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GEOMORPHIC FEATURES AND ASSOCIATED IRON OXIDES OF THE DALLOL BOSSO OF NIGER (WEST AFRICA)

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Summary

Ironstone occurs in four landscape positions in the Dallol Bosso valley of Niger:

1. on a high plateau,
2. on terraces,
3. in dunes and
4. in partially or completely filled channels.

The Fe oxide mineralogy of the older plateau and terrace ironstones contrast with that of the newly formed pedogenic ironstone of the valley. Plateau ironstone is characterized by a hematite-rich phase whereas terrace gravels are goethitic. In the valley, ironstone occurs at the base of dunal soils along the contact between medium to fine eolian sands and coarser fluvial sands; there it consists of quartz sand cemented by goethite. A maghemite-hematite association occurs at the top of the ground water table. Neoformation of the valley mineral phases occurs in an aquic soil environment and is driven by the large amount of surface evaporation in the semi-arid climate. The presence of Fe in the ground water of the Dallol Bosso suggests an active process of Fe movement. There is an abundant reservoir of Fe in the plateau ironstones that may be slowly released by physical and chemical weathering. Although the source of the Fe is speculative, secondary Fe phases are likely to continue to form as the Dallol Bosso landscape evolves.

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1 Introduction

The landscape of West Africa is controlled by levels of ironstone; hence, it is not surprising that processes involving Fe-oxide formation have fascinated geologists and soil scientists working there. Only a few of the more recent studies will be cited: NAHON (1976) in Senegal; MICHEL (1973) in Gambia; NAHON et al. (1980) in Ivory Coast; LEPRUN (1981) in Burkina Faso; GAVAUD (1977) and DUBOIS (1979) in Niger; ADETUNJI and KOGBE (1987); ADELEYE (1973) and SOMBROEK and ZONNEVELD (1971) in Nigeria. Ironstone features have been called by various names (LEPRUN 1981; GOUDIE 1973) and

have been used to reconstruct climatic fluctuations by some (ADETUNJI and KOGBE 1987; GAVAUD 1977; SOMBROEK & ZONNEVELD 1971). Ironstone deposits which are used today as road-bed materials, also played an important role in the past development of native populations of smelters.

In Niger, the oldest existing ironstone deposits date from the late Cretaceous to Tertiary. Their geologic history is discussed in GREIGERT (1966) and DUBOIS (1979). 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 in the late Cretaceous. They 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 & KOGBE 1987; KOGBE 1978; ADELEYE 1973; SOMBROEK and ZONNEVELD 1971). Since the uplift and dissection of the basin, these iron-rich deposits have been recycled several times in the landscape. This paper discusses some of the pathways of iron-oxide formation and accumulation in the Sahelian environment using the Dallol Bosso region of Niger as an example.

1.1 The study area

The Dallol Bosso is the fossil valley of the section of the ancient Azaouak River that runs North-South in western Niger from 15° to 12° North latitude along 3° East longitude (fig.1). In Niger, the word "dallol" refers to a wide, dry valley drained by intermittent streams during the rainy season only (DONAINT 1975). The Dallol Bosso is the largest of several dry or intermittent stream valleys in the Iullemmeden basin of Niger.

The Dallol Bosso covers an area of about 3400 km^2 within the Sahelian climatic zone. This is the semi-arid belt south of the Sahara desert that has a long dry season lasting from October through April and a short rainy season between May and September. The mean annual rainfall is 200 mm in the northern Dallol Bosso and increases to 600 mm in the south. The average annual temperature is 30° although highs between 40° and 45° are recorded during the dry season. The average monthly evapotranspiration is 2100 mm. The natural vegetation is characteristic of a steppe with annual grasses, scattered shrubs and trees.

During fieldwork in 1984, soils of the Dallol Bosso and several "ground-water" ironstones were sampled as part of a pedologic and geomorphic study (BUI 1986). The basic geomorphic units distinguished going east to west across the Dallol Bosso (fig.2) were: a disected plateau, a discontinuous terrace capped by ironstone, a scarp face, a talus slope, an alluvial fan surface, and valley sediments which could be separated into dunes and channels. Distinctive iron phases were identified in four landscape positions:

1. in the ferruginous sandstone cap of the plateau,
2. in terrace gravels,
3. in the valley, at the base of dunal soils along the edges of some old channels, and
4. in channel soils.

The Fe-mineralogy of the older plateau and terrace deposits contrasts with that of the newly formed ironstone of the valley.

