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Desert flash floods form hyperpycnal flows in the coral-rich Gulf of Aqaba, Red Sea

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A B S T R A C T

Running rivers are very scarce in globally distributed hyperarid and arid coastlines (∼28,000 km worldwide), and it is ephemeral rivers that carry most terrestrial sediment into the sea in these regions. However, there is very little information regarding the contribution of terrestrial sediment and dynamics of transport of sediment that enter marine basins from these rivers. One hyperarid region, the Gulf of Aqaba received an exceptional number of flashflood events during the winter of 2012–2013. The results illustrate, for the first time, how the high volume of flashflood sediment influences the distribution of coral reefs; dwarfs the contribution of airborne dust; elevates floodwater densities to produce hyperpycnal flows, despite highest ocean salinities; and is subsequently transported to the deep basin where it may be preserved as a climate archive.

1. Introduction

Rivers carry ∼95% of the terrestrial sediment that reach the sea (Syvitski et al., 2003) and it has been suggested that the contribution from smaller drainage basins (<10,000 km^2) exceeds that estimated from their water volume alone (Milliman and Syvitski, 1992). The practical difficulties of studying and monitoring the far more numerous rivers on the small end of the spectrum result in a general knowledge gap regarding their characteristics and impact relative to contributions from the larger, major world rivers. The contribution and dynamics of ephemeral rivers, which constitute the vast majority of rivers along arid and hyper arid coastlines, is even less understood.

Alluvial sediment discharged into the coastal ocean may disperse in different ways. Mostly, when reaching the ocean, alluvial sediment disperses within plumes of fresh, buoyant river water (hypopycnal plumes) that overlay the denser, saline seawater and gradually flocculate and settle to the seafloor (Geyer et al., 2004). However, when concentrated enough, alluvial sediment can disperse as hyperpycnal flows. Hyperpycnal flows may form when the incoming freshwater is loaded with enough sediment (Mulder et al., 2003) to become denser than the seawater it enters, and therefore plunges to the seafloor. There, providing bottom slope >0.7° they flow as gravity currents (Bhattacharya et al., 2009). Another way in which hyperpycnal flows are formed is when river discharges with as little as 1 kg sediment m^{-3}, enter the ocean as hypopycnal flows, but owing to convective instability, sediment trickle to the seafloor creating a sediment-laden layer of bottom water that flows downslope as a hyperpycnal flow (Parsons et al., 2001; Warrick et al., 2008). The plunging of sediment laden water and formation of hyperpycnal flows from river discharge may occur immediately near-shore but also kilometers away from the discharge point at the shoreline depending on the discharge strength, slope and sediment concentration (Lamb and Mohrig, 2009).

Alluvial sediment dispersion into the sea from small, ephemeral desert-rivers that flow seldom, and then for very short periods

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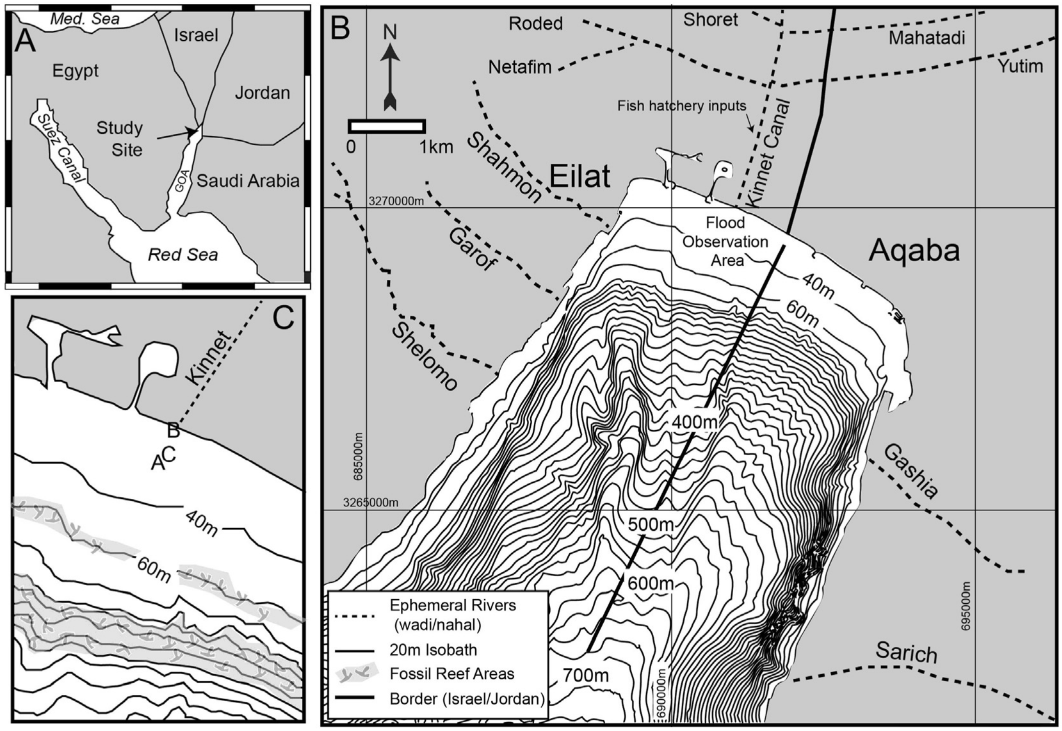

