Cretaceous Research 50 (2014) 332–343

Contents lists available at ScienceDirect

Cretaceous Research

journal homepage: www.elsevier.com/locate/CretRes

Sedimentology and Paleontology of the Upper Cretaceous Wahweap Formation sag ponds adjacent to syndepositional normal faults, Grand Staircase-Escalante National Monument, Utah

E.L. Simpson [a,*], R. Koch [a], E.A. Heness [a], M.C. Wizevich [b], S.E. Tindall [a], H.L. Hilbert-Wolf [c], K. Golder [d], A.K. Steullet [e]

[a] Department of Physical Sciences, Kutztown University of Pennsylvania, Kutztown, PA 19530, USA
[b] Central Connecticut State University, Department of Physics and Earth Sciences, New Britain, CT 06050, USA
[c] School of Earth and Environmental Sciences, James Cook University, Townsville, QLD 4811 Australia
[d] Department of Earth and Environmental Sciences, Wesleyan University, Middletown, CT 06459, USA
[e] ConocoPhillips School of Geology and Geophysics, University of Oklahoma, Norman, OK 73019, USA

ARTICLE INFO

Article history:
Received 9 October 2013
Accepted in revised form 1 May 2014
Available online 19 June 2014

Keywords:
Cretaceous
Sag pond
Normal fault
Utah
Paleoseismology

ABSTRACT

During the development of the East Kaibab monocline, listric normal faulting related to outer arc influenced the sedimentation style of the Upper Cretaceous Wahweap Formation. The initiation of the Laramide Orogeny was therefore recorded in the sedimentary record of south-central Utah. Evidence for this includes the preservation of sag ponds adjacent to two of the normal faults in our study area, which developed when fault movement created topographic features. Ancient sag-pond deposits are likely under-identified in the rock record. This study demonstrates their significance and potential for unraveling fault histories.

The northern, younger, sag-pond deposit is located at the boundary between the upper and capping sandstone members of the Wahweap Formation, and consists of sandstone dikes and sills hosted in gray mudstones and siltstones with no discernable invertebrate fauna, but some small macerated flora. The second southern sag-pond fill, is located at the base of the upper member. The sag pond is older, larger in area, and contains a thicker deposit. In contrast to the northern sag-pond deposit siltstones and mudstones are gray and visiblity structureless. Within the southern sag pond there are a series of fossil horizons consisting mainly of juvenile unionid bivalves, a lesser number of gastropods, and macerated plants. Comparison of the two preserved Upper Cretaceous sag-pond deposits suggests two distinct responses to fault movement, perhaps governed by fault kinematics, manifested in sedimentation style and type; the impact of faunal invertebrate invasion; and post-sedimentation deformation.

1. Introduction

Historical and recent fault movements are potentially decipherable by distinctive geomorphic features, such as offset drainage and terraces, liquefaction features, pressure ridges and development of sag ponds (Sieh, 1978; Sanders and Slemmons, 1979; Schubert, 1982; Sylvester, 1988; Tuttle and Seeber, 1991; Obermeier, 1996; Audemard Mennessier, 1997; Audemard Mennessier et al., 1999; Lienkaemper et al., 2002; Prentice et al., 2006; Rymer et al., 2006). Fault-related sag ponds develop when divergent movement associated with either transtensional or extensional faulting creates a topographic depression, or sag, and local hydrologic conditions maintain water levels in the depression.

Sag ponds are internally drained systems that may fill rapidly by slope-wash, rill-wash, or small ephemeral-stream sedimentation processes (Weldon et al., 1996). In areas with a high water table, shallow ponds develop that have been reported up to a few hundred meters in length parallel to the fault and a few tens of meters across (Weldon et al., 1996). Locally derived sediment is often deposited subaqueously in these ponds as stratified sand, silt, clay or organic matter fill; however, possible periods of subaerial exposure may result in various degrees of pedogenic overprint of the sediment (Weldon et al., 1996; Lienkaemper et al., 2002). In arid settings the sag depressions may remain unfilled for extended

