in the Dallol Bosso has been conducted by Bui (1986). In southern sections (south of Baleyara), major soils recognized are Typic Ustipsamments, Aquic Quartzipsamments, Alfic Ustipsamments, Alfic Ustochrepts, and Aeric Haplaquepts. In northern sectors major soils are Psammentic Haplustalfs and Ustic Torripsamments. Soils in the dallols generally are less red, less freely drained, coarser-textured, and more susceptible to wind erosion and instability than the Dayobu soils (Ustoxic Quartzipsamments) on the Center. In the dallols, the landscape is characterized by dunes with relief differentials of 1 to 2 m between crests and troughs. This may suggest greater dunal instability during recent time.

Soils in the dallols differ from those in other areas where soils have been classified as Ustoxic Quartzipsamments in that (1) the sand grain-size tends to be coarser; (2) the sand unit exhibits evident stratification; (3) the sand grains tend to have thinner iron-oxide clay coats in upper sola and are uncoated or bleached in lower sola; (4) a water table occurs between 2.0 and 2.5 m during the wet season (sometimes at the surface or within 1 m); and (5) the soils generally have higher pH values throughout. The sandy parent sediments of these soils are primarily quartz. Fine sand grains appear frosted,

but the mode of origin is both eolian and fluvial (Bui, 1986; Bui et al., 1989).

General properties

Soils of the ICRISAT Sahelian Center and in areas of this study are dominated by kaolinitic, iron-oxide and quartzitic minerological systems (West et al., 1984; Bui, 1986; Bui et al., 1989). The soils have low charge characteristics and low buffering capacities. They are mineralogically stable residual systems. It may be very difficult to demonstrate pedogenic age relationships among these soils even if chronologic differences occur.

The chemical properties of these soils are dynamic, slightly buffered, and difficult to measure accurately. The renewal vector for nutrients is primarily from eolian dusts, biocycling by plants during fallow periods, and termite activity. No plinthitic materials were observed in any of the soils or subadjacent stratigraphic units. On all geomorphic surfaces, the segregations of iron are in the form of strongly indurated ironstone gravels (septaria) or sheets.

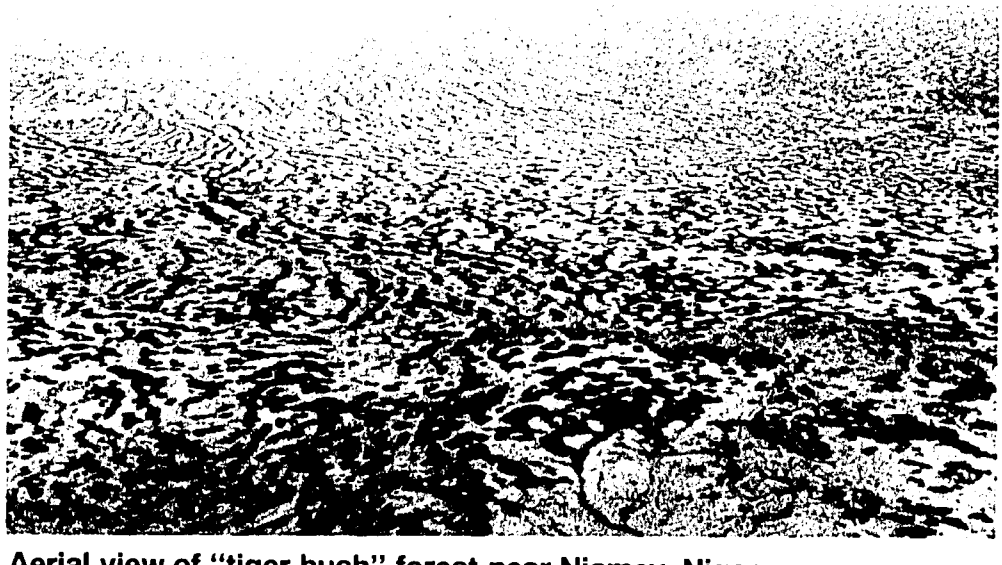
Depending on the geomorphic position, the mineralogy of iron oxides is dominantly hematite or goethite (Bui and Wilding, 1988; Bui et al., In press). On plateaus it is primarily hematite, but on younger, lower geomorphic positions it is dominantly goethite. The clay mineralogy is dominantly kaolinite with secondary or trace amounts of mica, feldspars, quartz smectites, and aluminum-hydroxy interlayer components (West et al., 1984; Bui, 1986).

Hydrology and Soil Erosion

The ICRISAT Center can be used for hydrologic or soil moisture studies for the finer-textured areas of the sand plains, but not for the coarser-textured parts of these plains. For the latter areas, off-Center investigations should be conducted. The same is true for lower segments of the valley systems, the dallols, and the plateau breakaways.

Wind-erosion research at the Center can be transferred to most of the sand plains and the valley systems because the surface textures are similar. Extension of the work to the dallols must be approached with caution because they seem to be more fragile systems than other sandy areas.