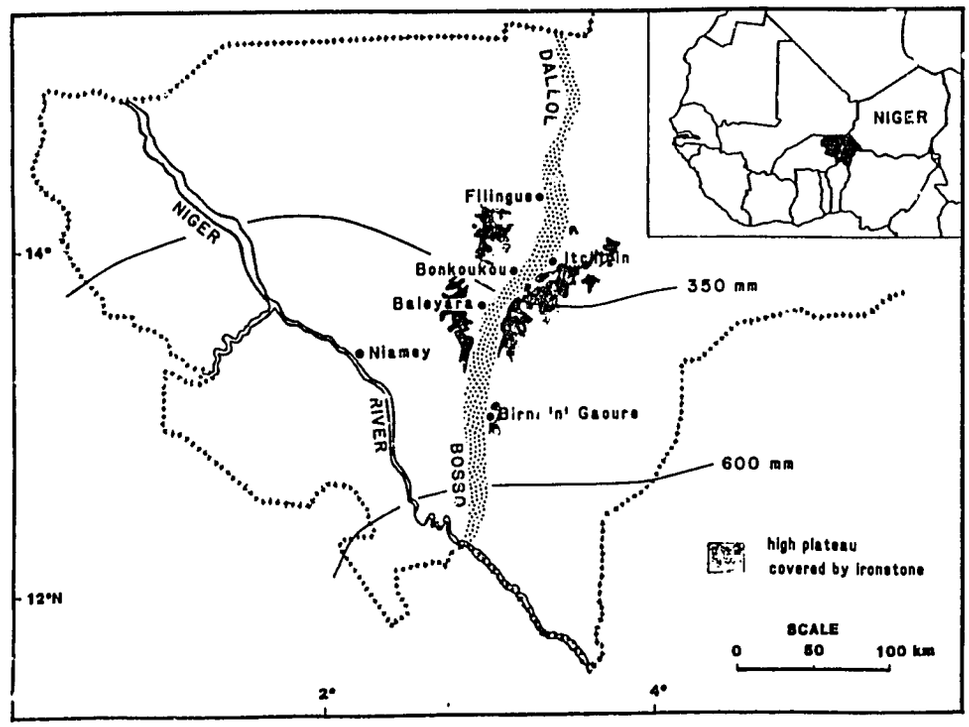

Fig. 1: *Location of the Dallol Bosso and of the ironstone-capped plateaus along the valley.*

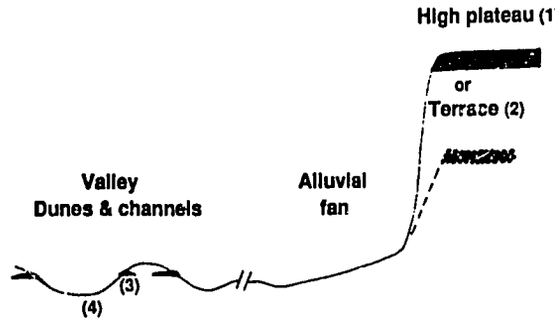

Fig. 2: *Idealized cross-sections of the Dallol Bosso showing the four landscape positions in which Fe phases occur.*
(1) Plateau,
(2) stream terrace,
(3) base of dunal soil, and
(4) channel soil.
Note, that position (2) is not observed in most cross-sections.

2 Materials and methods

Detailed descriptions of sites of ironstone occurrence were made in the field. Several large (>300 g) oriented samples were collected from each site for further study. Samples were taken from a ferruginous sandstone capping the Continental Terminal near Bonkoukou (280 m, elevation), south of Baleyara (240 m), and north of Birni'n'Gaoure (241 m), from a gravely terrace near Itchigin (225 m) and from several ironstones formed in the valley (ca. 195 m) between Baleyara and Birni'n'Gaoure (positions 1,2, and 3, respectively, of fig.2).

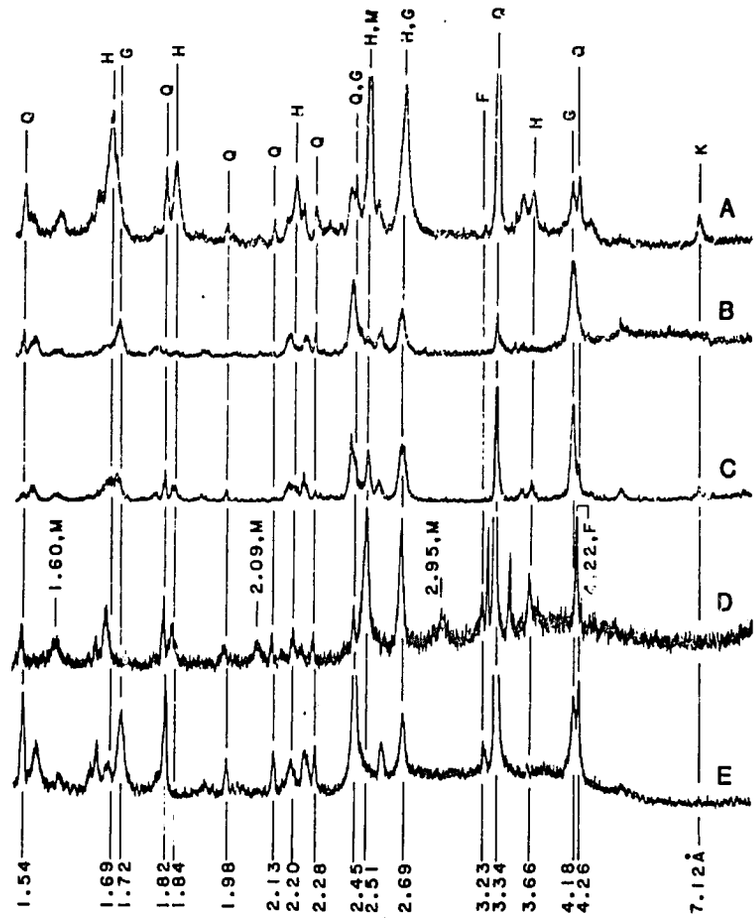

Fig. 3: *X-ray diffractiograms of (A) ferruginous sandstone cap; (B) oolite-rich zone in ferruginous sandstone; (C) terrace gravels; (D) magnetic residue from ground-water; (E) sheet ironstone.*
K = kaolinite, Q = quartz, G = goethite, H = hematite, M = maghemite, F = feldspar

X-ray diffraction. Ironstone samples were ground to silt size in a disk mill and powder mounts were analyzed on a Philips-Norelco X-ray diffractometer equipped with a Cu-target X-ray tube and curved graphite monochromator, and operated at 30 kV and 18 mA. The samples were scanned at a goniometer speed of 1/2° 2θ per min to measure peak widths at half-maximum intensity (WHH). Mean crystallite dimension (MCD) was estimated using the Scherrer equation (KLUG & ALEXANDER 1974).

