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Sedimentology and vertebrate taphonomy of the Moradi Formation of northern Niger: A Permian wet desert in the tropics of Pangaea

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ABSTRACT

Pangaean paleogeographic models place the Tim Mersoi basin of northern Niger in a 5000-km-wide corridor between Gondwana and Laurasia approximately 15 degrees south of the paleoequator. Late Permian paleoclimate models position this basin between tropical summer-wet to the north and desert to the south. Recent investigations of the fossil vertebrates and paleosols in the late Permian (Lopingian) Moradi Formation confirm that the climate was warm and hyperarid with highly seasonal monsoonal rainfall. Possibly as a result of these unusual "wet desert" conditions, the tetrapod fauna shows a high degree of endemism. This study tests existing paleoclimate models by providing additional data on sedimentary environments and vertebrate taphonomic processes. The Moradi red bed sequences accumulated in a gently subsiding sag basin to the west of the tectonically active Massif de l'Aïr. Low angle gravelly alluvial fans prograded westward from the massif and at times impinged on a large stable northward flowing meandering channel system. The interchannel mudrock sequences are over-thickened by the accumulation of loessic silts and preserve isolated skull and post crania of amphibians (*Nigerpeton* and *Saharastega*) as well as semi-articulated captorhinids (*Moradisaurus*). Detailed surface mapping of a fossil-rich exposure revealed an anastomosed network of loess-filled distributary channels incised into the floodplain mudrocks. This provided a locus for the accumulation and rapid burial of at least 15 associated skeletons of the pareiasaurian *Bunostegos*. Semi-permanent ponds are evidenced by patches of fissile red mudstone containing rare bivalves and spiral coprolites. In the distal floodplains away from the main river channels, the combination of a generally high groundwater table, warm mean annual temperatures, and deflation of fines from the floodplain surface promoted the formation of gypsiferous paleosols and end-point playa lakes. Carbonate-rich mud accumulated around the lake margins and provided ideal conditions for the imprinting and preservation of tetrapod trackways.

1. Introduction

Results of past computer-generated Pangaean climate models based on ocean–atmosphere circulation around the Permian continental configuration (e.g. Rees et al., 1999; Fluteau et al., 2001; Gibbs et al., 2002) have been compared with available climate-sensitive fossil and rock data (Fig. 1). These climate indicators and proxy data originate mainly from Permian strata in basins that were positioned in the mid and high latitudes of both northern and southern Pangaea (e.g., Ziegler et al., 1998; Rees et al., 1999). To date, there is little empirical data from Permian strata deposited in tropical and equatorial latitudes to compare with model-based studies. This study attempts to fill that knowledge gap.

The Moradi Formation of northern Niger is a terrestrial redbed sequence containing vertebrate, invertebrate, plant, and trace fossils that provide one among only a few opportunities to study the paleoecology of a central Pangaean basin (e.g., Ziegler et al., 1998; Ricardi-Branco, 2008). The Tim Mersoi and Iullemeden basins in which the Moradi Formation was deposited were located around latitude ~15° South, in a sub-equatorial region (indicated by the star on Fig. 1). According to existing models, the upper Permian Moradi Formation strata accumulated in an intracontinental basin in a transitional region between desert and tropical summer-wet rainfall regimes (e.g., Poulsen et al., 2007; Peyser and Poulsen, 2008; Tabor et al., 2011). In order to reconstruct depositional sedimentary environments, we report on a field investigation of the vertebrate-fossil-bearing intervals of the Moradi Formation that integrates sedimentary facies descriptions with taphonomic modes of *in situ* vertebrate fossils to reconstruct the depositional sedimentary environments.