The results of hydrologic studies for irrigation potential cannot be extrapolated to many areas beyond the Center. The Center receives little run-on from higher areas and has neither a dallol nor a valley system within its boundaries. Finding areas for these studies should be relatively easy but must be based upon good geologic and pedologic work in order to be of value in extrapolating to other areas.



Aerial view of "tiger-bush" forest near Niamey, Niger.

Speculation and Questions

Several questions about the stratigraphy, geomorphology and hydrology of the area were raised during this investigation. Considerable field and laboratory work will be required to answer these questions.

Multiple Ironstone Sheets

The ironstone sheets pose an interesting stratigraphic and geomorphic problem. Before their genesis and local significance is understood, we must know more about their distribution away from the outcrop, both where they form a surface or near-surface layer and where deeper sheets are exposed at the breakaway. If they are a near-surface feature, i.e., formed only at or near the outcrop, they may considerably post-date the overlying and underlying sediments (Jones, 1948). If those lower sheets exposed at breakaways are continuous beneath the plateau, then the ideas of Sombroek and Zonneveld (1971) that the sheets represent land surfaces later buried by sediments must be carefully considered.

If the sesquioxide sheets exposed lower in the section at the breakaways are only near-surface (in relation to the face of the breakaway) features, are they related to dissection of the landscape? If this idea is true, it means that each lower level should be younger than the adjacent higher sheet. A chronology may be established if any of the sheets are magnetically reversed. But careful field work, including drilling to establish or refute the presence of continuous sesquioxide sheets deep in the section, should be completed before samples are taken for magnetic studies.

Plateaus

The plateaus are impressive features, and their origin and ages have been and probably will continue to be a source of controversy for years. Two ideas can be tested. The first is that the plateaus are old erosion surfaces capped by a thick ironstone layer. In this case the plateaus should have gradients toward ancient valleys consistent with the idea of subaerial erosion. The direction of slope should also be consistent with local valleys or possible valleys. The lower sesquioxide sheet should not continue beneath the higher plateau at the breakaway.

The second theory is that the plateau levels are controlled by sesquioxide sheets and are related to continuous sheets that were deeply buried but later exhumed. The sesquioxide sheet should be traceable beneath the sediments at the breakaway. If the ideas of Sombroek and Zonneveld (1971) are correct, then the gradients on the plateau most likely would be similar to those developed as an erosion surface. But the slope direction would not necessarily conform to present valleys.

Coversands

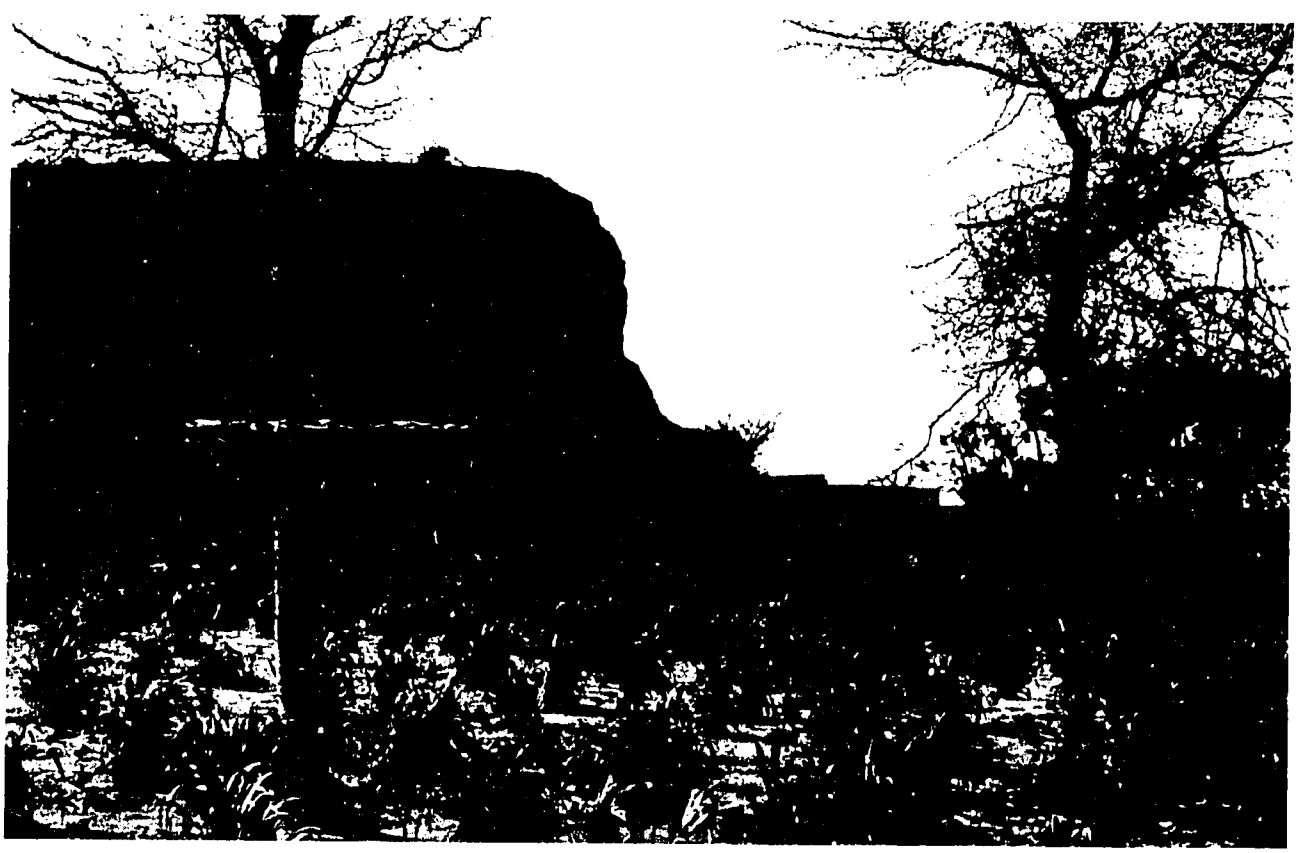
Coversands are ubiquitous features on plateaus, valleys, and sand plains. Delineating the various sands may not be possible even though one would suspect that, regardless of gross similarities, they are not all related in space and time. It is still unclear whether the sands of the plateaus and high terraces or steps in the valleys are derived largely from Miocene beds, or whether they represent different periods of fluvial and eolian activity of sediment derived from the Niger River. If the sands are derived from the Miocene beds, textural, mineralogical, and surface properties may be of little use as marker indices. Obtaining evidence to support the idea that the sands may have different origins and ages will be difficult and will require excellent field and laboratory control. Using quartz grain-size and

