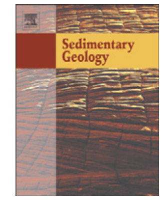
Sedimentary Geology 297 (2013) 50–62

Contents lists available at ScienceDirect

Sedimentary Geology

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



An example of liquefaction-induced interdune sedimentation from the early Jurassic Navajo Sandstone, USA

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ARTICLE INFO

Article history:
Received 11 July 2013
Received in revised form 30 August 2013
Accepted 1 September 2013
Available online 11 September 2013

Editor: B. Jones

Keywords:
Navajo Sandstone
Soft-sediment deformation
Interdune
Lacustrine
Carbonate
Eolian

ABSTRACT

Extensive outcrops of Navajo Sandstone in the southwestern United States expose eolian dune deposits that are subdivided in a complex array of foresets and bounding surfaces. In the Glen Canyon region, and other places, this architecture is frequently disrupted by large-scale, soft-sediment deformation features. These features have been attributed to episodic liquefaction events that affected saturated sand below the level of the interdune surface. Though erosional truncation of deformation features indicates that liquefaction often occurred in the uppermost levels of Navajo dune deposits, very few paleotopographic disruptions due to subsurface deformation have been documented. Navajo Sandstone outcrops in West Canyon, Utah, provide unusually comprehensive exposure of architectural details linking large-scale deformation features and associated interdune deposits, enabling a well constrained appraisal of their genesis. At this location, a 23 m succession of sandstone, mudstone, carbonate, and chert deposits overlies a zone of deformation that extends, laterally, for hundreds of meters. This horizontally stratified lens occupies an abrupt synform along a bounding surface between successive crossbeds that otherwise appears as a featureless, sub-horizontal plane. Large-scale foresets below this bounding surface oversteepen at the margins of the synform and grade downdip into contorted stratification and structureless expanses.
The authors propose that liquefaction in the Jurassic erg caused localized subsidence of a minor portion of a dry interdune surface to a position several meters below the contemporary water table. A succession of hyperpycnal sand flows, lacustrine evaporites, and eolian sheet and dune deposits filled this depression prior to the advance of large dunes across the site. The process/response dynamics evident in this outcrop suggest that deformation may have exercised significant, non-systematic control over depositional architectures in areas of the erg prone to liquefaction. Similar dynamics are unknown from modern desert environments and their intrinsic scale defies laboratory simulation; therefore, close investigation of these ancient features is essential for exploring the full range of depositional controls that may be encountered in other ancient eolianites on Earth and in eolian accumulations on other planets.

1. Introduction

1.1. Purpose of this report

This report documents field relationships between depositional facies architecture and associated soft-sediment deformation features exposed in outcrops of the Navajo Sandstone in West Canyon, Utah. It offers an interpretation of those relationships that emphasizes genetic links between a deformation event and a subsequent depositional episode. That interpretation constitutes a case study of one way in which autogenic depositional patterns in the ancient Navajo erg responded to disruptive events emerging from the complex interplay between diverse controls, which included: autogenic controls on sorting and packing of sand grains; climatic controls on sediment saturation; tectonic controls on intraplate stress generation, as well as sediment supply; and structural controls on the localization of stress-releasing events.

The process/response dynamics featured in this report have not been observed in any modern environment. With regard to proposed classification schemes, their salient features are not usefully represented by any particular genetic grouping (e.g. van Loon, 2009) or morphological class (e.g. Chan et al., 2007). However, field reconnaissance in the Glen Canyon region of the Colorado Plateau suggests that comparable disturbances may have been commonplace in that portion of the Navajo erg and a small sample of these has already been published in a summary article (Bryant and Miall, 2010), including a partial representation (Fig. 11) of the study site that is the focus of the present report. Here, we provide detailed architectural information by which process interpretations can be advanced, evaluated, and refined. Besides opening a unique window on the exotic dynamics of an ancient desert

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http://dx.doi.org/10.1016/j.sedgeo.2013.09.001

environment, this report expands the range of hypotheses available to interpret less favorably exposed outcrops, and provides a new target for experimental production of soft-sediment deformation structures.

1.2. General geologic setting

The Navajo Sandstone (Fig. 1) is a very extensive eolianite, spectacularly exposed on the Colorado Plateau, in the United States. It accumulated near sea level in the southern part of the Western Interior Basin during the initial stages of the break-up of Pangea, in the early Jurassic (Peterson, 1994). This broad, back-arc area was the site of episodic eolian deposition from the late Paleozoic through the Jurassic (Blakey et al., 1988; Peterson, 1988), prior to inundation by an epicontinental seaway, during eustatic highs in the Cretaceous (Hallam, 2001).

