This thematic set of papers is intended to raise awareness of the types, nature, effects and impacts of geohazards in Central China. The papers will be published in this and subsequent issues of *QJEGH* and demonstrate the significant impacts that are wrought on the lives and livelihoods of those who live and work in the mountainous areas of Central China.

China is all too often in the news as a result of geohazards that have a severe impact on lives and livelihoods. The mountainous terrain of Central China is subject to frequent hazards of high intensity with recent examples such as the 2008 Wenchuan earthquake and the 2010 Zhouqu debris flow. Rapid economic development brings with it expansion of urban centres and infrastructure networks, which not only increases the exposure of the population to natural processes in a dynamic environment, but can also lead to further strains on a landscape that is only marginally stable. Frequent geohazard events have sparked much research in an effort to better understand processes and material properties that can be used to inform and implement effective strategies to mitigate against the negative consequences of these geohazards.

Owing to their location along the eastern margins of the Tibetan Plateau the provinces of Gansu, Sichuan and Yunnan are particularly affected by geohazards (Fig. 1). This tectonically active region is strongly affected by continuing uplift and, towards the east and NE, crustal stress release has resulted in the formation of some very large systems of NNE–SSW- and WNW-ESE-trending strike-slip and thrust fault zones (e.g. Dijkstra *et al.* 1993). Differences in relative uplift and displacement along these faults have had a significant impact on the present physiography of Central China. Several important geohazard regions can be distinguished and in this introduction we briefly highlight issues in two of these regions: the loess plateau of the Lanzhou region and the mountainous fringes along the northeastern and eastern margins of the Tibetan Plateau.

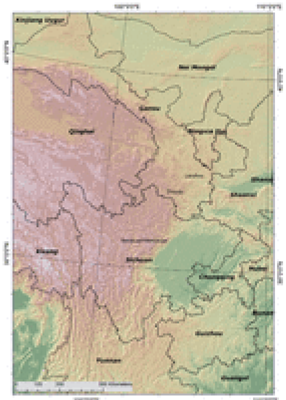

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Fig. 1.

Shaded relief map of Central China, based on ChinaW Dataset (©Zumou Yue, G. William Skinner and Mark Henderson, University of California, Davis, Regional Systems Analysis Project, January 2007) and CHGIS, Version 4 (Harvard-Yenching Institute, Cambridge, MA, January 2007). Provincial and country boundary information from gadm.org v2.0 (January 2012).

Geohazards in the Lanzhou loess region

The extensive Loess Plateau covering much of Gansu, Ningxia and Shaanxi provinces provides an environment of tremendous economic opportunity for the people of China. The fertile soils that developed in these thick aeolian silt deposits have long been regarded as worthy of protection from hostile forces from the north, and Smalley (1968) attributed the positioning of the Great Wall of China to the need to protect this valuable resource. However, exploiting the benefits of these soil resources comes at a price. Loess is a metastable material and mass movements are a frequent occurrence that can have severe impacts. In 1920 the Haiyuan earthquake (magnitude 7.8) triggered a very large number of landslides in loess, predominantly in the form of rapidly moving flow slides (Zhang & Wang 2007). Close & McCormick (1922) described the scenes as ‘Mountains that moved in the night; landslides that eddied like waterfalls, crevasses that swallowed houses and camel trains and villages that were swept away under a rising sea of loose earth’. Estimates of the human cost vary widely, but it is generally accepted that more than 200000 people lost their lives during these events. This was one of the deadliest earthquake events in history, mainly as a consequence of the large number of landslides that were generated by the seismic shocks.

Lanzhou is the capital of Gansu Province and the landslides occurring in the thick loess deposits of this western part of the Chinese loess plateau have been well documented by Derbyshire *et al.* (2000) and Dijkstra (2000). These metastable slopes continue to affect socio-economic development in this region. Owing to the physiographic constraints of this region, Lanzhou has been developed on a set of fluvial terraces of the Yellow River (elevations of *c.* 1500 m above sea level (a.s.l.)) and is surrounded by a hilly to mountainous terrain formed in predominantly thick loess deposits that cover a partly planated bedrock surface. At Jiuzhoutai Mountain (2067 m a.s.l.) in north-central Lanzhou, loess reaches its greatest thickness of some 325 m (Derbyshire *et al.* 2000). Elsewhere in the Lanzhou region, thicknesses between 50 and 100 m are commonly observed. Creating space to accommodate urban expansion requires levelling of large parts of the hills surrounding the city and this has been progressing for more than 25 years (Fig. 2).

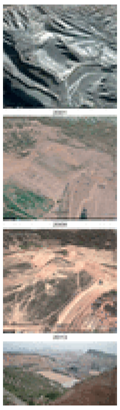

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Fig. 2.

Examples of landscape transformation in the Lanzhou region. Upper three images are satellite images from Google Earth™. (Google and the Google logo are registered trademarks of Google

Inc., used with permission.) The lowermost photograph (by J. Wasowski, 2012) is a view of landscape modifications that continue to take place in north-central Lanzhou, taken from a position just south of the images above and looking north.