-shape analysis to distinguish mode of origin may be one possibility (Bui et al., 1989). Sombroek and Zonneveld (1971) mapped three sand units in northwest Nigeria, and any work near Niamey should attempt some regional correlations.

The sands in the valleys and sand plains have different weathering (color) profiles that suggest possible age differences. In an area of extremes in precipitation, the possible role of dust infall in producing the textural and color differences and in maintaining the relatively favorable pH and base status should be carefully examined.

Dallols

The dallols are very interesting areas. At this time little is known about the thickness and properties of the sediments in the dallols, their ability to function as local and regional aquifers, or the quality, quantity, and source of recharge. Considerable stratigraphic and hydrologic data should be gathered from the dallols and the adjacent areas. Because the dallols receive sediment and water from plateaus and adjacent areas, the interaction of the entire system should be examined before the potential of these areas can be evaluated. Several questions should be studied. For example, should the plateaus be used as runoff areas to recharge the dallols, or should they be reforested for fuel with a subsequent decrease in runoff? Studies on integrated watershed management that verify the relative contributions of different geomorphic and watershed components on hydrologic recharge to the dallols are prerequisite to the development of small-scale subsistence irrigation programs. The influence of conservation-intervention practices on water recharge to the dallols should be a part of these studies. Texas A&M University is conducting such a project; it is called "Integrated Management of Agricultural Watersheds" (IMAW, 1989).



Dallols such as the one shown above receive rainwater runoff from adjacent plateaus.

Log of Observations

LOG OF OBSERVATIONS

Stop #	Horizon	Thickness (cm)	Color	Texture* (cm)	pH	Moist** (cm)	Slope	Landform***	Classification (Remarks)
Plateau Divides									
1	East-Southeast of Niamey (about 15 km off R.N. #1)								
	Com****	0-200	10YR 3/4	strongly indurated gravels	6.0	—	0.5%, planar	broad plateau divide	(road cut—no soil)
	2Bt	200-300+	7.5YR 6/8 & 2.5YR 4/8	scl	7.0				(Miocene sediments)
3	No detailed description. Soil has 1fs Bt 75 cm thick over laterite - pH 4.5 at base. Classified as Petroferric Kanhaplustults.								
4	Escarpment cut E of Birni-N-Gaouré (about 1 km E off R.N. #1)								
	Com	0-100	10R 3/4	indurated sesquioxide sheet	—	—	2-3%, planar	near edge of plateau divide	(escarpment edge capped by laterite; thick soil developed in Miocene-age sediments with thick well-expressed argillic separated by five sesquioxide sheets)
	2Bt	100-400	2.5YR 4/8	scl	6.5				
	2Com	400-450	10R 4/8	indurated	—				
	3Bt	450-800	2.5YR 4/8	scl	6.5				
	3Com	800-830	10R 4/8	indurated	—				
	4Bt	830-1200	2.5YR 4/8	scl	6.5				
	4Com	1200-1230	10R 3/4	indurated	—				
	5Bt	1230-1500	2.5YR 4/8	fsl-scl	6.5				
	5Com	1500-1540	10R 3/4	indurated					
	6Bt	1540-2000	2.5YR 4/8	fsl	6.5				

