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Dating of debris flow fan complexes from Lantau Island, Hong Kong, China: The potential relationship between landslide activity and climate change

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ABSTRACT

Five debris flow fan complexes bordering the coastal foothills of western Lantau Island, Hong Kong, have been the subject of a stratigraphic and dating study to explore the potential relationship between past periods of climate change and landslide activity. Luminescence (OSL) ages from the fan complexes, supported by a few calibrated radiocarbon (^{14}C) ages on duplicate samples, suggest six main periods of accumulation: 28,000–20,000 ka, 14,500–10,500 ka, 5800–5000 ka, 4370–4230 ka, 3560–3320 ka, and 1350–1050 ka. The younger periods (<10,000 ka) appear to be dominated by relatively thin (0.5–1.5 m) units deposited mainly by debris flood events whereas the older periods are dominated by thicker (1.0–3.5 m) units deposited by debris flow events. We hypothesise that immediately prior to the Last Glacial Maximum (LGM, i.e., 21,000 ka), the climate was cool and dry. Upland areas were probably devoid of vegetation, providing favourable conditions for sediment production in source areas. These debris-laden source areas are likely to have been mobilised during periodic rainstorm activity, rapidly channelised over relatively short drainage courses, and then deposited as thick, sediment-rich, debris flow deposits along the coastal foothills. During the early to middle Holocene, the climate was warmer and more humid. Pluvial conditions dominated; forests occupied the upland source areas, leading to possibly reduced sediment yields, more frequent flash floods and deposition dominated by debris floods. Compared with recent studies on the weathering and erosion history of the Pearl River Delta, our landslide age data are indicative of a potential link between increased landslide activity and intensification of the East Asian monsoon during the early to middle Holocene.

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1. Introduction

Understanding the landscape response to climate change has become a high priority topic of research following confirmation of unequivocal warming of the global climate system (IPCC, 2007, 2013). Recent projections for East Asia, including Southeast China, suggest rises in sea level of between 0.48 and 1.0 m by 2100 coupled with intensification of the East Asia monsoon. Current Probable Maximum Precipitation (PMP) analysis (e.g., Lin, 2009) suggests the likelihood of increased frequency of extreme weather events, including typhoons, and unprecedented extreme rainfall events.

With a population of over 7 million people concentrated within a relatively small, predominantly steep area (1104 km^2), the Hong Kong Special Administrative Region, China (hereafter Hong Kong), is especially vulnerable to extreme weather events. Landslides and flooding are the most readily identifiable natural hazards but little is known about how the steep terrain in general will respond to climate change and what the characteristics of the landslides will be under these new conditions.

Debris flow fan complexes along mountain range fronts are known to be sensitive indicators of changes in hydrological conditions and hence may serve as a proxy for climate change (Nott et al., 2001; McDonald et al., 2003; Thomas, 2004; Dühnforth et al., 2007; Sohn et al., 2007; Crozier, 2010). Previous research in high altitude, arid areas has revealed that changes in landslide activity can be linked with changes in climate (Bookhagen et al., 2005; Dortch et al., 2009; Borgatti and Soldati, 2010; Reynard et al., 2012; Stoffel et al., 2014). However, it is uncertain to what effect such a link can be extended to include low altitude, subtropical climates. In order to explore these issues, this study focuses on five large debris flow fan complexes which have

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the morphology of alluvial fans but are composed dominantly of debris flow and debris flood deposits (hereafter debris fan complexes) along the coastal foothills of western Lantau Island (Fig. 1) to examine how the Hong Kong landscape has responded to past periods of climate change, the timing of these changes, and the characteristics of the landslide deposits.

2. Background

In 2004, the Geotechnical Engineering Office of the Civil Engineering and Development Department (GEO/CEDD) commenced a high precision numerical landslide dating programme in order to assist with landslide hazard assessments. The first step was to conduct a pilot study to test which methods of dating landslides would be most suitable for Hong Kong (Sewell and Campbell, 2005). The study proved that radiocarbon dating, optically stimulated luminescence (OSL) dating, and surface exposure dating (cosmogenic nuclide dating) could be applied reliably and effectively, despite the seemingly unfavourable circumstances of low altitude and low latitude (Sewell et al., 2006). Subsequently, a broader dating study was carried out to examine the potential relationship between neotectonic activity and natural terrain landslides. Although no unequivocal link could be established between neotectonic activity and landslides, nevertheless, by 2012, 24 landslide sites across Hong Kong, featuring mostly deep-seated scarps and debris lobes, and also some clusters of boulders from rockfalls, had been successfully dated (Sewell and Tang, 2015).

