Introduction

A paleosol or fossil soil is a soil that formed on a landscape of the past. Soils form because of the physical, biological and chemical modification of sediment or rock exposed at the earth surface (Kraus, 1999). The qualitative and quantitative applications of paleosols to paleoenvironmental interpretations have been fully discussed in Kraus (1999) and Sheldon and Tabor (2009). Paleosols are in most cases assumed to be a product of alluvial settings. Two lithologic sections of the Lower Bima member of the early Cretaceous Bima Sandstone have been logged and the result shows occurrence of calcrete Paleosols in the Bima Hill section and ferruginous soil in the Wuyo section. The calcrete occurs in two forms: immature white calcrete peds and crystalline mature calcrete nodules with associated slickenslides. Both the peds and the nodules were formed under semi-arid to arid climatic conditions and are interpreted as representing diastem surfaces within the Lower Bima member. The slickensides is inferred to be of tectonic origin. The ferruginous soil of the Wuyo section also represents semi-arid climatic conditions and marks an interval of sub aerial exposure at the upper boundary of the Lower Bima member.

Keywords: lower Bima member, calcrete paleosols, diastems, semi-arid

Stratigraphic Setting

The Early Cretaceous continental Bima Sandstone unconformably overlies the Pan African basement rocks over most of the Upper Benue Trough (Carter et al., 1963; Guiraud, 1990; Zaborski, 1998). In most places it represents by far the greatest proportion of the lithostratigraphic succession in the Upper Benue Trough (Zaborski, 1998). The formation is divided into three silicilastic members: lower (B1); middle (B2); upper (B3) members (Guiraud, 1990). The protorift tectonostratigraphic sequence, the Lower Bima member, is a highly variable unit with an overall thickness of 0 to 1500m. Individual lithofacies distribution was controlled by synsedimentary tectonic activity which created a number of sub-basins with associated volcanism; lithofacies association within a sub-basin consists of conglomeratic alluvial fan/debris flow deposits, adjacent to active basin-forming faults grading laterally into fining upward successions and in places into...
lacustrine deposits with interbedded clays, fine-grained sandstone and calcareous sandstones (Zaborski et al., 1997). These successions may occur towards the axes of the sub-basins (Dike, 2002, Dike and Maigari, 2009). The Middle Bima member forms the post proto rift mega sequence and consists of gravels to coarse grained sandstones dominated by large scale trough cross-bedding. The middle Bima member is overlain by the medium to coarse-grained sandstones of the Upper Bima member. This member is comparatively homogeneous, consisting of a succession of tabular cross-bedded sandstones with overturned cross-bedding, convolute lamination and minor trough-cross stratification. These sands were probably deposited within large braided-stream systems.

Description of Lithostratigraphic Succession

**Bima Hill Section**

The Bima hill lithostratigraphic section (BHL) (Fig. 2) comprises of over 160m of sediments, located at the south-eastern part of Bima Hill. Four different lithofacies are defined on the basis of Miall (1978). (i) sandy mudstone (fm); (ii) calcrete (p); (iii) trough cross-bedded sandstone (st); (iv) massive sandstone (Gm); and (v) muddy sandstone facies. The fm facies is composed of reddish-gray sandy mudstone, it alternates with the st facies throughout the section. Bed thicknesses are variable; laterally they can be traced for a distance of over 1km. Many of the beds have been weathered but still retain the distinctive reddish-gray colour. The st facies is characterized by coarse grain size, trough cross-bedding, and sub rounded to rounded pebbles that are up to 50mm in size. Paleocurrent directions measured from imbricated pebbles show a dominant southeasterly transport direction. Some beds contain 30% to 40% of mud and are therefore referred to as muddy sandstone. The calcrete facies occurs at five stratigraphic horizons within the section. This facies is subdivided into three structural elements based on their level of calcretization. The first, immature element comprises white peds (Fig. 3) randomly dispersed within the fm parent material. The peds are platy, lensoid or blocky in

![Fig. 3](modified after Miall et al., 1981).
Fig. 2: Lithostratigraphic Succession Bima Hill Section.
shape and can measure up to 20mm in size. The second structural element is the nodular calcrete (Fig. 4). The nodules measure up to 13cm in diameter and result from the coalescence of peds. Characteristically, the nodules are white crystalline carbonate with wispy lines of reddish parent material (Fig. 5). In some instances, the nodules have hollows that contained the residues of the parent material (Fig. 6). Contacts between the first and the second elements are both sharp and gradational (Fig. 7). The third element is calcrete slickenside (Fig. 8). This structure is subdivided into small layers of 1-2mm by the sediments of the parent material. Slickenside formed on associated sandstone has similar orientation of striations (N58°E) with those of the calcrete slickenside, suggesting a tectonic origin of the element probably during the Albian tectonic episode that affected the Lower Bima Sandstone and related units in the Upper Benue Trough (Guiraud, 1993; Dike, 2002). Driesse and Foreman (1992) proposed that paleosol slickensides are formed in clay rich soils when swelling pressures exceed shear strength at a depth where vertical movement is confined, resulting in development of extensive slickensides (shear planes).

