Earth-Science Reviews 135 (2014) 17–37

Contents lists available at ScienceDirect

Earth-Science Reviews

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

Flood stratigraphies in lake sediments: A review

Daniel N. Schillereff *, Richard C. Chiverrell, Neil Macdonald, Janet M. Hooke

School of Environmental Sciences, Roxby Building, University of Liverpool, Liverpool L69 7ZT, United Kingdom

ARTICLE INFO

Article history:
Received 30 September 2013
Accepted 31 March 2014
Available online 13 April 2014

Keywords:
Lake sediments
Palaeoflood
Geochemistry
Particle size
Limnology
Extreme events

ABSTRACT

Records of the frequency and magnitude of floods are needed on centennial or millennial timescales to place increases in their occurrence and intensity into a longer-term context than is available from gauged river-flow and historical records. Recent research has highlighted the potential for lake sediment sequences to act as a relatively untapped archive of high-magnitude floods over these longer timescales. Abyssal lake sediments can record past floods in the form of coarser-grained laminations that reflect the capacity for river flows with greater hydrodynamic energy to transport larger particles into the lake. This paper presents a framework for investigating flood stratigraphies in lakes by reviewing the conditioning mechanisms in the lake and catchment, outlining the key analytical techniques used to recover flood records and highlighting the importance of appropriate field site and methodology selection. The processes of sediment movement from watershed to lake bed are complex, meaning relationships between measureable sedimentary characteristics and associated river discharge are not always clear. Stratigraphical palaeoflood records are all affected to some degree by catchment conditioning, fluvial connectivity, sequencing of high flows, delta dynamics as well as within-lake processes including river plume dispersal, sediment focussing, re-suspension and trapping efficiency. With regard to analytical techniques, the potential for direct (e.g., laser granulometry) and indirect (e.g., geochemical elemental ratios) measurements of particle size to reflect variations in river discharge is confirmed. We recommend care when interpreting fine-resolution geochemical data acquired via micro-scale X-ray fluorescence (μXRF) core scanning due to variable down-core water and organic matter content altering X-ray attenuation. We also recommend accounting for changes in sediment supply through time as new or differing sources of sediment release may affect the hydrodynamic relationship between particle size and/or geochemistry with stream power. Where these processes are considered and suitable dating control is obtained, discrete historical floods can be identified and characterised using palaeolimnological evidence. We outline a protocol for selecting suitable lakes and coring sites that integrates environmental setting, sediment transfer processes and depositional mechanisms to act as a rapid reference for future research into lacustrine palaeoflood records. We also present an interpretational protocol illustrating the analytical techniques available to palaeoflood researchers. To demonstrate their utility, we review five case studies of palaeoflood reconstructions from lakes in geographically varied regions; these show how lakes of different sizes and geomorphological contexts can produce comprehensive palaeoflood records. These were achieved by consistently applying site-validated direct and proxy grain-size measurements; well-established chronologies; validation of the proxy-process interpretation; and calibration of the palaeoflood record against instrumental or historical records.

Contents

* Corresponding author. Tel.: +44 151 794 2858; fax: +44 151 795 2866.
E-mail address: dns@liv.ac.uk (D.N. Schillereff).

http://dx.doi.org/10.1016/j.earscirev.2014.03.011

1. Introduction

1.1. Rationale behind lake palaeoflood research

Researchers (e.g., Milly et al., 2002; Gorman and Schneider, 2009) have suggested that the frequency and intensity of extreme flood events may be increasing due to the high sensitivity of the hydrological cycle to a warming climate (Knox, 2000), triggering an intensification of the water cycle (Huntington, 2006). Recent modelling by Hirabayashi et al. (2013) projects a current 100-year return period flood is likely to occur every 10–50 years in the 21st century. However, the complexity inherent in the climate–flood relationship, coupled with the infrequent and short-lived nature of extreme floods, means few data are available for evaluating long-term trends in their frequency and magnitude (IPCC, 2012). Acquiring long-duration datasets of historical floods that extend beyond available instrumental records is clearly an important step in attributing trends in flood frequency and magnitude to climate change and addressing future flood risk. Conventional flood histories derived from instrumental data rarely span sufficiently long timescales to capture the most extreme events (Brázdil et al., 1999; Macdonald, 2012) nor do they enable climatic (non-)stationarity or the attribution of the intensification of precipitation events by global warming to be assessed (Min et al., 2011). Various sources are routinely accessed in order to acquire information on historical floods on timescales extending beyond the instrumental record, including documentary records (e.g., Benito et al., 2004) and sedimentary records extracted from river flood-plains and slackwater deposits (e.g., Baker, 1987).

Lakes act as efficient repositories for clastic material eroded from catchment slopes and floodplains and subsequently transported through the fluvial system (Mackereth, 1966; Oldfield, 2005). If the hydrodynamic relationship between river discharge and entrainment potential of specific particle sizes is reflected in the materials received by the lake basin and incorporated into the sediment record, high-magnitude flows should appear as distinct laminations of coarse material. As a result, a growing number of palaeolimnologists are searching for lake sediment sequences from which records of past floods can be uncovered (e.g., Noren et al., 2002; Czymzik et al., 2013; Gilli et al., 2013; Wilhelm et al., 2013; Wirth et al., 2013a,b; Schlolaut et al., 2014). Lake sediment records can contribute valuable data on flood frequency and, potentially, single-event magnitude over several millennia (Noren et al., 2002). Improvements in the mechanics of coring technology (e.g., UWITEC-Niederreiter (Schultze and Niederreiter, 1990); Mingram et al., 2006) and resolution of analytical methods (e.g., micro-scale X-ray fluorescence (μXRF); Croudace et al., 2006) have aided the extraction of palaeoflood records from lakes in Africa (Baltzer, 1991; Reinwarth et al., 2013), Asia (Ito et al., 2009; Nahm et al., 2010; Li et al., 2013; Schlolaut et al., 2014), Europe (Arnaud et al., 2002; Bøe et al., 2006; Wilhelm et al., 2012; Wirth et al., 2013a), New Zealand (Orpin et al., 2010; Page et al., 2010), North America (Brown et al., 2000; Noren et al., 2002; Osleger et al., 2009) and South America (Chapron et al., 2007; Kastner et al., 2010).

A comprehensive review of the acquisition of flood frequency and magnitude data from lake sediments, the proxies available and the challenges that may hinder robust interpretation is thus timely. Here we outline the flow processes and physical controls on river plume dispersal both to and within a lake, assess how process-controls map to the lake stratigraphical record and evaluate the proxies employed by palaeolimnologists to identify palaeoflood deposits. This paper presents a conceptual model that assesses the catchment-to-lake water and sediment flow pathways and their relative importance for the successful extraction of palaeoflood sequences. It also develops a decision tree outlining the analytical procedures available for identifying and interpreting these data and presents five case studies where these protocols have been applied to reconstruct palaeofloods at widely distributed lakes with different characteristics.

1.2. Non-lacustrine sources of flood data

Gauged river flow data are widely available for the last 30–40 years in Australia and most European countries (Benito et al., 2004), a comprehensive hydrometric network (>3000 gauging stations) has existed in Canada since 1975 A.D. (Pyrce, 2004), and the United States Geological Survey (USGS) has operated an effective, centralised stream gauging programme since 1970 A.D. (Benson and Carter, 1973). In