* Corresponding author.
E-mail addresses: simpson@kutztown.edu (E.L. Simpson), rkoch986@gmail.com (R. Koch), eheness@gmail.com (E.A. Heness), wizevichmic@ccsu.edu (M.C. Wizevich), tindall@kutztown.edu (S.E. Tindall), hannah.hilbertwolf@my.jcu.edu.au (H.L. Hilbert-Wolf), kgolder@wesleyan.edu (K. Golder), Steulletalk@ou.edu (A.K. Steullet).

http://dx.doi.org/10.1016/j.cretres.2014.05.001
0195-6671/

periods of time (Walker et al., 2008). The possibility for applying radiocarbon and thermoluminescence dating techniques to sag-pond sediments (e.g. Forman et al., 1989; McCalpin, 1996; Obermeier, 1996) may help unlock an area's kinematic tectonic history. Additionally, reports on the micro- and macrofauna development in modern sag ponds are sparse and this revealing component may be overlooked when reconstructing fault activity (Saul, 1961; Lienkaemper et al., 2002).

Sag ponds are under-recognized in the rock record probably from the lack of recognition of their distinctive features (Simpson et al., 2009). In the Upper Cretaceous Wahweap Formation of Grand Staircase – Escalante National Monument (GSENM) in southern Utah, two sag pond deposits are recognized adjacent to two syndepositional listric normal faults, one near the base of the upper member and the second located at the contact between the upper and capping sandstone members (Fig. 1; Simpson et al., 2009). The two sag ponds are described with respect to sediment fill, deformational history, and invertebrate paleontology. Causative mechanisms are proposed to explain the dissimilar size, fill content, deformation, and paleontology of the sag ponds.

2. Geologic background

Within the GSENM, the Wahweap Formation conformably overlies the Straight Cliffs Formation and is in turn overlain by the Kaiparowits Formation. These stratigraphic units are dominated by fluvial systems derived from highlands to the northwest or south and were deposited in the evolving Cordilleran foreland basin (Fig. 1; Peterson, 1969; Eaton and Nations, 1991; Lawton et al., 2003; Roberts, 2007; Simpson et al., 2008; Jinnah and Roberts, 2011). The Wahweap Formation is divided into four informal stratigraphic units, from oldest to youngest: lower, middle, upper, and capping sandstone members (Eaton, 1991). In the study area the upper member consists of tan to buff lithic sandstones, whereas the capping sandstone member is white and dominated by quartz sandstones (Eaton, 1991; Eaton and Nations, 1991; Pollock, 1999; Lawton et al., 2003; Simpson et al., 2008; Jinnah and Roberts, 2011).

The age of the Wahweap Formation is constrained by Ar^{40}/Ar^{39} dates from tuffs distributed throughout the overlying Kaiparowits Formation (Roberts et al., 2005) and complementary micro-vertebrate biostratigraphy throughout the units (Eaton, 1991; 2002). Recent Ar^{40}/Ar^{39} ages from a bentonite horizon within the middle member of the Wahweap Formation affirm a Late Cretaceous middle Campanian age, 80.1 to 75.1 Ma (Jinnah et al., 2009; Titus et al., 2013).

Three arcuate faults, with apparent right- and left-separation in map view, offset the Wahweap Formation along the East Kaibab monocline (Figs. 1 and 2; Tindall et al., 2010). The northeast-striking faults lose displacement up-section toward the northeast and do not extend into the Kaiparowits Formation (Tindall et al., 2010). The two southernmost faults curve down-section and are bedding parallel in the Jurassic Carmel Formation, which consists of shales and evaporites that acted as a décollement for the evolving syndepositional listric normal faults that impacted sedimentation from the middle through capping sandstone members of the Wahweap Formation (Figs. 1C and 2; Tindall et al., 2010). Where these faults cross the Wahweap Formation, growth strata record evidence of multiple phase movement (Storm et al., 2008; Tindall et al., 2010). Rotation of the eastward-dipping bedding along the East Kaibab monocline to horizontal restores the southern faults to south-dipping listric orientations that display normal slip (Simpson et al., 2009; Tindall et al., 2010). Rotation of bedding to horizontal also indicates that the northern fault is a north-dipping listric normal fault (Fig. 1B; Simpson et al., 2009; Tindall et al., 2010). Both the northern and southern faults are a response to outer arc extension as the East Kaibab monocline started to form during the initial stage of the Laramide Orogeny (Tindall et al., 2010). Both sag-pond deposits are preserved on the restored hanging wall adjacent to the faults and abut against the fault planes (Fig. 1).