The occurrence of numerous debris flows and debris floods in catchments supplying fans along the coastal foothills of western Lantau Island during a severe rainstorm in June 2008 provided the impetus for this study. The rainstorm was especially intense, with over 670 mm of rain falling within 48 h, including a one-hour period when more than 100 mm was recorded (Lam et al., 2012). Over 2400 small volume (mostly <1000 m^3) landslides (Wong, 2009) were generated, some of which resulted in debris flows and debris floods with unusually long run-outs (AECOM Asia Company Limited, AECOM, 2012). Thus, the June 2008 rainstorm highlighted the possibility that a change in landslide behaviour might be linked to a changing climate. Accordingly, a project examining how the landscape might have responded to past periods of climate change was initiated, particularly focusing on debris fan complexes along the coastal foothills of western Lantau Island. Key objectives were to: 1. obtain numerical age data on debris fan deposits to calibrate landslide activity with the timescale of responses to climate change, 2. integrate these new data with previously acquired age data on deep-seated landslides and rockfalls, and 3. forecast possible future behaviour of Hong Kong landslides with respect to IPCC climate change models.

3. Physiological and geological setting

Hong Kong has a humid subtropical climate and experiences an average annual rainfall of about 2200 mm. Its location on the edge of the northwest Pacific tropical cyclone belt means that during the summer months an average of 5 to 7 typhoons per year approach within 500 km of the territory. The East Asian Summer Monsoon blows mainly from the southwest during the months of April to September, while the East Asian Winter Monsoon blows from the northeast during the months of October to March. On average, 320 landslides per year are recorded on Hong Kong's steep natural terrain (Wong et al., 2006) which comprises 60% of the land area and reaches a maximum elevation of about 956 m above mean sea level.

Western Lantau Island, Hong Kong, is underlain mainly by Upper Jurassic silicic ash-flow tuffs and volcaniclastic rocks (Langford et al., 1995; Sewell et al., 2000; Campbell et al., 2007). The highest point is Lantau Peak (934 m) which lies on a central divide separating drainage basins from the north and south (Fig. 1). A narrow (600 m) strip of low land along the northern coast is underlain by Jurassic sedimentary rocks, intruded by granites and mainly in fault contact with the volcanic rocks. As there is no strong evidence for faults displacing Late Pleistocene and Holocene superficial deposits in Hong Kong, it is considered that local neotectonic fault movement has not had a major influence on natural slope stability (Sewell and Tang, 2015).

The foothills along the northern coast are bordered by numerous fans that are thought to have been active since the Late Pleistocene (Langford et al., 1995). These debris fans emanate from relatively short stream courses with small catchments that drain the steep volcanic

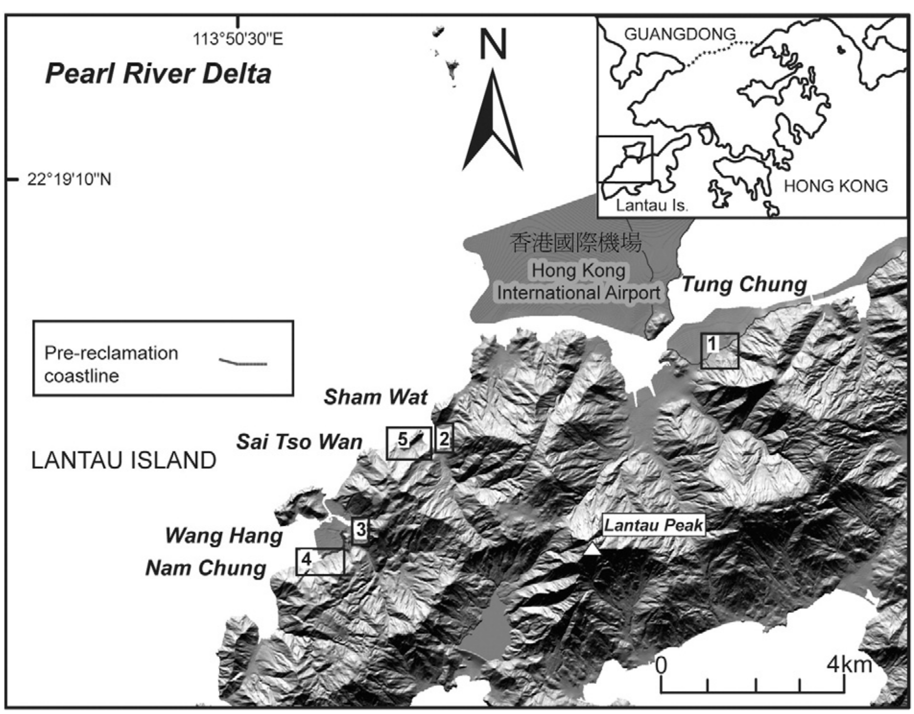

Fig. 1. Location map of dated fan complexes on Lantau Island.

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