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Relief inversion in the geomorphological evolution of sub-Saharan West Africa

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ABSTRACT

The geomorphology of much of sub-Saharan West Africa is dominated by the presence of plateaux and plains with ferruginous and, locally, aluminous (bauxitic) duricrusts. The plateaux occur at different elevations and have been correlated as two or more palaeosurfaces across much of the region. The duricrusts have generally been considered to be residual, formed by conformable erosion and chemical wasting of immediately underlying bedrock. This concept has been central to interpretations as diverse as the formation and evolution of the landscape and the development of geochemical exploration models. Recent regolith landform mapping, field observations and experience from mineral exploration in southern Mali and Burkina Faso, however, demonstrate that the duricrusts are mainly ferricretes, i.e., Fe oxide-cemented sediments. These observations require a re-interpretation of the geomorphological evolution of the region during the Cenozoic. The landscape has evolved by several cycles of weathering and erosion–deposition, triggered by climatic, tectonic or other environmental changes. It is proposed that an initial bauxitic/lateritic regolith was partly eroded following uplift and/or a change to a more arid climate, and that the detritus, rather than being removed, was deposited on slopes and valleys. During a subsequent humid period of lateritic weathering, Fe oxide cementation of this detritus formed ferricrete. Dehydration and hardening of the ferricrete after further uplift or aridity increased its resistance to erosion, resulting in relief inversion, with the detritus, in turn, being deposited downslope. This too has been weathered and cemented, to form a younger ferricrete. The occurrence of ferricrete landforms in adjacent countries, noted by field observation and inferred from satellite imagery, demonstrates that relief inversion is a very widespread and important phenomenon in southern Mali, Burkina Faso and adjacent countries in semi-arid West Africa.

1. Introduction

Interest in the geomorphology of sub-Saharan West Africa (Senegal, southern Mali, Burkina Faso and northern Côte d'Ivoire, Fig. 1) over the past 50 years has focussed on the origins of the plateau landforms and the deeply weathered regolith and duricrusts developed on them. At a practical level, the studies have investigated properties related to soil formation and their impact on agricultural production, the development of secondary mineral deposits (e.g., bauxite) within the regolith, and addressed the challenges posed to exploration for bedrock mineralization concealed by the regolith. Three broad scenarios have been developed for the formation of the plateaux and the regolith.

1: Michel (1973) observed and defined a succession of surfaces at different elevations and ages, ranging from the Labé surface at 1400–850 m near Fouta Djallon, Guinea, to the lowest pediment associated with alluvial plains in the valleys of the present major rivers (Fig. 2). The three highest and oldest surfaces (Labé, Dongol-Sigon and African) have aluminous (bauxitic) duricrusts, whereas the more widespread lower surfaces (Haut-glacis, Moyen-glacis) have ferruginous duricrusts. The lowest surface (Bas-glacis) is still developing. These surfaces have subsequently been mapped throughout the region (see Tardy, 1997). King (1962) observed similar plateaux in southern Africa, considering that each represented an erosional surface that could be related to a particular age, climatic episode and period of epeirogenic uplift. He correlated these plateaux across the African continent and, indeed, between continents, developing a comprehensive model for landscape development. Michel's Labé surface may correlate with King's Gondwana surface (Gunnell, 2003).

2: Zeegers and Leprun (1979) considered there is only one undulating ferruginous (lateritic) surface and the duricrusts at the different levels merge laterally. This surface developed under humid conditions, and has been partly eroded during a later arid phase. The possible equivalence of the bauxitic and lateritic surfaces was left open.

3: Burke and Gunnell (2008) proposed that there is a single composite African surface (combining the Labé, Dongol-Sigon and African surfaces of Fig. 2) with bauxitic duricrusts, and one or more lower surfaces with lateritic duricrusts. They postulated that the bauxites formed at 70–40 Ma at quite low elevations under very humid climates. After 34 Ma, epeirogenic tectonism led to the formation of the African basin and swell structure (Fig. 3A), causing major changes to erosional base levels that terminated the formation of the African

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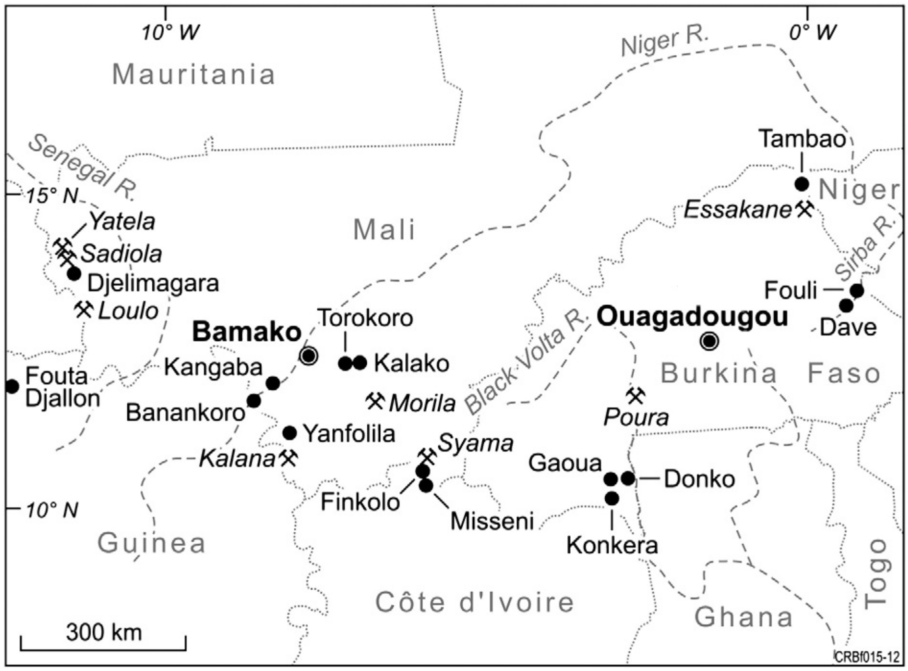

