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Position of the Triassic–Jurassic boundary and timing of the end-Triassic extinctions on land: Data from the Moenave Formation on the southern Colorado Plateau, USA

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ABSTRACT

Strata of the Moenave Formation on and adjacent to the southern Colorado Plateau in Utah–Arizona, U.S.A., represent one of the best known and most stratigraphically continuous, complete and fossiliferous terrestrial sections across the Triassic–Jurassic boundary. We present a synthesis of new biostratigraphic and magnetostratigraphic data collected from across the Moenave Formation outcrop belt, which extends from the St. George area in southwestern Utah to the Tuba City area in northern Arizona. These data include palynomorphs, conchostracans and vertebrate fossils (including footprints) and a composite polarity record based on four overlapping magnetostratigraphic sections. Placement of the Triassic–Jurassic boundary in strata of the Moenave Formation has long been imprecise and debatable, but these new data (especially the conchostracans) allow us to place the Triassic–Jurassic boundary relatively precisely in the middle part of the Whitmore Point Member of the Moenave Formation, stratigraphically well above the highest occurrence of crurotarsan body fossils or footprints. Correlation to marine sections based on this placement indicates that major terrestrial vertebrate extinctions preceded marine extinctions across the Triassic–Jurassic boundary and therefore were likely unrelated to the Central Atlantic Magmatic Province (CAMP) volcanism.

1. Introduction

The end of the Triassic has long been described as the time of one of the "big five extinctions," one of the most devastating mass extinctions of the Phanerozoic (Sepkoski, 1982). However, the hypothesis of a single end-Triassic extinction of overwhelming suddenness and severity has been questioned, and some workers propose instead that the latest Triassic records a series of extinctions that are poorly resolved stratigraphically (Hallam, 2002; Tanner et al., 2004; Lucas and Tanner, 2008; Deenen et al., 2010). Given that the end-Triassic extinctions took place on both land and in the sea, the correlation of terrestrial and marine events across the Triassic–Jurassic boundary (TJB) is crucial to distinguishing the chronology of the extinctions (Lucas and Tanner, 2007b).

We have extensively studied one of the world's best known and most stratigraphically continuous, complete and fossiliferous terrestrial sections across the TJB—strata of the Moenave Formation on and adjacent to the southern Colorado Plateau in Utah–Arizona, USA (Fig. 1). We present here an analysis of new biostratigraphic and magnetostratigraphic data collected from the Moenave Formation across its outcrop belt, from the St. George area in southwestern Utah to the Tuba City area in northern Arizona (Fig. 1), including palynomorphs, conchostracans and vertebrate fossils (bones and footprints) and the polarity record of four magnetostratigraphic sections. Two localities where the upper, Whitmore Point Member of the formation is well exposed – Johnson Farm in Utah and Potter Canyon in Arizona – are of particular biostratigraphic importance (Fig. 1).

Placement of the TJB in strata of the Moenave Formation has long been imprecise and debatable, but new biostratigraphic and magnetostratigraphic data allow us to place the TJB relatively precisely (within a few meters) in the middle part of the Whitmore Point Member of the Moenave Formation (Fig. 2). This placement has important implications for the timing of the end-Triassic extinctions, and supports the conclusion that terrestrial vertebrate extinctions preceded marine extinctions at the end of the Triassic Period and are unrelated to the CAMP eruptions.

2. Study area, lithostratigraphy and database

Strata of the Moenave Formation, the basal formation of the Glen Canyon Group (Harshbarger et al., 1957), are exposed in southwestern

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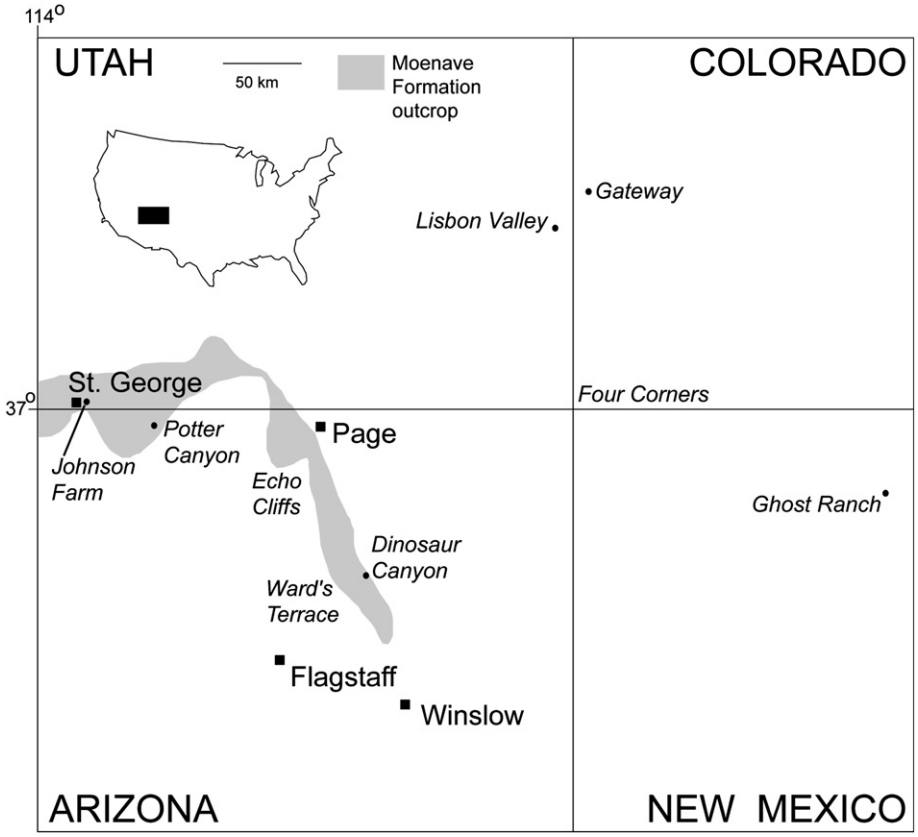