Scanning electron microscopy. Whole specimens were mounted on Al stubs with silver paint, sputter-coated with 200 Å of Au-Pd and examined on a JEOL SM-25SII scanning electron microscope at 15 kV accelerating voltage.

Transmission electron microscopy. Specimens were diluted in H_2O, sonicated, and dried onto a C-film on a Cu-grid. Shadow casting was performed by sputter-coating with Pt-C at an incident angle of 14°.

Petrography. Oriented specimens were dried overnight at 60°C and impregnated in epoxy (Scotch-cast electrical resin) under vacuum (INNES & PLUTH 1970). Thin-sections were cut and hand-ground to 30–40 μm thickness. Observations were made under a Zeiss petrographic microscope. Micromorphology was described using the terminology of BREWER (1976).

3 Results: Geomorpholoy and iron oxide properties

3.1 Plateau

The Dallol Bosso section of the Azaouak River is cut into the poorly lithified Eocene-Miocene Continental Terminal sandstones. The exposed thickness of these sandstones is 20 to 30 m in the middle section of the valley and 50 to 70 m in the northern section. The sandstones are generally pink, white and yellow with clayey interstitial material and isolated segregations of red to purple clay about 10–20 cm in diameter. The white to yellow clay is dominantly kaolinite (DUBOIS 1979). The plateau has been dissected by small tributaries of the Dallol Bosso into a number of mesas capped by resistant ironstone that rise above the valley floor by 50 to 70 m in the northern section and 20 to 30 m in the middle Dallol Bosso. The incision of the valley probably corresponds to a phase of downcutting throughout Africa and the Sahel in the Pleistocene, between 900,000 to 200,000 years B.P. (SOMBROEK & ZONNEVELD 1971).

The ironstone cap on the mesas is generally 10 to 50 cm thick but may be a meter or more thick. It is a very hard, variegated, yellow (10YR 7/6) to purplish red (2.5YR 3/6 to 10R 3/6, dry color of crushed samples) ferruginous sandstone sometimes containing small blocks of oolitic ironstone (photo 1). The dominant Fe-oxide mineral in the groundmass of the ferruginous sandstone is hematite as identified by X-ray peaks at 2.69, 2.51, 1.69 and 1.84 Å (fig. 3A). The narrowness of the X-ray diffraction peaks (WHH = 0.325° 2θ for the 110 reflection) suggests that the hematite is coarsely crystalline, and the corresponding estimated MCD is 54 nm. Scanning electron microscopy shows that it consists of closely knit, intergrown platelets several microns in diameter, often arranged in rosettes (photo 2). The coarseness of these hematite crystals and their face to face and edge to face contacts contribute to the resistance of the cap. It is possible also that the crystal arrangement in rosettes contributes to the purplish red visual appearance of the ferruginous sandstone (Torrent & Schwertmann, 1987). The quartz grains in the sandstone are angular and appear fractured and corroded; their long axes are less than 100 μm (photo 1). Their occurrence as free floating grains imbedded in the groundmass suggests that they are detrital grains that have been partially replaced by the Fe oxide cement.

The oolites are spheroidal with a concentrically laminated fabric and are generally less than 1 mm in diameter (photo 1A). Some are hollow. Because the dominant mineral in the oolite-rich zones is goethite as indicated by x-ray peaks at 4.18, 2.45, 2.58 and 1.72 Å (fig. 3B), the oolites are goethitic and