*Legend for field textures given below. The (+) and (-) signs associated with these textural classes as superscripts imply the textural class is at the upper end of clay range for a (+) and at the lower end for a (-) superscript:

ms—medium sand
fs—fine sand
vfs—very fine sand
lfs—loamy fine sand
sl—sandy loam
fsl—fine sandy loam
scl—sandy clay loam
gr. ls—gravelly loamy sand
gr. sl—gravelly sandy loam
gr. fs—gravelly fine sand
gr. lfs—gravelly loamy fine sand
v. gr. ls—very gravelly loamy sand
v. gr. sl—very gravelly sandy loam

**"Moist" indicates the thickness of soil that was moist at time of observation. A dash (—) indicates the soil was dry throughout when observed.

***LRD means local relief differential from crest to trough of dunal landforms.

****The ironstone contact may be either a pedogenic or a geogenic zone. If pedogenic it would be designated "Bom." Because frequently it could not be observed in detail and the origin is not well verified, the designation "Com" has been used.

Stop #	Horizon	Thickness (cm)	Color	Texture* (cm)	pH	Moist** (cm)	Slope	Landform***	Classification (Remarks)
8	West of Niger River (about 10 km ESE of Kollo)								
	A	0-8	5YR 4/6	ls*	4.5	0-8	0-0.5%, planar	broad plateau divide	Ustoxic Dystropepts, sandy skeletal, siliceous, isohyperthermic
	2Bwc	8-51	5YR 4/8	v.gr.ls* to v.gr. sl	4.5-5.0				
	3Com	51+	couldn't penetrate deeper with spade because of petroferric contact						
18	East of Dallol Bosso (about 7 km ESE of Tabla)								
	A	0-5	5YR 4/6	fs (20% gr.)	6.5	—	1%, slightly concave	slight depression in broad divide	Petroferric Kanhaplustults, coarse-loamy, siliceous, isohyperthermic
	2A2	5-18	5YR 4/4	fs	4.5-5.0				
	2Bt1	18-28	5YR 4/6	sl	4.5-5.0				
	2Bt2	28-85	5YR 5/6	sl	4.5-5.0				
	3Com	85+	couldn't penetrate laterite layer with auger						
26	East of Dallol Bosso (about 35 km NNE of Sabongari)								
	A	0-9	5YR 4/4	fsl	4.5-5.0	—	0-0.5%, planar	broad plateau divide	Petroferric Dystropepts, loamy skeletal siliceous, isohyperthermic
	2Bw	9-26	5YR 5/4	gr. sl* (40-50%) laterite gr.	4.5-5.0				
	3Com	26+	couldn't penetrate deeper with spade because of petroferric contact						
34	West of ICRISAT Sahelian Center (about 3 km SSW of Damari—9 m above Stop #33)								
	A	0-6	5YR 4/6	sl (5-10% rounded laterite gr.)	6.5	3-33	0-0.5%, planar	broad plateau divide	Petroferric Kanhaplustalfs, loamy skeletal siliceous, isohyperthermic (soil has a compact, thin, platy crust to 1 cm with 2-4 mm laterite pebble pavement at surface)
	2Bt	6-33	2.5YR 4/6	gr.ls* (60% ironstone gravels)	5.5 upper 6.5 lower				
	3Com	33+	couldn't penetrate deeper because of petroferric contact						
Sand Plains (Terraces)									
7	INRAN Center at Ndounga Tarey								
	Ap	0-40	7.5YR 4/4	fs	7.0-7.5	0-66	1-2%, slightly convex	weakly dunal with LRD of <25 cm; site on crest of dune	Psammentic Paleustalfs, sandy, siliceous, isohyperthermic
	Bt	40-118	7.5YR 4/6-5/4	ls*	7.0-7.5				