Fig. 1. Map of part of the southern Colorado Plateau (inset map shows location in USA) showing Moenave Formation outcrop belt and localities mentioned in the text.

Utah and northwestern Arizona, north of the Grand Canyon, and to the southeast on the Navajo Nation in north-central Arizona (Fig. 1). The Moenave Formation encompasses two members—the Dinosaur Canyon and Whitmore Point. The widespread, mixed fluvial and eolian Dinosaur Canyon Member both underlies and is (in its upper part) laterally equivalent to the dominantly lacustrine Whitmore Point Member, which has a much more limited outcrop area (Lucas and Tanner, 2007a; Tanner and Lucas, 2007, 2009) (Fig. 2). The Moenave Formation rests disconformably on Upper Triassic strata of the Owl Rock Formation of the Chinle Group, and some of its lowermost strata (basal part of the Dinosaur Canyon Member) are laterally equivalent to the upper part of the Rock Point Formation of the Chinle Group, strata that also disconformably overlie the Owl Rock Formation (Fig. 2). The Owl Rock–Moenave/Rock Point unconformity was long termed the J-0 unconformity because it was thought to coincide with the TJB (Pipiringos and O'Sullivan, 1978), but it is now referred to as the Tr-5 unconformity, a within-Triassic hiatus (Lucas, 1993, 1997; Lucas and Tanner, 2007a). The Springdale Sandstone Member of the Kayenta Formation disconformably overlies the Moenave Formation at the sub-Springdale unconformity (Marzolf, 1994; Lucas and Tanner, 2006).

Across its outcrop belt, the Moenave Formation is about 100 m thick and is mostly fine-grained sandstone, siltstone and shale (Harshbarger et al., 1957; Wilson, 1967; Tanner and Lucas, 2007, 2009, 2010). The thickest part of the formation is the Dinosaur Canyon Member, a succession of brightly colored, reddish-orange to light brown, eolian and fluvial sandstone and siltstone beds. In the Moenave type section, near Tuba City, Arizona, the formation consists entirely of the Dinosaur Canyon Member, as it does throughout the Moenave outcrop belt in the Navajo Nation of northern Arizona. However, north of the Grand Canyon in Arizona and in southwestern Utah (i.e., St. George area), the upper part of the Moenave Formation comprises the lacustrine strata of the Whitmore Point Member (Wilson, 1967)—laminar gray, ocher and red shale and siltstone up to 26 m thick.

On the Navajo Nation lands, the lower part of the Dinosaur Canyon Member grades laterally into the upper part of the Rock Point Formation, which is generally included in the Chinle Group (Harshbarger et al., 1957; Lucas and Tanner, 2007a), although some authors now consider it the basal unit of the Glen Canyon Group (e.g., Marzolf, 1994; Dickinson and Gehrels, 2009). To the east of the Moenave outcrop belt, in the Four Corners, the Wingate Sandstone is the lateral equivalent of the Moenave Formation (Harshbarger et al., 1957; Edwards, 1985; Clemmensen et al., 1989; Tanner and Lucas, 2007) (Fig. 2). The Wingate is usually 100 m thick and consists almost exclusively of thick beds of eolian sandstone that often form spectacular cliffs (Harshbarger et al., 1957; Clemmensen et al., 1989). Similar, albeit much thinner, beds of eolian sandstone are found in parts of the Dinosaur Canyon Member of the Moenave Formation to the west, supporting the concept of the dry, eolian-dominated system of the Wingate (to the east) being laterally equivalent to the wet, mixed eolian/fluvial system of the Moenave (to the west) (Edwards, 1985; Clemmensen et al., 1989; Blakey, 1994; Lucas and Tanner, 2007a; Tanner and Lucas, 2007). Also, strata of the Rock Point Formation in this region include extensive eolian-dominated beds, further supporting the concept of a gradational contact between the Rock Point and Wingate formations (Lucas et al., 1997; Lucas and Heckert, 2001). Indeed, detailed stratigraphic work (e.g. Lucas et al., 1997; Lucas and Tanner, 2007a) confirms most of the basic stratigraphic relationships among the Rock Point, Wingate and Moenave formations originally advocated by Harshbarger et al. (1957) (Fig. 2).

The Whitmore Point Member, as established by Wilson (1967), comprises purple and gray laminated mudstones and shales in the upper part of the Moenave Formation. The type location is just east of Potter Canyon, at Whitmore Point (Fig. 1), a south-facing promontory of the Vermillion Cliffs in Mohave County, Arizona, where the unit comprises 22 m of fish- and coprolite-bearing shales, siltstones, sandstones, and minor limestones. At the type location, the strata form a tripartite vertical sequence comprising a lower, finer-grained