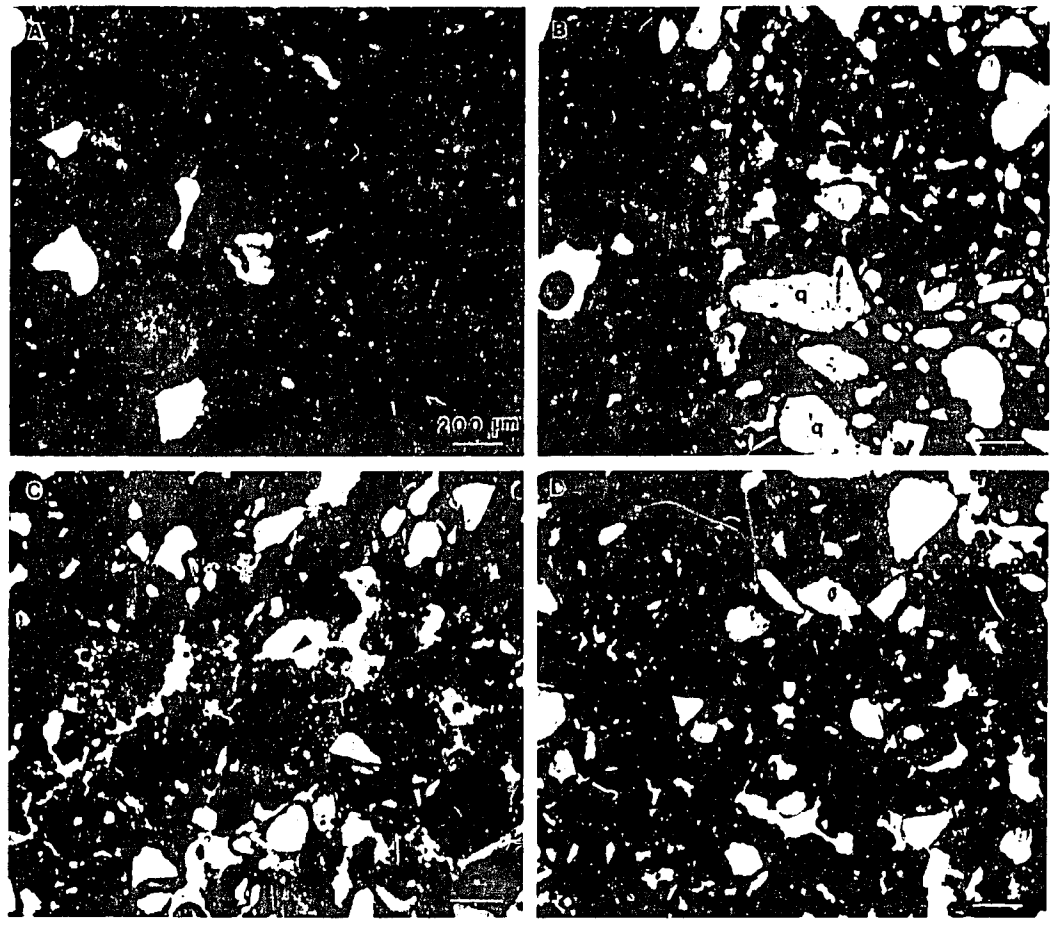

Photo 1: *Optical micrographs of the thin sections of plateau ironstone viewed under plain polarized light.*
(A) oolites in ironstones; (B) edge of oolitic ironstone in ferruginous sandstone; (C) and (D) ferruginous sandstone. Note the irregular, corroded quartz grains (q) in the hematitic plasma and the lining of kaolinite and goethite along void walls (arrows in C)

are imbedded in goethite plasma.

3.2 Terrace

In places, the plateau cap has been eroded and the valley has a terrace constructed of cemented laterite and siliceous gravels at a lower elevation. In general however, the terrace does not exist and a coalescing alluvial fan surface (bajada, in the Southwestern U.S.) is present on either side of the valley. The slope of this surface is 5-10%. Approximately 30-50% of the fan surface is covered with ironstone gravels derived from the mesas. The fan sediments are yellowish red (5YR 4/8 to 5/6 (moist) and of sandy loam to sandy clay loam texture, reflecting pigmentation by the Fe oxides of the plateau ironstone and the contribution of the clayey sandstone

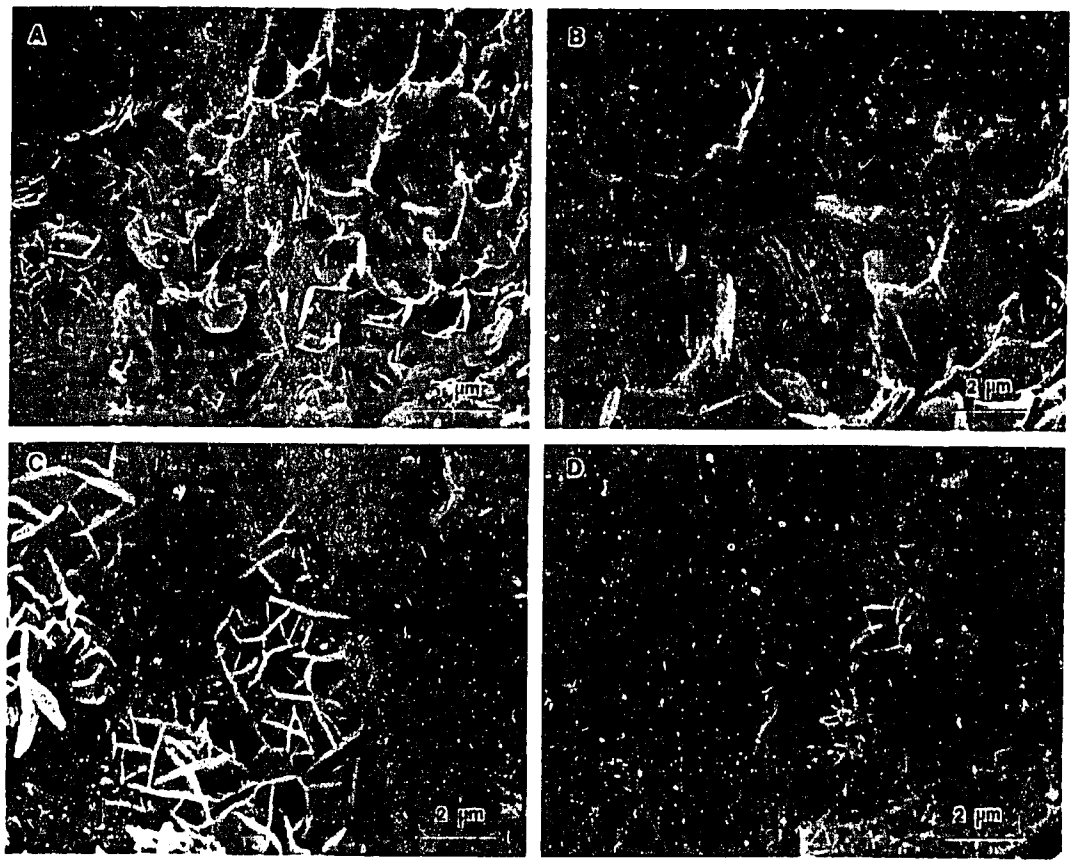

Photo 2: *Scanning electron migrographs of plateau ironstone showing hematite crystal intergrowths.*
Crystal rosettes (A and B) and boxwork-like arrangements (C and D) are common.

cement. The alluvial fan surface is separated from the valley sediments proper by an entrenched stream on either side of the valley.

Remnants of a terrace capped by cross-bedded, very well-rounded, smooth-surfaced ironstone and quartz gravels of 0.5–3 cm in diameter and cemented by Fe oxides were found near Itchigin (fig. 1), about 10 m above the valley floor. The ironstone gravels have a dark gray metallic luster. In the vicinity, a similar terrace deposit had been mined and used for road-bed material.