Stop #	Horizon	Thickness (cm)	Color	Texture* (cm)	pH	Moist** (cm)	Slope	Landform***	Classification (Remarks)
	2Btb	118-370	7.5YR 4/8 to 5YR 4/6	ls	7.5-8.0				
	2BCb	370-460	5YR 5/8	ls-	8.0				
	2C	460-558	5YR 5/8	fs	7.5-8.0				
	3Com	558+	2.5YR 4/8	cemented laterite gravels—couldn't penetrate					
11	About 0.2 km E of NE corner of ICRISAT Center (first terrace level—highest)								
	Ap	0-50	7.5YR 4/6	fs	5.5	0-290	1.3%, convex	moderately dunal with LRD of <50 cm; on crest of dune	Psammentic Paleustalfs, sandy, siliceous, isohyperthermic
	Bt	50-265	2.5YR 4/6-4/8	lfs	5.0				
	C	265-410	5YR 5/6	fs	5.5				
	2Com	410+	cemented laterite gravels—couldn't penetrate deeper						
12	East of ICRISAT Center (NE of Sonderi) (second terrace level—3-4 m below first terrace level)								
	Ap	0-15	didn't read colors	fs	6.5	0-100	1%, convex	moderately dunal with LRD <50 cm; on crest of dune	Psammentic Haplustalfs, sandy, siliceous, isohyperthermic (borderline to Ustoxic Quartzipsamments)
	Bt	15-75		ls-	5.5				
	BC	75-100		ls-	—				
	C	100+		fs	5.5-6.0				
13	Northeast of ICRISAT Center at Doguel Kiana (second terrace level—middle)								
	Ap	0-40	didn't record	fs	6.0-6.5	0-110	1-3%	strongly dunal with LRD of 1-2 m; on crest of dune	Psammentic Haplustalfs, sandy, siliceous, isohyperthermic (borderline to Ustoxic Quartzipsamments)
	Bt	40-80	5YR 4/8	ls-	5.0				
	BC	80-110	5YR 5/8	fs	5.5				
	C	110+	5YR 5/8	fs	—				
14	Northeast of ICRISAT Center at Doguel Kiana (third terrace level—lowest)								
	Ap	0-65	5YR 4/4	fs	—	0-855	1%, slightly concave	head of stream dissection into sand plain; dunal topography with LRD of <50 cm. Lower terrace surface adjacent to Niger River; about 5 m lower than Stops #12 & #13	Psammentic Haplustalfs, sandy, siliceous, isohyperthermic (borderline to Ustoxic Quartzipsamments)
	Bt	65-120	5YR 5/8	ls	6.5				
	BC	120-170	5YR 5/8	fs-					
	C1	170-348	7.5YR 5/8-6/8	fs	7.5-8.0				
	C2	348-760	10YR 7/6 mottled w/ 10YR 5/6 10YR 7/8 at depth	fs					
	C3	760-830	7.5YR 5/8 to 5 YR 5/8 at depth	fs-ms					

Stop #	Horizon	Thickness (cm)	Color	Texture* (cm)	pH	Moist** (cm)	Slope	Landform***	Classification (Remarks)
	C4	830-855	2.5YR 4/8 to 5/8 and 10YR 7/6 at base	fs-ms					
	2Com	855+	abrupt boundary with laterite cemented gravels—couldn't penetrate deeper						
15	Northeast of Niamey on high terrace position above Niger River (about 4 km E along R.N. 25)								
	Soil not described in detail but is very similar to Zogoti (Psammentic Paleustalfs) series at ICRISAT Center. It consists of about 1.5 to 2 m of sands with a sl+ lower Bt overlying a channeled laterite (petroferric) cap about 25 cm thick, which overlies a thick 2-3 m paleosol in Miocene sediments. The surface has weakly dunal relief, and this site is on a 4% SW-facing slope.								
20	West side of Dallol Maouri at Tourobon								
	Bt	0-100	2.5YR 5/8	ls-	5.0	—	7%, planar	upper backslope of valley dissecting into sand plain	Psammentic Haplustalfs, sandy, siliceous, isohyperthermic (borderline to Ustoxic Quartzipsamments) (soil has been truncated so surface is gone)
	C	100+	5YR 5/8	fs	5.0				
21	West side of Dallol Maouri (about 4 km E of Tourobon)								
	Ap	0-38	5YR 4/4	fs+	5.5	0-118	<1%, convex	slightly dunal with LRD <50 cm; on crest of dune	Psammentic Haplustalfs, sandy, siliceous, isohyperthermic (borderline to Ustoxic Quartzipsamments)
	Bt	38-110	2.5YR 4/6	ls-	5.0				
	BC	110-150	2.5YR-5YR 4/6	fs+ ls	5.5				
	C	150-160+	5YR 5/8	fs	5.5				
22									
	Ap	0-20	5YR 4/4	fs	5.0	—	3%, convex	broad dunal relief with 50 m between crests and with LRD 1-2 m; on crest of dune	Psammentic Haplustalfs, sandy, siliceous, isohyperthermic (borderline to Ustoxic Quartzipsamments)
	Bt	20-70	5YR 4/6	fs+	5.0-5.5				
	BC	70-160+	2.5YR 4/8	fs	5.0-5.5				
23	East of Dallol Maouri (between Beri-Beri and Kalep)								
	Ap	0-26	5YR 4/4	fs	5.0	0-110	<1%, convex	slightly dunal relief with <50 cm LRD; on crest of dune	Psammentic Haplustalfs, sandy, siliceous, isohyperthermic (borderline to Ustoxic Quartzipsamments)
	Bt	26-78	5YR 4/8	lfs-	5.0				
	BC	78-135	5YR 5/8	fs	5.0				