Wizevich et al. (2008) recognized local in the upper member fluvial deposits from braided, trough cross-bedded and soft-sediment deformed facies to meandering, inclined heterolithic facies, and attributed this change to seismic activity and extensional movement on the southern normal faults (Fig. 4). However, Jinnah and Roberts (2011) did not recognize this fault movement impact in a wider study of the basinal distribution of facies in the upper member. Nonetheless systematic examination of the geographic distribution, scale, and intensity of soft-sediment deformation in

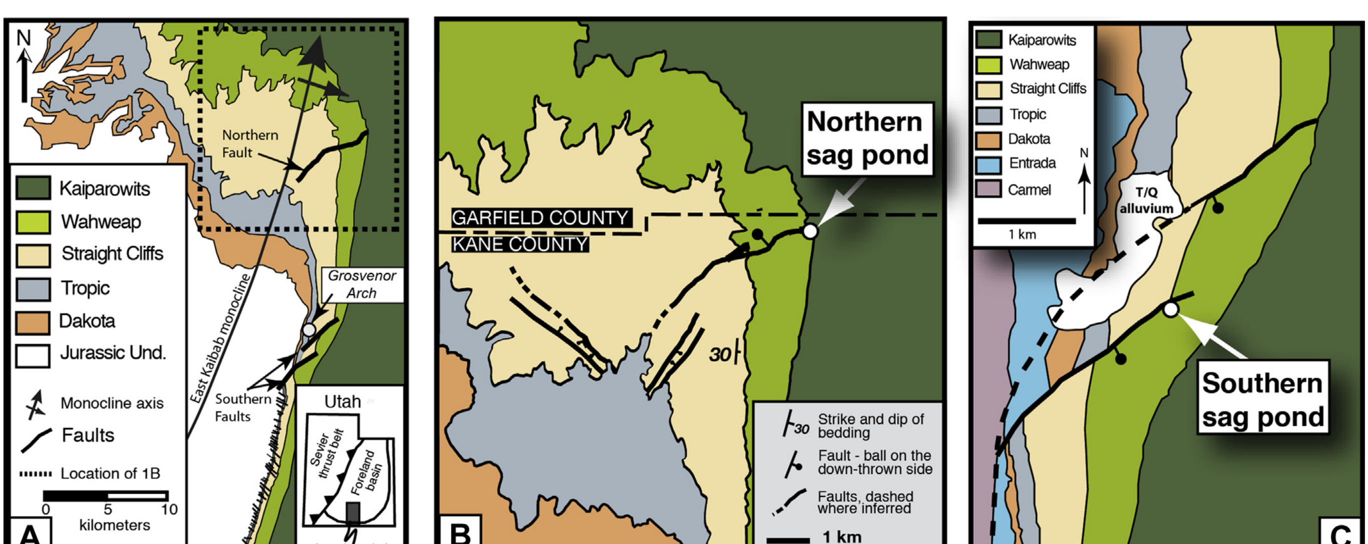

Fig. 1. A) General geologic map of a portion of the Kaiparowits Basin in Grand Staircase-Escalante National Monument (geologic map modified from Sargent and Hansen, 1982). B) Geologic and locality map of the sag pond deposit located at the upper and capping sandstone members contact and adjacent to the northern normal fault near Bull Flat (geologic map modified from Sargent and Hansen, 1982). Note the location of the study area at the fault tip line. C) Geologic and locality map of the upper member sag pond deposit adjacent to the southern-most fault (geologic map modified from Tindall et al., 2010).