The dominant Fe oxide in these terrace gravels is goethite with hematite second (fig. 3C). Their Fe oxide mineralogy is different from that of the hematitic plateau cap and scanning electron micrographs (photo 3) show their morphology to be different also. From the WHH of the 111 reflection of goethite, the MCD is estimated to be 30 nm. Goethite crystals appear to radiate within a botryoidal structure (photo 3B) or to be arranged in ridges inside the gravel (photo 3D).

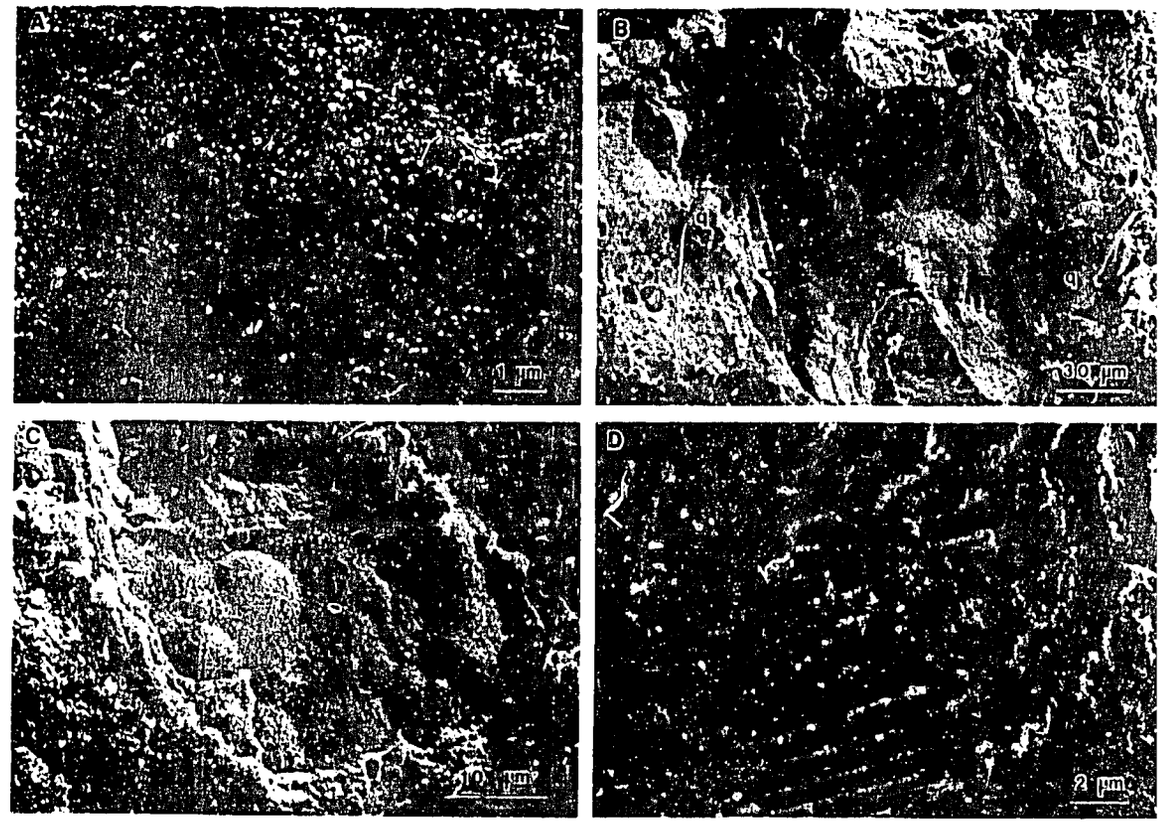

Photo 3: *Scanning electron micrographs of ironstone gravels at Itchigin.*
(A) Close-up of lustrous, smooth surface showing rounded ends of acicular goethite crystals; (B) and (C) Botryoidal growth of radiating, acicular crystals inside gravel. (D) Ridge-like arrangement of goethite crystals inside gravel. Note the incorporation of some quartz grains (q) in (B).

3.3 Valley

Dunal sands cover about 80% of the valley floor. The dunal micro-relief ranges from 1 to 6 m. In the middle and southern reaches of the valley, 2-4 m of fine to medium dunal sands overlie a series of coarser textured fluvial material (BUI 1986). Channels cover an increasing percentage of the valley surface in the southern part. Channel deposits consist of 1–1.5 m of sandy clay over sand, or they can be sandy throughout. Many of the ancient channels are plugged by sand and form closed depressions that are often alkaline and gleyed where the water table is shallow.

Divalent Fe is present in the ground water of the Dallol Bosso as indicated by dark greenish gray (5GY 4/1 to 5Y 3/2 (m)) gleyed horizons (SCHWERTMANN 1985) and by strong positive reaction to α, α-dipyridyl. Suspended residue isolated from a ground water sample was magnetic and contained a mixture of maghemite and hematite (fig. 3D & photo 4). The green-rust Fe(II,III)-hydroxysalt precursor of maghemite is suggested in the

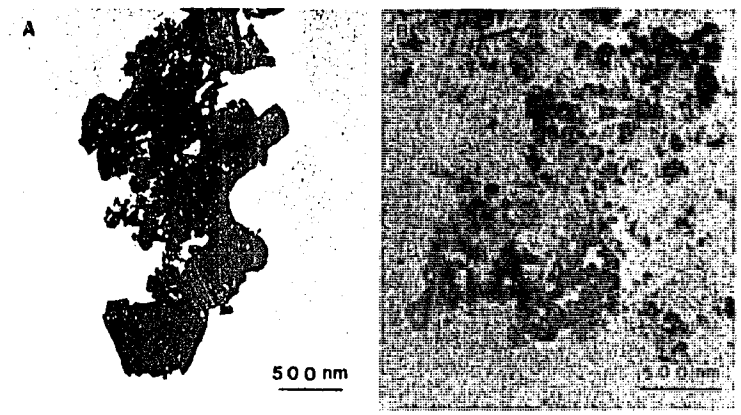

Photo 4: *Transmission electron micrographs of (A) magnetic residue from groundwater, shwoing maghemite-hematite association; (B) clay from the Bg-horizon of a Halaquept (BUI & WILDING 1988) before NH_4-oxalate extraction of iron.*
The dark, electron-dense, circular particles are believed to be maghemite.