Fig. 1. Map showing locations of the Djelimagara and Misséni-Finkolo mapping areas and other sites mentioned in the text.

surface. Domed swells in Senegal, Guinea, Côte d'Ivoire and Nigeria locally uplifted this surface by over 1 km, whereas the basin in northern Mali, Burkina Faso and Niger formed a depression. On the flanks of the swells, partial erosion of the African surface, and ongoing weathering forming new surfaces at lower elevations, gave rise to the stepped plateaux landscape. Due to a change to a less humid climate, the later surfaces are ferruginous not bauxitic.

In first two scenarios, altitude indicates age, with the highest surface being the oldest, and lower, younger, surfaces formed after erosion triggered by climate change. In the third scenario, altitude is largely a function of tectonism which, together with climate change, also caused instability and erosion. In each scenario, the regolith on the surfaces is interpreted to have formed by intense chemical weathering under humid conditions. Argon–argon dating of Mn oxides at Tambao, northern Burkina Faso, suggests several episodes of weathering from the Palaeocene to Pliocene, ages that have been tentatively ascribed to each of the surfaces (Beauvais et al., 2008).

Tardy (1997) and many other workers consider that the landscape evolved conformably, that is, chemical wasting and erosion caused surfaces at different elevations to be lowered parallel to themselves, at different rates. The duricrusts are generally thought to be residual, formed from the immediately underlying bedrock. Although this is the generally prevailing view, some authors (e.g., Maignien, 1966; Thomas, 1994) advocated a role for relief inversion. They noted that iron leached from upper slopes can be precipitated as oxides in valley sides and floors, in both residual and transported regolith. As the landscape evolved, the iron oxides indurated the matrix which became resistant to erosion, resulting in relief inversion. Tardy (1997) considered this to be a localized phenomenon, whereas for Pain and Ollier (1980) and Bolster (1999), it is an important

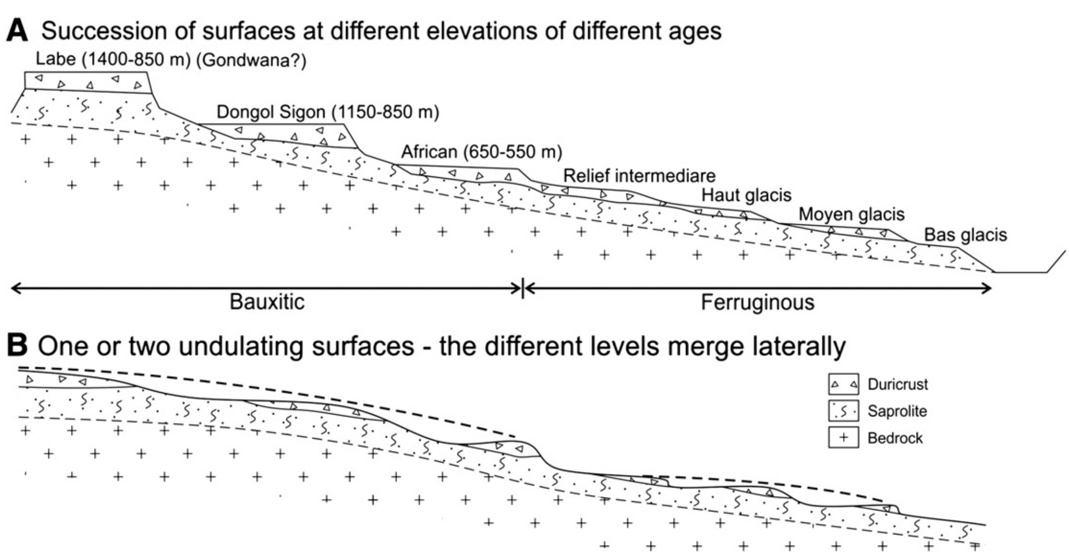

Fig. 2. Interpretation of plateau landscapes in West Africa. (A) Each plateau level is regarded as being of a distinct relative elevation and age (Michel, 1973; Tardy, 1997). Modified after Gunnell (2003). (B) There are two groups of plateaux of similar ages, developed on an undulating surface and/or subject to later upwarping (Zeegers and Leprun, 1979).