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Review

Desert wetlands in the geologic record

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ABSTRACT

Desert wetlands support flora and fauna in a variety of hydrologic settings, including seeps, springs, marshes, wet meadows, ponds, and spring pools. Over time, eolian, alluvial, and fluvial sediments become trapped in these settings by a combination of wet ground conditions and dense plant cover. The result is a unique combination of clastic sediments, chemical precipitates, and organic matter that is preserved in the geologic record as groundwater discharge (GWD) deposits. GWD deposits contain information on the timing and magnitude of past changes in water-table levels and, therefore, are a potential source of paleohydrologic and paleoclimatic information. In addition, they can be important archeological and paleontological archives because desert wetlands provide reliable sources of fresh water, and thus act as focal points for human and faunal activities, in some of the world's harshest and driest lands. Here, we review some of the physical, sedimentological, and geochemical characteristics common to GWD deposits, and provide a contextual framework that researchers can use to identify and interpret geologic deposits associated with desert wetlands. We discuss several lines of evidence used to differentiate GWD deposits from lake deposits (they are commonly confused), and examine how various types of microbiota and depositional facies aid in reconstructing past environmental and hydrologic conditions. We also review how late Quaternary GWD deposits are dated, as well as methods used to investigate desert wetlands deeper in geologic time. We end by evaluating the strengths and limitations of hydrologic and climatic records derived from GWD deposits, and suggest several avenues of potential future research to further develop and utilize these unique and complex systems.

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1. Introduction

Desert wetlands form in arid environments where water tables approach or breach the ground surface. When active, they serve as watering holes for local fauna, support vegetation that depends on access to ground water for survival, and act as catchments for eolian, alluvial, and fluvial sediments. Active wetlands and springs also serve as a focus of human activity in arid lands, and thus archeological materials are frequently found in association with fossil wetland deposits (Nicholas, 1998; Ashley, 2001).

Wetlands are relatively common features in arid environments, and encompass a variety of hydrologic settings, including seeps, springs, marshes, wet meadows, ponds, and spring pools. Ground water feeding these settings can originate from a number of different sources, ranging from deep-seated bedrock aquifers to shallow alluvial aquifers. Hot springs fed by deeply-circulating ground water are widespread and have been the topic of a number of recent studies (e.g., Hancock et al., 1999; Fouke et al., 2000; Jones and Renaut, 2003; Crossey et al., 2006; Costa et al., 2009). In this paper, however, we focus on low-temperature ground-water discharge systems found in arid and semi-arid environments. Similarly, we have chosen to focus on the freshwater springs that we are most familiar with and do not address saline springs such as those found on the floor of Death Valley (Forester et al., 2005). A final caveat, the springs and wetlands we describe herein are not necessarily related to nearby lakes or rivers as reviewed by Tooth and McCarthy (2007), but rather are stand-alone systems fed by ground water.

Geologic deposits associated with desert wetlands, called groundwater discharge (or GWD) deposits, are also common in arid environments. Since they were first described systematically in the 1980's (Quade, 1986; Quade and Pratt, 1989), GWD deposits have been identified in all four deserts of the American Southwest (Chihuahuan, Great Basin, Mojave, and Sonoran), the Atacama Desert of northern Chile, the Middle East, North Africa, Australia, and Tibet (Paces et al., 1996, 1997; Deocampo et al., 2002; Rech et al., 2002; Liutkus and Ashley, 2003; Smith and Giegengack, 2003; Ashley et al., 2004; Owen et al., 2004; Smith et al., 2004a, 2004b; Quade et al., 2008; Pigati et al., 2009; Winer, 2010). In the Mojave Desert of southern California, detailed mapping of surficial deposits has identified GWD deposits at more than 130 different locations in this small desert alone (Schmidt and McMackin, 2006; Bedford et al., 2010; Miller, 2010; Amoroso and Miller, 2012; Phelps et al., 2012). To our knowledge, comprehensive geologic mapping that includes these features has not been conducted in other deserts, but we contend that, by extension, GWD deposits are likely as common, but underrecognized, elsewhere in the world's arid lands.

Ground-water discharge deposits, which are also called spring or wetland deposits, record past climatic and hydrologic conditions (Mensing et al., 2008, 2013). For example, the average temperature of emergent ground water in isolated, low-temperature wetlands typically approaches the mean annual air temperature at the point of discharge (Quade et al., 2003). Thus, geologic deposits that are associated with desert wetlands can be used to reconstruct past air and water temperatures on a variety of spatial and temporal scales. Similarly, GWD deposits contain information on the timing and magnitude of episodes of high water-table conditions related to moister and/or cooler conditions in the past.

Importantly, researchers must be able to discern between GWD and lake deposits (they are commonly confused) as conditions required to support the two systems can be markedly different. In arid lands, for example, low precipitation and high evaporation rates can make it difficult to maintain perennial lakes, whereas wetland systems can survive periods of relatively low effective precipitation because aquifers that feed wetlands are largely shielded from evaporation. Misidentifying the different deposits, therefore, may lead to erroneous interpretations of past climate regimes. By improving our ability to recognize and interpret GWD deposits, we can more accurately estimate the magnitude of past climate and hydrologic changes, better address what drove the changes, and place constraints on what it might mean for the future of freshwater springs.

In this paper, we review a number of topics related to low-temperature springs and wetlands that are preserved in the geologic record. We begin with a general discussion of how and where desert wetlands and GWD deposits are formed, their physical attributes and chemical composition, and the microfauna (specifically ostracodes and gastropods) that are preserved within the sediments. We then discuss how microfauna and different sedimentary facies can be used to reconstruct specific environments within paleowetlands, and review some approaches that can be used to differentiate GWD and lake deposits. We end with a discussion of chronologic techniques that can be used to establish the age of GWD deposits, an evaluation of the strengths and limitations of hydrologic and climatic records derived from GWD deposits, and suggest further avenues of research related to desert wetlands. In the discussions that follow, we rely heavily on our experience working with GWD deposits in the deserts of the American Southwest and the Atacama Desert of northern Chile. However, the lessons learned should be applicable throughout the world's arid lands.

2. Desert wetlands

Wetlands constitute ~0.3% of the total land cover in the deserts of the American Southwest (Cowardin et al., 1979). In many settings, ground water in shallow alluvial aquifers originates as precipitation and snowmelt in the uplands of nearby mountain ranges and flows under unconfined or semi-confined conditions into valley-fill sediments (Mifflin, 1968). The topography of the water table in these systems generally mimics the local land topography, and groundwater flow continues through the aquifer until the water table intersects the ground surface, often near the distal toe of an alluvial fan or where shallow faults or bedrock force ground water to the surface. Ground-water discharge systems that are not associated with faults or bedrock can be either localized or fairly widespread, ranging up to a few km^2 or more in the American Southwest depending on the local topography (Quade, 1986). Where ground water encounters shallow faults or bedrock, however, discharge is generally more restricted in spatial extent and is often expressed on the landscape as one or more point sources or as a linear feature across an area of near-constant elevation (Quade et al., 1995). Desert wetlands can also act as discharge areas for confined regional aquifers by similar processes, although usually on a larger scale.

Extant springs and wetlands have been subject to a multitude of classification schemes based on characteristics such as water temperature (thermal, non-thermal, hot, warm, cold), water chemistry (sulfurous, saline, calcareous/lime, gypsum, borax, etc.), water persistence (perennial, permanent, intermittent, temporary), volume of discharge