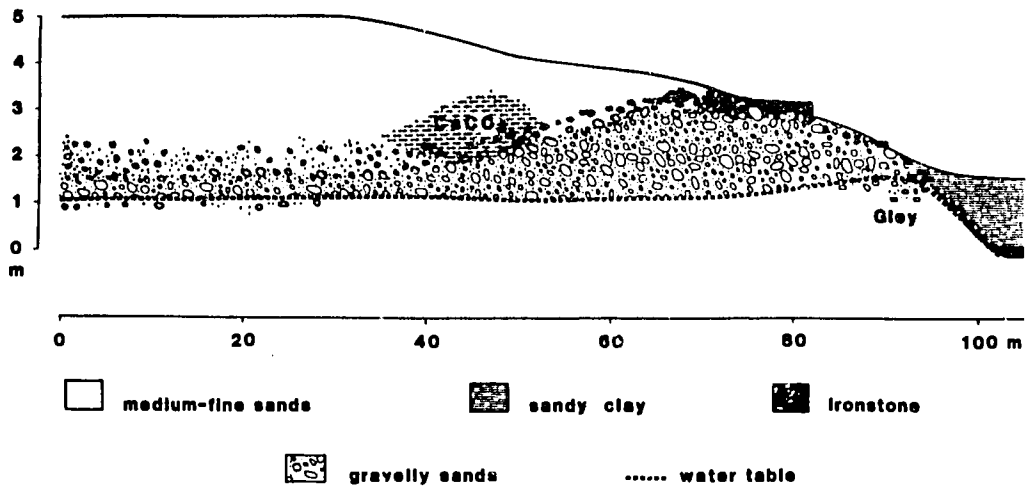

Fig. 4: *Cross-section showing sheet ironstone at the base of a dune.*

gleyed horizon because of a color change to brown on exposure to air (BUI & WILDING 1988). Maghemite contains some structural Fe(II) and its occurrence with hematite probably reflects the presence of both Fe(II) and Fe(III) with fluctuations in the micro-aeration of the capillary fringe at the top of the water table (TAYLOR & SCHWERTMANN 1974).

Sheet ironstone or "ground-water laterite" is found at the base of the eolian sands along the edges of former channels (fig. 4). These ironstone sheets tend to cover areas of a few square meters. Their thickness varies from about 10 cm to 30 cm and they grade into pisolitic

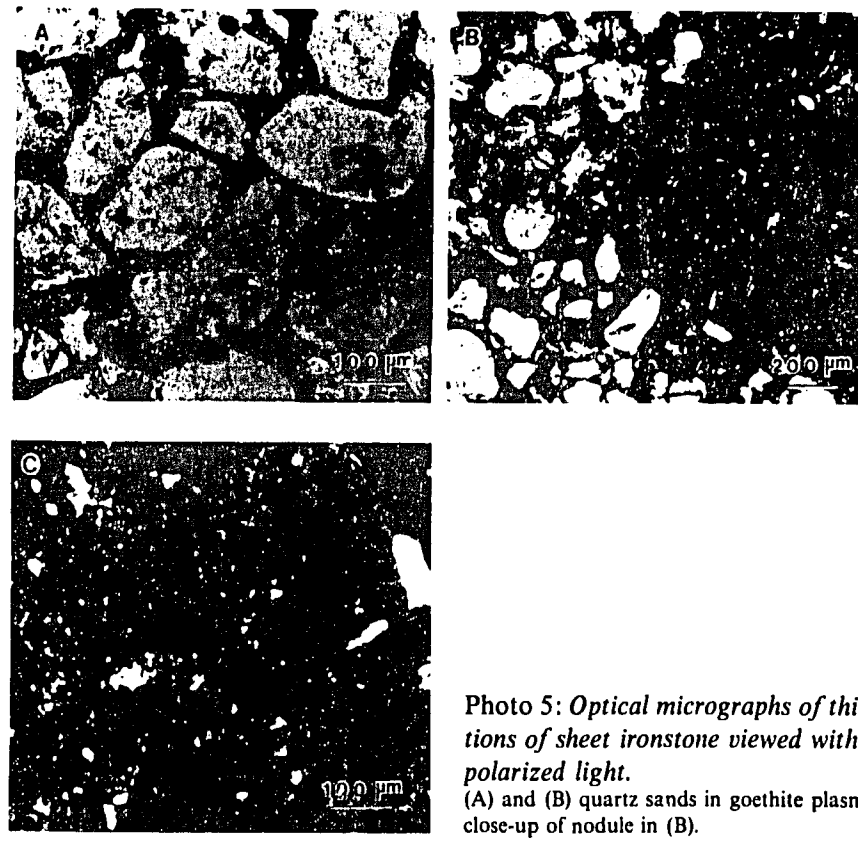

Photo 5: *Optical micrographs of thin sections of sheet ironstone viewed with plain polarized light.*
(A) and (B) quartz sands in goethite plasma; (C) close-up of nodule in (B).

