Earth and Planetary Science Letters 390 (2014) 209–221

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Glacial–interglacial variation in denudation rates from interior Texas, USA, established with cosmogenic nuclides

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ARTICLE INFO

Article history:
Received 18 September 2013
Received in revised form 8 January 2014
Accepted 9 January 2014
Available online 31 January 2014
Editor: T.M. Harrison

Keywords:
^{10}Be denudation rates
Gulf of Mexico
climate change
sediment flux
coastal plain
TCN

ABSTRACT

The Brazos, Colorado, and Trinity rivers of Texas drain a tectonically quiescent, non-glaciated, and low-relief landscape inland from the Gulf of Mexico, where long-term [10^3–10^5 a] changes in denudation rates are probably driven largely by climate change. Here, we use cosmogenic ^{10}Be to obtain spatially averaged denudation rates for these river catchments, primarily from terrace deposits associated with glacial or interglacial intervals over the past half million years. The denudation rates are ∼30–35% higher during interglacial periods than during glacial periods, and correlate broadly with temperature. The results are consistent with predictions from the BQART sediment flux model, and support the hypothesis that increased weathering rates associated with warmer climates will accelerate landscape erosion. Furthermore, by analyzing ^{26}Al/^{10}Be in these deposits, we can estimate the bed load sourced from up-catchment surfaces. The stored coastal plain fraction varies from ∼10% to 30%, and is greater during times of relatively lower sea level. The results indicate that although sediment flux is moderated by coastal-plain storage, increased up-catchment flux during warmer interglacial periods outpaces evacuation of stored sediment during glacial periods, resulting in a net increase in sediment flux to the ocean during warm intervals. If this temperature–sediment flux relationship is valid beyond the Plio-Pleistocene transition, then global sediment flux to the ocean from passive, non-glaciated, and low-relief landscapes would have been greater during the Pliocene than in the cooler Quaternary.

1. Introduction

The relative importance of mechanisms driving global sediment flux over the last 5 Ma is uncertain. The first-order mechanisms are tectonic uplift (Raymo and Ruddiman, 1992) and global climate (Molnar, 2004; Molnar and England, 1990; Peizhen et al., 2001), with secondary, related factors including threshold changes in vegetation (Antinao and McDonald, 2013; Bull, 1991; Hay et al., 2002), permafrost (Mason and Knox, 1997), and aridity (Bull, 1991; Molnar, 2001; Pederson et al., 2000), changes in the global proportions of fluvial and glacial erosion (Koppes and Montgomery, 2009; Montgomery, 2002), and the average gradients of continental surfaces (Willenbring et al., 2013). The interconnected nature of these processes often precludes the isolation of a single mechanism, and has led to an inability to resolve the role of climate in controlling global sediment flux.

Furthermore, globally integrated sediment flux estimates have remained elusive. Modern sediment flux from a single river cannot be measured with high accuracy, and the variation in sediment flux with time is even less well known. Instead, proxy data such as mass reconstructions based on preserved basin fills (Hay et al., 1989; Peizhen et al., 2001), isotopic signatures of oceanic sediment (Willenbring and von Blanckenburg, 2010), and numerical models trained on modern rivers that implement space-for-time substitutions (Milliman and Syvitski, 1992; Syvitski and Milliman, 2007) are utilized. However, these proxies have produced conflicting results. In fact, one can infer that net sediment flux to the oceans may have increased (Molnar, 2004; Peizhen et al., 2001), decreased (Syvitski and Milliman, 2007), or remained the same (Willenbring and von Blanckenburg, 2010) over the Plio-Pleistocene transition.

To improve our understanding of the landscape response to climate change a study area must (1) be removed from effects of tectonics, changes in sediment routing, and direct glaciation so that the climatic component can be isolated, and (2) have robust measurements of paleo-sediment flux that can be traced to a specific land surface. Toward this goal we compare catchment-wide average denudation rates during glacial and interglacial periods based on Quaternary fluvial deposits from three river systems that drain the Texas interior and enter the Gulf of Mexico. These rivers drain a large [∼3×10^5 km^2] area of low-relief and a gently-sloping landscape. This type of landscape has recently been suggested as a significant contributor to global sediment flux (Willenbring et al., 2013) [although not the dominant contributor as initially

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0012-821X/$ – see front matter
http://dx.doi.org/10.1016/j.epsl.2014.01.011

suggested (J.K. Willenbring, 2014)], and therefore the erosional history of these rivers is broadly relevant to global sediment budgets. The river catchments have maintained an approximately constant drainage area, have never been glaciated, and drain a passive margin with minimal tectonic influence over the duration of interest. The aim of this study is to determine how denudation rates in these regions respond to glacial and interglacial climate.

We obtain our catchment-wide denudation rates using in situ-produced ^{10}Be in fluvial sediment (Bierman and Steig, 1996; Brown et al., 1995; Granger et al., 1996). This approach can be used to determine both modern and past denudation rates (e.g. Charreau et al., 2011; Fuller et al., 2009; Matmon et al., 2012; Refsnider, 2010; Schaller et al., 2002). Our denudation rates are integrated over ∼15–45 ka, a sufficiently short period to capture potential changes in rates due to the eccentricity-driven 100 ka climate cycle, but sufficiently long to minimize anthropogenic input for modern rates. We test and support the hypothesis that, where tectonic activity is minimized and glaciers are absent, long-term variation in denudation rate correlates broadly with mean catchment temperature, as inferred from the model predictions of Syvitski and Milliman (2007) and Kettner and Syvitski (2008).