Stop #	Horizon	Thickness (cm)	Color	Texture* (cm)	pH	Moist** (cm)	Slope	Landform***	Classification (Remarks)
25	East of Dallol Maouri (2 km E of Gueza)								
	Ap	0-26	5YR 4/4	fs	6.5	—	3%, planar	slightly dunal with LRD <50 cm; sideslope of a broad intermittent drainageway	Psammentic Paleustalfs, sandy, siliceous isohyperthermic (borderline to Ustoxic Quartzipsamments)
	Bt	20-160	5YR 4/8	lfs-	5.0-5.5				
28	East of Dallol Bosso (about 1 km S of Margou)								
	Ap	0-20	5YR 4/6	ls	5.5	—	<0.5%, convex	moderately dunal with 100 cm LRD; on crest of dune	Psammentic Paleustalfs, sandy, siliceous, isohyperthermic
	Bt	20-210	2YR 4/5-4/8	lfs+	5.0-6.5				
	2Com	210+	petroferric contact with cemented laterite gravels						
29	East of Dallol Bosso (about 8 km S of Margou)								
	Ap	0-25	didn't color	ls	—	—	1%, convex	slight dunal relief with <100 cm LRD; on crest of dune	Psammentic Paleustalfs, sandy, siliceous, isohyperthermic (soil is coarser than Stop 28 in lower Bt and minimum thickness for Paleustalf)
	Bt	25-150	2.5YR 4/6	lfs					
	BC	150-250	2.5YR 5/8	fs					
	C	250-420	2.5YR 5/8	fs					
	2Com	420-440	2.5YR 4/8	gr. sl (mod. cemented)					
	3Com	440+	couldn't penetrate with auger						
30	East of Dallol Bosso (about 6 km S and 2 km W of Gobéri)								
	Ap	0-13	5YR 5/6	fs	5.5	0-375	<0.5%, convex	slight dunal relief with LRD <50 cm	Psammentic Paleustalfs, sandy, siliceous, isohyperthermic
	A2	13-40	5YR 5/6	fs	5.0				
	Bt	40-296	2.5YR 4/8-4/3	lfs-	5.0				
	BC	296-326	2.5YR 4/8-5/8	fs	5.5				
	C	326-350	2.5YR-5YR-5/8	fs	5.5				
	2C	350-375	2.5YR 5/8	fs+ (5-10% ironstone gravels)	5.5				
31	East of Dallol Bosso (about 6 km S and 6.5 km W of Gobéri—20 m higher than Stop 30)								
	Ap	0-26	5YR 4/6	fs	6.0	5-120 and 250-350	<0.5%, convex	slight dunal relief with LRD <50 cm	Psammentic Paleustalfs, sandy, siliceous, isohyperthermic
	Bt	26-211	2.5YR 4/6-5/8	lfs- to fs+	5.0				
	BC	211-270	2.5YR 5/8	fs	5.5				
	C	270-350	2.5YR 5/8	fs	5.5				
	Com	350+	couldn't auger deeper—hit petroferric contact						

Stop #	Horizon	Thickness (cm)	Color	Texture* (cm)	pH	Moist** (cm)	Slope	Landform***	Classification (Remarks)
37	About 3 km NW of Niamey and 1 km NE of Tillaberi Road. Observations made in a gravel pit next to city (2 km NE of Niger River—level plateau or terrace on which Niamey is located)								
	No detailed description at this site but cementation of laterite gravels well exposed. About 1 m sands over laterite gravels with some siliceous gravels (1-2 m thick). Miocene sediments within 2-3 m of surface because lower gravels composed mostly of iron-cemented Miocene sandstone. Some gravels can be broken by hand while others require hammer. Some gravels more strongly cemented with laminar sesquioxides cement with appearance of sesquioxide plugging of pores analogous to genesis of petrocalcic horizon with carbonates. Upon exposure gravels become disaggregated—perhaps hydration of clays? Soils developed in eolian sands have finer Bt's than ICRISAT Center with more silt and clay. Bt maxima are scl, cl and l*. Colors are 2.5YR 4/8 and 5/8.								
38	About 10 km NW of Niamey and 1 km NE of Tillaberi Road (2 km NE of Niger River—level plateau or terrace around Niamey)								
	Ap	0-25	2.5YR 5/8	fs	5.5	0-230	<1%, convex	strongly dunal with LRD of 150-200 cm; on crest of sand dune	Psammentic Paleustalfs, sandy, siliceous, isohyperthermic
	Bt	25-340	2.5YR 4/6, 5/6 & 5/8	lfs*	6.0-6.5				
	2Ab	340-350	5YR 4/6	lfs (10-20% rounded ironstone gravels strongly cemented)	6.5				
	3Btb	350-400	2.5YR 4/6	gr. lfs* (15-20% rounded ironstone & siliceous gravels)	6.5				
	4Com	400+	laterite gravel contact—can't auger deeper						
Valley Sand Systems									
2	Between Niamey and Birni-N-Gaouré—just W of Gosselbodi								
	Ap	0-30	10YR 4/6	ls*	7.0	—	<1%, planar	alluvial toe slope with 30-cm-deep eolian deflation basins	Psammentic Haplustalfs, sandy, siliceous, isohyperthermic
	Bt	30-120	5YR 4/8	ls					
	2BC	120-130	2.5YR 4/6	lfs (Paleosol in Miocene sediments)					
9	Broad valley cut a few meters lower than plateau at Stop #8								
	Ap	0-23	2.5YR 4/6	fs	4.5-5.0	0-140	<1%, concave (almost depressional)	broad saddle inset into plateau	Psammentic Haplustults, sandy, siliceous, isohyperthermic
	Bt	23-120	2.5YR 4/8	ls*	5.0				
	BC1	120-270	2.5YR 4/8	ls* fs at depth	4.5				