Photo 6: *Scanning electron micrograph of sheet ironstone from the village of Tinoma near Birni'n'Gaoure.*

gravels as they extend back under the dune. Their color is yellowish brown (10YR 5/6) to strong brown (7.5YR 5/8 (d & m)). The ironstone morphology is alveolar, with vertically oriented cavities and branches. The ironstone consists of a skeleton of quartz sands and gravels cemented by goethite (fig. 3E & photo 5) that are not merely fragments of recemented plateau ironstone. The estimated MCD from the WHH of the 130 reflection of goethite is 32 nm. Scanning electron micrographs do not reveal individual crystals of goethite but rather, globules of variable sizes (photo 6).

4 Discussion

4.1 Plateau

The ferruginous sandstone cap of the plateau, which is interpreted as the result of erosion and redeposition of the original oolitic beds, is probably post-Miocene in age since the oolitic iron layers were interbedded with the Eocene-Miocene Continental Terminal formation. It is older than the incision of the dallol. The size, shape, arrangement and color of the hematite crystals are consistent with the considerable age implied from the stratigraphic and geomorphic records. Oolitic ironstones similar to the one studied here are described by ADETUNJI & KOGBE (1987) in northwestern Nigeria. On the basis of lithology and trace fossil evidence, ADETUNJI & KOGBE (1987) argue convincingly that oolites they studied are unlikely to have formed during a process of lateritization. Although NAHON et al. (1980) have shown that ferruginous oolites can form as a consequence of lateritic weathering, our evidence supports the interpretation of ADETUNJI & KOGBE (1987). The oolites are of regular size and shape; they are not deformed; and they are not intergrown with one another. The edges of oolitic blocks show that the oolites are broken and that the contact between the blocks and the groundmass is sharp. All these observations suggest that the oolites are not growing in situ and the development of the ferruginous sandstone is a result of erosion, redeposition and cementation of the oolitic beds.

4.2 Terrace

The gravels of the terrace near Itchigin are likely derived from a topographically higher, hematitic, ferruginous ironstone and have undergone a hematite-to-goethite transformation since erosion and deposition. It is unfortunately not possible to correlate this gravelly terrace with any of the dated terraces in the Air and Hoggar mountains. On the basis of texture, which can be extremely variable depending on depositional environment, it may be equivalent to T3, the middle terrace of the Air mountains (DURAND et al. 1983), whose age is estimated between 30,000 and 6,500 years B.P.

4.3 Valley

Under the present climate, the following mechanism for the formation of sheet ironstone in the Dallol Bosso is proposed. Free Fe oxides present in the fluvial parent material of local soils (BUI 1986) and Fe-rich dust infalls serve as sources of Fe. The Fe is anaerobically reduced by microorganisms and transported as Fe(II) in the ground water. The Fe(II) is oxidized and Fe(III) oxides are concentrated at the fine to coarse layer interface by evaporation which is strongest along the edges of channels.

The zone at the base of the dune is impregnated and hardens to ironstone as the Fe oxide crystals grow (SHADFAN et al. 1985). The ironstone thickens and hardens as the wet and dry cycles are repeated for many years.

Similar alveolar ironstones in low topographic positions have been reported throughout the Sahel (CLARK et al. 1973; HERVIEU 1977; MALEY 1981; DURAND et al. 1983) and have been estimated mid-Holocene (i.e. 6,000-4,500 years B.P.) in age. This type of ironstone can form in decades (MAIGNIEN 1954), and it is unlikely that it is as old as mid-Holocene in the Dallol Bosso. Ground water laterite forms along channel banks in the valley, at the base of dunes developed on a young terrace. This terrace is possibly correlated to terrace T5 upstream in the Air mountains which is estimated to be 1,000 years of age (DURAND et al. 1983). Even though the climate of the last 200 years has been trending toward increasing aridity in the Sahel (MALEY 1981) and this is probably enough time for the Dallol Bosso ironstone to have formed, it is possible that not all ironstone in the valley is the same age. Ironstone formation there depends more on local geochemical and hydrological processes than on general climate.

In the oxidized section of some channel soils, goethite pedotubules and Fe-rich smectite are present (BUI & WILDING 1988). The driving force behind the neoformation of the Fe-rich smectite appears to be a geochemical process active under the semi-arid climate. Under the high evapotranspiration of this climatic regime, Na-carbonates accumulate at the soil surface by capillary rise and generate a high pH environment that, in turn, leads to the solubilization of silica. In the poorly-drained, Fe-rich environment, silica is believed to recombine with Fe and other cations to form an Fe-rich smectite (BUI & WILDING 1988). The goethite pedotubules are believed to be relict features having precipitated around the roots of aquatic plants in a waterlogged environment.

5 Conclusions

In the Dallol Bosso, iron oxide properties are correlated with position in the landscape. Although mineralogy is not strictly associated with one position, hematite is more abundant in the high plateau and goethite in the lower positions. The oxides with orderly structural arrangements of crystals are found on the older plateau and terrace surfaces while the oxides with more disorderly arrangement of crystals occur in the younger valley.

The presence of Fe(II) in the ground water and of several Fe-oxide phases in the valley indicate an active process of Fe movement and oxide precipitation. There is an abundant reservoir of Fe in the plateau ironstones that may be slowly released by physical and chemical weathering. Although the source of the Fe is speculative, secondary Fe phases are likely to continue to form as the Dallol Bosso landscape evolves. The diverse occurrences of Fe compounds in the Dallol Bosso landscape underscores the complex genetic history of ironstone deposits in West Africa and the danger of using ironstone as an indicator of paleoclimate on a regional rather than a local scale.