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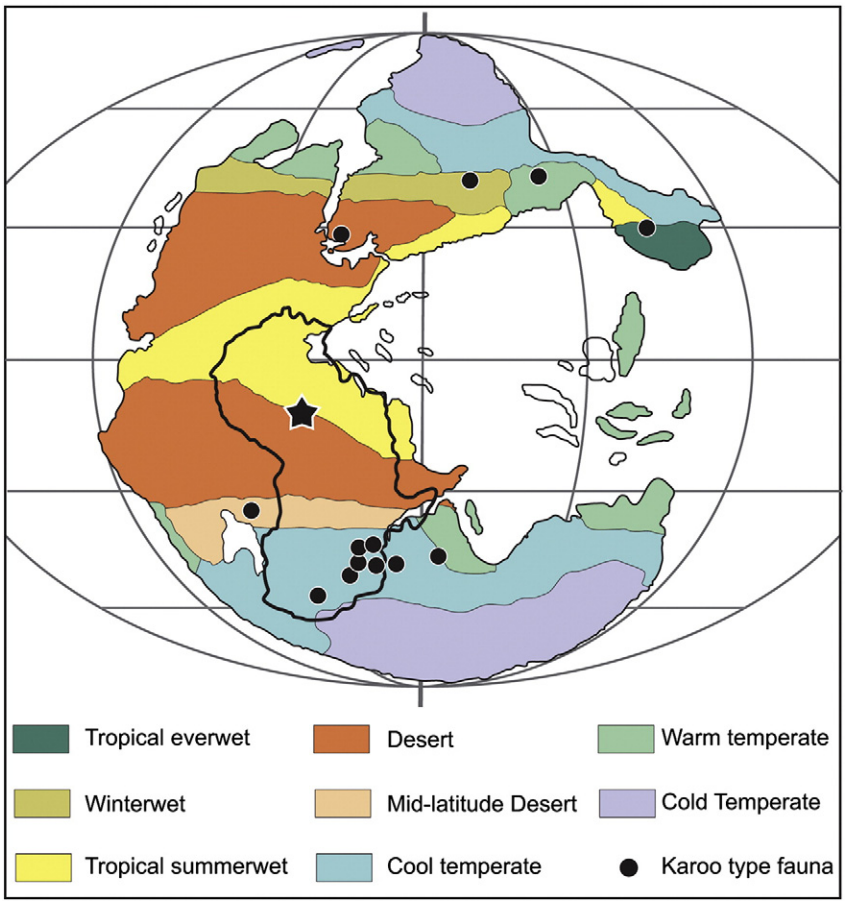

Fig. 1. Model-based paleoclimatic zones and distribution of Late Permian terrestrial vertebrate fossils in Karoo equivalent basins throughout Pangaea. The black star represents the Moradi fauna of northern Niger. Modified from Sidor et al. (2005) and Rees et al. (1999).

Our results agree with the Pangaean climate model for the late Permian and show that the transition between desert and summer-wet rainfall regimes in a continental lowland setting produced an unusual "wet desert" terrestrial habitat (Eriksson, 1981). This habitat is characterized by a warm hyperarid, sparsely vegetated landscape with a high groundwater table sustained by subsurface discharge from an adjacent highland. Sidor et al. (2005) demonstrated that the new Moradi temnospondyl taxa recovered during this study displayed relatively conservative characters and suggested that they belonged to an isolated refugial population that had probably been subjected to climatically induced endemism.

2. Geological setting

The upper Permian (260–252 mya) Izegouandane Group was deposited in the large Tim Mersoi sag basin to the west of Massif de l'Aïr, a tectonically active block of Precambrian basement rocks (Fig. 2B). The mechanism of uplift and subsidence is not well understood although it has been proposed that compressional forces resulting from the collision of Gondwana and Laurasia caused reactivation of deep-seated N-S aligned strike-slip faults in the underlying basement, leading to uplift of the Massif de l'Aïr and concomitant down-warping of the adjacent crust (Moreau et al., 1987). Orographic rainfall on the elevated fault scarps sourced numerous rivers that flowed west and north into the lowlands distributing their coarse- to fine-grained clastic load to the Moradi floodplains during warm and seasonally hyperarid climatic conditions (Tabor et al., 2011).

The Izegouandane Group consists of up to 250 m of nonmarine fluvio-lacustrine siliciclastics subdivided into four formations possibly representing different depositional loci on large low angle distributary fan systems (Fig. 2A). Lowermost is the gravelly-sandstone-dominated Izegouandane Formation, followed by the mudstone-dominated Teja, arenaceous Tamamaït, and uppermost, 100 m-thick siltstone with interbedded pebbly sandstones of the Moradi Formation (Wright et al., 1993). Moradi strata have been informally subdivided into lower, middle, and upper units based on sandstone–mudrock packages (Baudet et al., 1977; Tabor et al., 2011). The lower Moradi unit is composed of rubified mudstone with interbedded lenses of calcareous muddy sandstone and quartz-granule conglomerate. The middle unit consists of thick beds of muddy siltstone interbedded with red argillaceous sandstone, and the upper Moradi Formation is composed of red siltstones intercalated with linear intraformational channel lag conglomerates in the lower two-thirds of the unit, and toward the top, barchanoid-shaped lenses of conglomeratic sandstone with ventifacts.

3. Sedimentary facies and paleoenvironments of the vertebrate fossil-bearing localities in the upper Moradi Formation.

All of the late Permian tetrapods recovered to date have come from a 10-m-thick succession of red mudrocks with interbedded gravelly sandstones and rare limestone lenses in the upper Moradi Formation (See Fig. 3.). Fig. 4 shows the stratigraphic and sedimentological context of the fossils recovered by our team during the 2003 (prefix S) and 2006 (prefix T) expeditions (refer to supplementary Table 1 for details). The upper Moradi is composed of three distinctive associations of sedimentary facies which we interpret as having accumulated in discrete sub-environments of the Moradi alluvial plain. They are facies association (A) high sinuousity stream-channel fill and point bar, (B) loessic floodplain and incised distributary channels, and (C) end-point playa (see Fig. 4).