2. Study area

2.1. Overview

The Colorado, Brazos, and Trinity Rivers (Fig. 1) drain the majority of inland Texas [∼110,000 km^2, ∼115,000 km^2, and ∼45,000 km^2, respectively] and supply most of the sediment to the Gulf Coast. The coastal plain extends inland ∼200 km from the present Texas shoreline, and represents the landward portion of a succession of coalescing alluvial-deltaic deposits associated with Neogene progradation of the continental margin (DuBar et al., 1991; Galloway et al., 2000). Tectonic activity in source terrains for these rivers has been minimal since the Pliocene (DuBar et al., 1991). Although salt tectonics and growth faults are ubiquitous on the outer coastal plain and shelf (Diegel et al., 1995; Ewing, 1991), their effect on erosion rates of upstream source terrains is assumed to have been negligible, and any local fault-induced coastal plain incision would have contributed little to the total sediment supply. The Texas drainage basins have experienced isostatic adjustment in response to incision and sediment loading and may have been marginally affected by post-Laramide broad-wavelength epeirogenic uplift (sensu Pazzaglia and Gardner, 1994) associated with the Rocky Mountains (McMillan et al., 2002, 2006). However, changes in neither of these effects would have significantly affected sedimentation rates over tens of thousands of years, the period over which our ^{10}Be denudation rates have been integrated. Furthermore, post-depositional tilt measurements of the Miocene Ogallala Group bordering the Rocky Mountains indicates a minimal change in slope at distances >200 km from the foothills (McMillan et al., 2002), where the catchment headwaters reside. Long-term regional tectonic stability, a virtually continuous record of sedimentation along the coastal plain, and a pre-existing geochronological framework [discussed below] make the Texas coastal plain a suitable setting for studying the effect of long-term climate change on sediment supply.

The drainage basins are dominated by flat-lying siliciclastic rocks, with modern river sediment consisting almost exclusively of mature, clean, and quartz-rich sand. Exceptions to this include Cretaceous carbonates that crop out in the Edwards Plateau province of west-central Texas, within the Colorado and Brazos river catchments, and exhumed Precambrian igneous and metamorphic rocks [Llano region] in the Colorado catchment. The Colorado and Brazos rivers were sourced in the southern Rocky Mountains until their headwaters were captured by the Rio Grande system in the Pliocene (Galloway et al., 2011; Gustavson and Finley, 1985), but their catchments have maintained roughly the same configuration since then (Galloway et al., 2011; Reeves, 1976; Winker, 1979). Thus, we assume that modern river drainage areas are similar to the catchment areas over the Quaternary.

The study area has experienced climate-driven variations in temperature, precipitation, and vegetation cover that likely influenced these river systems. Pollen, fossil vertebrate, and plant macrofossil data (Bryant and Holloway, 1985; Hall and Valastro, 1995; Toomey III et al., 1993), atmospheric noble gases in ground water (Stute et al., 1992), and speleothem growth rates (Musgrove et al., 2001) have all been used to locally reconstruct glacial climate in central Texas, and collectively indicate that glacial periods were cooler [∼5 °C] and wetter than present-day interglacial conditions.

2.2. Stratigraphy and chronology of the Texas coastal plain

Within the inner coastal plain upstream of the hinge zones (Fig. 1), denoted by the transition between long-term net erosion and net aggradation, the rivers flow through mixed bedrock-alluvial valleys (Blum et al., 2013; Blum and Aslan, 2006; sensu Howard et al., 1994), with flights of down-stepping terraces that consist of mostly sandy point-bar deposits. Downstream, on the outer coastal plain, each river emerges onto aggradational alluvial plains where channel-belt sand is flanked by thick flood-plain muds with numerous paleosols formed during successive Quaternary interglacial sea-level highstands (Blum and Price, 1998). At a larger scale, alluvial plains from the individual rivers have coalesced to create composite and nearly seamless topographic surfaces. In the shallow subsurface, beneath aggradational highstand deposits, channel-belt sands represent glacial periods of lowered sea level, when rivers were extended across the emergent shelf and discharged to deltas at the shelf margin (Blum and Hattier-Womack, 2009; Blum and Törnqvist, 2000).

Pleistocene alluvial plains and their associated subsurface glacial-period channel belts are identified as the Early Pleistocene Lissie and Middle to Late Pleistocene Beaumont Formations (after Doering, 1935) (Fig. 1). Channel-belt deposits from the last glacial period are informally referred to as the Deweyville units (Blum et al., 1995), and post-Deweyville strata represent the post-glacial period of sea-level rise and the present sea-level highstand.

Pleistocene and Holocene fluvial deposits on the outer coastal plain are of primary interest to this study because (1) the depositional record is well preserved and mapped, (2) an independent chronostratigraphic framework exists (Blum and Price, 1998; Blum and Valastro, 1994; Garvin, 2008), and (3) the glacial or interglacial context is known for targeted Beaumont and post-Beaumont [Deweyville and Holocene] deposits based on mapping of stratigraphic relationships from cores and cutbank outcrops, soil development, topographic projection of surfaces, and supporting geochronological data (see Blum and Aslan, 2006 and references therein). Due to the composite nature of the coastal-plain deposits and lack of topographic expression, resolution of regional depositional ages beyond the glacial–interglacial cycles cannot be inferred from an age obtained elsewhere within a mapped unit. Thus, all sampling sites used for paleo-denudation rate measurements require chronological analysis (Table 1).

2.2.1. Lissie Formation

Precise age control for the Lissie Formation has not yet been obtained. Kukla and Opdyke (1972) measured reversed magnetic polarity for Lissie floodplain deposits, and suggested deposition during the Matayama [0.79–2.5 Ma] polarity chron. Upstream in the Colorado River catchment, the Lava Creek "B" ash (∼640 ka; Lanphere et al., 2002) was observed in deposits