Stop #	Horizon	Thickness (cm)	Color	Texture* (cm)	pH	Moist** (cm)	Slope	Landform***	Classification (Remarks)
	2BC2	270-280	2.5YR 4/8	gr. ls. (20% ironstone nodules)					(weathered Miocene sediments)
	2CrB	280-350	2.5YR 4/8 (7.5YR 6/3 bodies)	ls	5.5				(weathered Miocene sediments)
10	In gully (arroyo) incised into upper backslope of valley fill (about 8 km SW of Ko Kouarey Peul)								
	Ap	0-25	5YR 5/6	fs		0-250	2-3%, planar, SW-facing	upper backslope about 50 m beyond breakaway escarpment	Psammentic Paleustalfs, sandy, siliceous, isohypertnermic
	Bt	25-150	2.5YR 4/6-4/8	lfs					
	C	150-250	5YR 5/8	fs					
	2Btb	250-550	2.5YR 4/6	lfs*					
	3Com	550+	couldn't penetrate because of petroferric contact						
16	Barrow pit along highway between Niamey and Baleyara (just a few km SW of Dallol Bosso)								
	Ap	0-15	7.5YR 7/8	fs	5.0-5.5	0-360	2-3%, planar, NE-facing	lower backslope of valley fill—about 1 km from breakaway escarpment	Psammentic Paleustalfs (borderline to Ustoxic Quartzipsamment), sandy, siliceous. isohyperthermic
	Bt	15-75	5YR 5/8	ls*	5.0				
	BC	75-160	5YR 5/8	fs	5.5				
	C1	160-624	7.5YR & 5YR	fs - vfs at base	6.0				
	C2	624-680	2.5YR-5YR 5/8	fs	5.0				
	2Btb	680-790	2.5YR 4/8-5/8	lfs*	5.0				
	2BC	790+	didn't auger deeper, but sands continued						
19	East-Southeast of Dosso along R.N. #1 (about 2.5 km from Dosso) (2 or 3 km E of breakaway escarpment—may be broad saddle in plateau)								
	Ap	0-30	7.5YR 4/4	lfs (2-5 mm crust—upper 10 cm contains 10-15% 2-5 mm rounded ironstone gravels)	4.5-5.0	3-30	0-5%, planar	midbackslope	Ultic Haplustalfs, (Kanhaplustults?) fine loamy, siliceous, isohyper-thermic

Stop #	Horizon	Thickness (cm)	Color	Texture* (cm)	pH	Moist** (cm)	Slope	Landform***	Classification (Remarks)
	Bt	30-128	7.5YR 5/8 (5YR 4/6 mottles)	scl (5-10% iron-stone gravels at 100-115 cm)	4.5-5.0				
	Com	128+	couldn't auger deeper—hit petroferric layer						
27	Near village of Boukagorou (2.5 km E of N.R. #7 between Dosso and Gaya)								
	A1	0-40	7.5YR 5/4	fs	5-5.5	—	2%, planar to slightly concave	lower backslope, about 1.25 km from plateau, slightly dunal relief	Ustoxic Quartzipsamments, siliceous, isohyperthermic, coated
	Bw	40-65	7.5YR 5/4-6/4	fs	5-5.5				
	BC	65-150	7.5YR 10YR 6/4	fs	5.5				
	C	150-160+	10YR 7/4	fs	5.5				
32	West of Niger River (0.2 km WSW of Damari) (valley dissection in sand plain—10 m lower than Stop #33 and 20 m higher than Stop #36)								
	Ap	0-20	5YR 4/6	fs	6.0	0-224	1%, planar, NE-facing	midbackslope on long fan (channeled with arroyos 25-100 cm deep)	Psammentic Paleustalfs, sandy, siliceous, isohyperthermic
	Bt	20-225	2.5YR 4/6 & 4/8	lfs	5.5 upper 6.5 lower				
	BC	225-265	2.5YR 5/8	fs	6.5				
	2C1	265-290	2.5YR 4/6	gr lfs (30% iron-stone gravel)	6.5-7.0				
	3Btb	290-308	2.5YR 4/4 (5YR 6/6 grayer bodies)	gr lfs (30-40% iron-stone), rounded gravels, mostly cemented fragments of Bt)	6.5-7.0				(Bt in Miocene sediments)
33	Same as Stop #32 but 2.8 km WSW of Damari (about 10 m higher than Stop #32 and 9 m lower than Stop #34)								
	Ap	0-13	2.5YR 4/6	fs+	5.5	0-117	4%, NE-facing	upper backslope, about 65 m from breakaway escarpment and 3 m lower. 1-3 m arroyos incised into sand apron	Psammentic Paleustalfs, sandy, siliceous, isohyperthermic
	Bt	13-160	2.5YR 4/6-4/8	lfs	5-5.5				
	BC	160-265	2.5YR 4/8-5/8	lfs-	5.5				
	2C	265-290	2.5YR 4/6	lfs (15% iron-stone gravels)	5.5				