During the early Jurassic, the basin was centered some 10°–20° north of the equator (Kocurek and Dott, 1983) and experienced warm, mostly dry conditions from general global warming (Fischer and Arthur, 1977), latitudinally zoned circulation patterns modified by seasonal monsoons, and rain-shadow effects from the volcanic arc to the west (Parrish and Peterson, 1988). Foreland basin subsidence accommodated thick accumulations along a NE/SW trend (Blakey, 1994b; Allen et al., 2000). Both the general tectonic setting of the depositional basin and angular relationships at the bounding unconformities of the early Jurassic sequences indicate widespread, though moderate, seismic activity during the depositional history (Peterson, 1994).

1.3. Stratigraphy

Fluvial deposits of the Kayenta Formation conformably underlie and intertongue with the Navajo Sandstone (Fig. 1). Modal analyses of detrital framework grains, augmented by detrital zircon provenance determinations, indicate that these sediments derived from tectonic

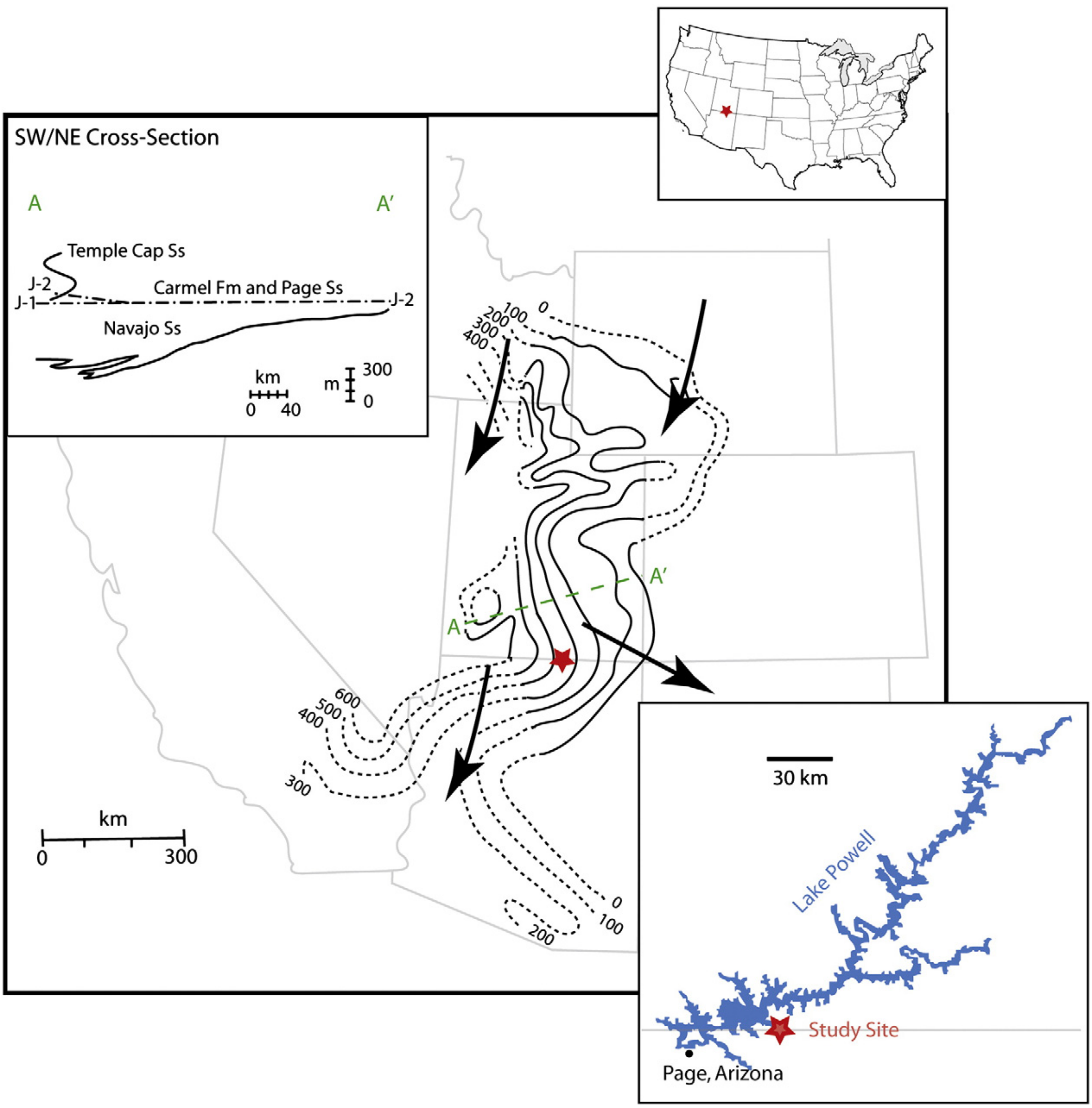

Fig. 1. Current field relations, in the American Southwest, between major features produced during the early Jurassic (Blakey, 1994b; Peterson, 1994; Dickinson and Gehrels, 2003). The inset figure is a generalized cross-section across the thickest part of the preserved Navajo accumulation (Blakey et al., 1988). The arrows in the paleogeographic reconstruction (Blakey and Ranney, 2008) represent prevailing transport winds across the Navajo erg (Parrish and Peterson, 1988).