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References

ADELEYE, D.R. (1973): Origins of ironstones, an example from the middle Niger valley, Nigeria. Journal of Sedimentary Petrology, **43**, 709–727.

ADETUNJI, J.R. & KOGBE, C.A. (1987): Geology, paleoclimatology and laterite genesis in the Gada sector of the Trans-Saharan seaway in northwestern Nigeria. Journal of African Earth Sciences, **6**, 643–653.

BREWER, R. (1976): Fabric and Mineral Analysis of Soils. J. Wiley & Sons, New York. 1–482.

BUI, E. N. (1986): Relationships between Pedology, Geomorphology and Stratigraphy in the Dallol Bosso of Niger, West Africa. Ph.D. dissertation. Texas A&M University. 1–226.

BUI, E. & WILDING, L. P. (1988): Pedogenesis and mineralogy of a Halaquept soil of Niger (West Africa). Geoderma. **43**, 271–287.

CLARK, J.D., Williams, M.A.J. & A.B. Smith. (1973): The geomorphology and archaeology of Adrar Bous, Central Sahara: a preliminary report. Quaternaria, **17**, 245–297.

DONAINT, P. (1975): Les Cadres Geographiques a travers les Langues du Niger. IRSH, Niamey, Niger. 1–287.

DUBOIS, D. (1979): Etude geologique de formations oolitiques ferrugineuses du bassin des Iullemmeden. These de doctorat de 3eme cycle. Universite de Niamey (Niger) et d'Orleans (France). 1–123.

DURAND, A., LANG, J., MOREL, A. & ROSE, T. J.-P. (1983): Evolution geomorphologique, stratigraphique et paleoclimatique au Pleistocene superieur et a l'Holocene de l'Air oriental (Sahara meridional, Niger). Rev. Geol. Dyn. Geogr. Phys. **24**, 47–59.

GAVAUD, M. (1977): Les Grands Traits de la Pedogenese au Niger Meridional. Travaux et Documents de l'O.R.S.T.O.M. no. **76**, O.R.S.T.O.M., Paris. 1–102.

GOUDIE, A. (1973): Duricrusts in Tropical and Subtropical Landscapes. Clarendon Press, Oxford. 1–174.

GREIGERT, J. (1966): Descriptions des Formations Cretacees et Tertiaires du Bassin des Iullemmeden (Afrique Occidentale). Bureau de Recherches Geologiques et Minieres, Paris. 1–234.

HERVIEU, J. (1977): Temoins paleoclimatiques et environnement prehistorique dans le massif de Termit (Niger Oriental). Cah. ORSTOM, ser. Geol. **IX**, 3–14.

INNES, R. P. & PLUTH, D. J. (1970): Thin section preparation using epoxy impregnation for petrographic and electron microprobe analysis. Soil Science Society of America Proceedings **34**, 483–485.

KOGBE, C.A. (1978): Origin and composition of the ferruginous oolites and laterites of North-Western Nigeria. Geologische Rundschau **67**, 662–674.

LEPRUN, J. C. (1981): Some principal features of ironcrusts in dry Western Africa. In: Lateritisation Processes. Proceedings of the International Seminar on Lateritisation Processes, Trivandrum, India. A.A. Balkema, Rotterdam. 144–153.

MAIGNIEN, R. (1954): Differents processus du cuirassement en A.O.F. In: C. R. 2eme Conference Interafricaine des Sols, Leopoldville, Belgian Congo. 1469–1486.

MAIGNIEN, R. (1966): Review of Research on Laterites. UNESCO, Paris, 1–154.

MALEY, J. (1981): Etude palynologique dans le bassin du lac Tchad et paleoclimatologie de l'Afrique nord-tropicale de 30,000 ans a l'epoque actuelle. Travaux et Documents de l'ORSTOM No. 129. ORSTOM, Paris.

MICHEL, P. (1973): Les bassins des fleuves Senegal et Gamie. Etude geomorphologique. Memoire O.R.S.T.O.M. No. **63**.

NAHON, D. (1976): Cuirasses ferrugineuses et encroutements calcaires au Senegal occidental et en Mauritanie. Systemes evolutifs: geochimie, structures, relais et coexistence. Memoires de Sciences Geologiques No. **44**. Strasbourg, 1–232.

NAHON, D., CAROZZI, A. V. & PARRON, C. (1980): Lateritic weathering as a mechanism for generation of ferruginous ooids. Journal of Sedimentary Petrology **50**, 1287–1298.

SHADFAN, H., DIXON, J.B. & CALHOUN, F.G. (1985): Iron oxide properties versus strength of ferruginous crust and iron-glaebules in soils. Soil Science **140**, 317–325.

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SCHWERTMANN, U. (1985): The effect of pedogenic environments on iron oxide minerals. In: B.A. Stewart (ed.), Advances in Soil Science, Volume 1 Springer-Verlag, New York, 171-200.

SOMBROEK, W.G. & ZONNEVELD, I.S. (1971): Ancient Dune Fields and Fluvia-tile Deposits in the Rima-Sokoto River Basin (N.W. Nigeria). Soil Survey Papers No. 5. Soil Survey Institute, Wageningen, The Netherlands, 1–109.

TAYLOR, R. M. & SCHWERTMANN, U. (1974): Maghemite in soils and its origin. I. Properties and observations on soil maghemite. Clay Minerals **10**, 289–298.

TORRENT, J. & SCHWERTMANN, U. (1987): Influence of hematite on the color of red beds. J. of Sedimentary Petrology **57**, 682–686.

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