Stop #	Horizon	Thickness (cm)	Color	Texture* (cm)	pH	Moist** (cm)	Slope	Landform***	Classification (Remarks)
35	Same as Stop #32 but 4-7 km SSW of Damari (on a broad upland depression in sand plain that is on upper plateau level and 1-2 km across—5 m higher than Stop #34)								
	Ap	0-20	5YR 4/4	fs	5.0	- -	<1%, slightly concave	slightly dunal w/ LRD <30 cm on coppice dunes	Ustoxic Quartzipsamments, siliceous, isohyperthermic, coated
	Bw	20-100	2.5YR-5YR	fs*					
	BC	100-125	5YR 6/8	fs	4.5-5				
	C	125-400	5YR 6/8	fs	4.5-5				
	2C	400-435	2.5YR 5/8	grfs (30-40% ironstone gravels)	5.0				
	3Com	435+	moderately indurated laterite gravel—very difficult to auger						
36	Same as Stop #32 but about 1 km N of Damari (on narrow floodplain about 50 m wide at base of small valley dissecting into sand plain—20 m lower than Stop #32)								
	C	0-13	5YR 6/8	fs	6.5	0-115	<1% on floor of valley	flood plain with steep valley sideslopes 6-8%	Typic Ustifluvents, sandy, siliceous, isohyperthermic
	2C	13-45	5YR 5/6-5/8	fs*	4.5-5.0				
	3Ab	45-68	5YR 4/6	fs	5.0				
	3Bwb	69-113	5YR 5/6-7.5YR 5/8	ls - sl	5-6.5				
	3BCb	113-150	7.5YR 5/6-2.5YR 5/8	lfs	6.5				
	4C	150-160+	7.5YR 5/6 stratified	lfs - fs	5.5				
Dallols									
5	Dallol Bosso (about 3 km N of Birni-N-Goauré on road to Tabla)								
	Ap	0-50	7.5YR 4/4	fs	7.0	175-230	1-3%, convex	strongly dunal landscape with LRD 1-2 m; on crest of sand dune	Typic Ustipsamments siliceous, isohyperthermic, coated; sands poorly sorted
	Bw	50-100	7.5YR 5/6	fs	5.5				
	C1	100-175	10YR 5/8	fs (occasional pebbles to 1 cm in diameter)	8.0				
	C2	175-275	10YR 8/3 (some 10YR 5/8 mottles)	fs	8.0				(sands well sorted) (free water table at 230 cm)

Stop #	Horizon	Thickness (cm)	Color	Texture* (cm)	pH	Moist** (cm)	Slope	Landform***	Classification (Remarks)
6	Dallol Bosso (about 13 km N of Stop #5)								
	Ap	0-40	10YR 5/6	fs	6.5	5-190	1-3%, convex	strongly dunal landscape with LRD 1-2 m; on crest of sand dune	Typic Ustipsamments, siliceous, isohyperthermic, coated (sands not as well sorted as B above) (free water table at 190 cm)
	Bw	40-90	7.5YR 5/8	fs	6.5				
	BC	90-116	10YR 7/8	fs	7.0-7.5				
	C	116-190+	2.5Y 4/4	ms	7.5				
17	Dallol Bosso (about 3 km SE of Baleyara on road between Baleyor and Loga)								
	Ap	0-40	7.5YR 4/4	ms	5.5	0-290	1-3%, convex	strongly dunal landscape with LRD 2-3 m; on crest of sand dune	Typic Ustipsamments, siliceous, isohyperthermic, coated (free water table at 290 cm)
	Bw	40-60	7.5YR 5/6	ms	5.6-6.0				
	BC	66-105	7.5YR 6/6	ms	6.5-7.0				
	C	106-290+	10YR 7/4-7/6	ms	7.0				
24	Dallol Maouri (about 5 km S of Doundio)								
	Ap	0-53	10YR 4/4 & 7.5YR 4/4	ms	5.0-5.5	0-225	1-3%, convex	strongly dunal landscape with LRD on 2-3 m; on crest of sand dune	Typic Ustipsamments, siliceous, isohyperthermic, coated (free water table at 225 cm)
	Bw	53-93	7.5YR 5/6	ms	5.0-5.5				
	BC	93-133	7.5YR 5/8	ms	6.0				
	2C	133-170	7.5YR 6/8	fs	6.5				
	3C	170-210	10YR 7/8	ms	6.5				
	4C	210-250+	10YR 6/8	ms	—				

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