Wuyo Section
This section is 20m thick and is characterized by mudstone, trough cross-bedded sandstone and a ferruginous soil facies (Fig. 9). The latter is 13cm thick and overlies cross-bedded sand. It is highly indurated and dark reddish brown (10R3/4). The upper surface of the soil is brown-yellowish and smooth. East of the section, this upper part has been eroded and the fragments incorporated in to the lower part of the overlying mudstone facies (Fig. 10) making an erosional contact.
Fig. 4: Mature calcrete (nodules exposed), Bima Sandstone, Bima Hill Section, Upper Benue Trough.

Fig. 5: Reddish blue colour of the parent material in a calcrete nodule Bima Sandstone, Bima Hill Section, Upper Benue Trough.
Fig. 6: Hollow in the mature calcrete, Bima Hill Section, Upper Benue Trough

Fig. 7: Sharp contact between mature calcrete nodule (N) and immature calcrete (I), Bima Hill Section, Upper Benue Trough.
Discussion and Conclusion
Paleosols can form because of lengthy episodes of landscape stability in which case they may eventually mark stratigraphic diastems or unconformities (Kraus, 1999). The occurrence of calcrete paleosol in the Bima Sandstone indicates that there were episodes of sub aerial exposure characterized by processes such as wetting and drying; water table fluctuations; and carbonate and iron mobilization and precipitation (cf. Jockel, 1995). Three factors control the formation of paleosol carbonates: i) the position of the water table, ii) the host rock, and iii) the length of sub-aerial exposure (Alonzo-Zarza, 2003). Greensmith (1981) believed that the clay fractions of semi-arid soils are base-saturated, usually with calcium, and consequently tend to have a mildly alkaline reaction. Retention of carbonate in a soil profile requires alkaline soil solutions and a rate of evaporation that greatly exceeds mean annual precipitation (Mack, 1991).

The model for the calcrete paleosols in the Lower Bima member assumes there was a time interval in which climatic conditions fluctuated leading to the development of the paleosols: first, alluvial sedimentation was interrupted by a rise in climatic condition leading to the formation of the immature calcrete (first structural element). Following this, a period of climatic condition probably with precipitation of less than
### Lithostratigraphic Sequence of Bima Sandstone at Wuyo, Upper Benue Trough

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Sequence</th>
<th>Paleocurrent Process</th>
<th>Paleoenvironment</th>
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</thead>
<tbody>
<tr>
<td>Trough cross bedded sandstone</td>
<td>20m</td>
<td></td>
<td>Braid bar (straight crested dunes and current ripples)</td>
</tr>
<tr>
<td>Mudstone</td>
<td>15m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planer/tabular cross bedded sandstone</td>
<td>10m</td>
<td></td>
<td>Floodplain with avulsive channel</td>
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<tr>
<td>Massive sandstone</td>
<td></td>
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<td></td>
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<tr>
<td>Current ripples</td>
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<tr>
<td>Ferruginious paleosol</td>
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</tbody>
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**Fig. 9**: Lithostratigraphic sequence of Bima Sandstone at Wuyo, Upper Benue Trough
60cm/year (Mack, 1991) and an evaporative loss that exceeded the supply of water to the surface by rainfall or flooding (Reading, 1996). These climatic conditions lead to the formation of a bed of 5m thickness of mature calcrete paleosol. Reprecipitation of the immature calcrete ended the formation of the calcretes paleosol and possibly completed the cycle of calcrete sedimentation. This situation is characteristics of an arid to semi-arid climatic conditions (Mack, 1991). In the Wuyo area the sediments probably were not charged with calcareous material therefore long period of aridity resulted in a ferruginised sandstone bed, this bed has been eroded and the fragments incorporated in the basal part of the overlying mudstone facies. Thus, the surface between the ferruginised sand and the overlying mudstone is here interpreted as an erosional surface. Below the ferruginous soil, there is a bed containing pebbles and cobbles made up of quartz, pegmatitic and granitic rocks indicating incomplete chemical weathering that is associated with semi-arid situations or more likely very rapid erosion. Elsewhere, Guiraud (1990) gave similar conclusion on the Lower Bima member.

In conclusion, the first and the second structural elements of the calcrete paleosol defined diastems within the Lower Bima member at the Bima Hill area, while the ferrugineous soil at Wuyo signifies the occurrence of a horizon of prolonged sub aerial exposure at upper part of the Lower Bima member. Guiraud (1990) advocated for angular unconformity at this boundary, this interpretation may not be correct. The calcretes and the ferrugineous paleosols are strong indicators of a semi-arid condition during the deposition of the Lower Bima member in the area. Because of the association of these hiatuses with climatic conditions, they could probably be of regional magnitude.
REFERENCES


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