Fig. 1. Maps of the head of the Gulf of Aqaba (GOA). (A) Regional Map. (B) A bathymetric map of the head of the GOA (adapted from Tibor et al., 2010) with schematic markings of the Israeli–Jordanian border (dashed line) and incoming ephemeral rivers (dotted lines) and UTM (zone 36N) gridlines. (C) Map highlighting flood observation area; white regions in this inset mark regions of sandy seafloor and patterned coloring represents fossil reefs (Tibor et al., 2010); 'A' indicates location of January 27, 2013 hyperpycnal flow observations and sample collections (13 m depth); 'B' indicates location of incoming flood water collections; and 'C', the location of push-core collections (10 m depth) during Jan and Dec 2011 and Jan 2013.

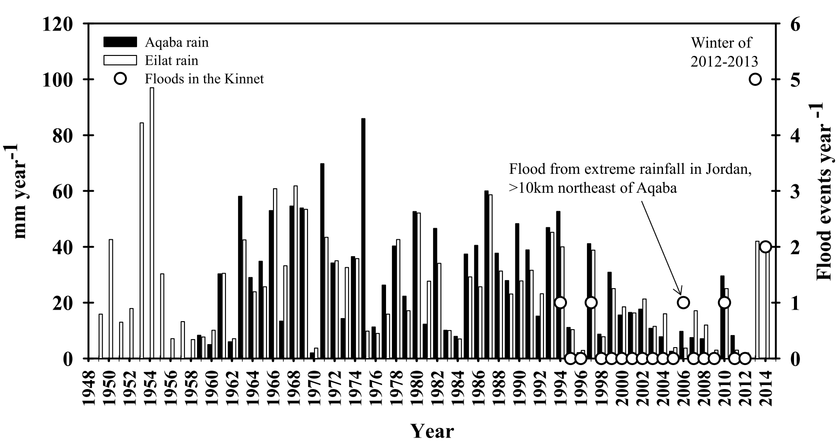

Fig. 2. Summary of available rainfall and flood records from the GOA. Dark bars mark the rainfall (mm) per calendar year in Aqaba (1960–2009) and white bars and grey circles respectively mark the rainfall in Eilat (1949–2014) and the number of flood events that entered the GOA through the Kinnet Canal (1994–2014) in a hydrological year (Oct to May the following year). Aqaba rainfall data was obtained from the Jordan Meteorological department, Eilat rainfall from the Israel Meteorological Service and flood data from the Arava Drainage Authority.

of time (hours), is poorly known. Due to the scarcity of rain in these areas, transport of terrestrial sediment to the sea via eolian processes is considered to be important. For example, Chen et al. (2008) proposed that eolian inputs may constitute the major source of terrestrial trace element in the hyperarid Gulf of Aqaba–Eilat (GOA). Yet, the relation between eolian and alluvial sediments in this and other hyper arid systems is not well resolved.

This study on sedimentary processes related to the discharge from ephemeral desert rivers into the sea was conducted in the northern tip of the GOA (Fig. 1). The area surrounding the GOA is a hyper-arid desert (Kafle and Bruins, 2009), with high temperatures and mean precipitation <30 mm rain yr^{-1}. The scarce and patchy rain events (Sharon, 1972) occur between October and May (Fig. 2). The very localized and short-lived rain events (hours) can cause flashfloods that carry eroded sediment from their drainage basins to terminal sedimentary basins, be it to on-land salt marshes, sabkhas, dry braided streambeds and alluvial fans, or the sea. These flashfloods may occur at a frequency of between several times in a year to once a decade. Whereas the significance of the flashfloods in sedimentary processes in the nearby desert has been extensively studied (Enzel et al., 2012), little is known of the dynamics and fate of the flood-born matter when it enters the sea. Rainfall and flood records indicate exceptionally low precipitation and only one flooding event between 1998 and 2009; this dry period had no apparent correlation to known, global climatic cycles e.g. the ENSO or NAO. Conversely, the winter of 2012–2013 had