Steep cut slopes in thick loess deposits provide an obvious hazard, but potentially the greatest hazard lies embedded in the ground. Extensive cut and fill operations have been taking place without apparent controls on the density and drainage of the fill. Loess is well known for its propensity to undergo significant volume reduction upon wetting, and piping erosion occurs throughout this region. It is therefore anticipated that along pre-existing drainage paths fabric collapse will progress, which ultimately will lead to widespread surface deformations and damage to construction and infrastructure. Large-scale cut and fill levelling exercises are taking place in many cities in China, often without proper engineering and scientific support, and with limited understanding of the geological and hydrogeological conditions. This poses a potentially severe risk to ground stability and the environment (e.g. Li *et al*. 2014).

Afforestation and other changes in land use have resulted in alterations of the groundwater regimes in these thick aeolian silts. Loess is very sensitive to changes in moisture content and can, upon wetting, transform from an open, cemented structure to a cohesionless, fine granular material. When this occurs, large and fast-moving mass movements are generated (Fig. 3). In 2009 such an event led to the destruction of a residential apartment block in Lanzhou, killing one of the occupants. It is thought that this landslide was caused by elevated groundwater levels gradually building up in the loess. The 2013 image of Figure 3 clearly shows the extent to which slope modification and stabilization are taking place.

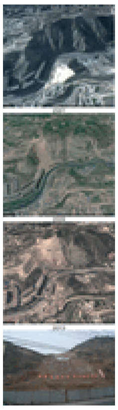

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Fig. 3.

Examples of the impact of loess landslides in the Lanzhou urban environment and the intensive slope modifications and stabilization interventions that are required to safeguard lives and livelihoods in this dynamic environment. Upper three images are satellite images from Google Earth™. (Google and the Google logo are registered trademarks of Google Inc., used with permission.) Lowermost photograph (by T. Dijkstra, December 2009) is a view of the 2009 landslide, taken from the street level in the centre of the images above.

Geohazards in the mountains of south Gansu and Sichuan

The Wenchuan earthquake of 12 May 2008 affected an area of more than 50000 km^2 and resulted in around 80000 fatalities. The stability of the landscape was severely compromised. Probably the largest recorded event database resulting from a single trigger was constructed and analysed by Xu *et al.* (2013). This database contains some 196007 landslides, collated following an intensive campaign of air-photograph and satellite interpretation. Throughout this region, covering much of north-central Sichuan and south Gansu, the mountainous slopes have now become sensitized to generate mass movements and it is likely that for the foreseeable future instability in the landscapes can be generated at much lower thresholds than before the Wenchuan earthquake, particularly for the initiation of debris flows (Cui *et al.* 2011).

In this mountainous terrain, limited vegetation cover, high-relief steep slopes and narrow valleys draining large catchments result in a rapid response of river flow regimes to rainfall inputs. This was the case in the night of 7–8 August 2010 in Zhouqu, in south Gansu. Only 30 min of very intense rainfall (>70 mm h^{-1}) was sufficient to mobilize material discharging at more than 1300 m^3 s^{-1} and reaching an estimated 10 m s^{-1} peak flow velocity (Tang *et al.* 2011*a*). The town is located on a fan structure that was formed by previous events and the small channel through the town could not contain the material that was delivered, and, as a consequence, the debris flow created a new wider path, leaving a trail of destruction and causing the deaths of more than 1700 people (Tang *et al.* 2011*a*; Dijkstra *et al.* 2012; Fig. 4).

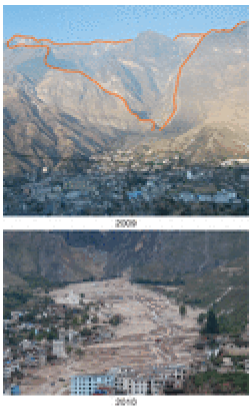

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Fig. 4.

The town of Zhouqu in 2009 before the debris-flow disaster, and in October 2010, 2 months after the disaster. The grey line in the 2009 photograph indicates the outline of the Sanyangyu watershed. (photographs T. Dijkstra).

The potential threat from debris flows in this region was well understood and a number of check dams were constructed in the mountainous catchments as part of a larger scheme to reduce the impact of debris flows on the settlements in the valleys below (e.g. Ma & Qi 2007; Ma 2010). However, the intensity of this event was many times greater than the design profile of these dams. It can be argued that, rather than reduce the consequences, these dams provide further material for entrainment in the debris flow and this contributed to the magnitude of the resulting event. There is also evidence that major rockfalls, possibly triggered by large earthquakes, impart controls on the longitudinal profiles of tributary channels. This results in abundant loose material forming large obstacles in narrow river valleys. Once sufficient erosive power is generated, these barriers provide ample material for entrainment into rapid discharges (Dijkstra *et al*. 2012).

The Zhouqu disaster triggered substantial investment in research, disaster relief and hazard management. It has also resulted in the construction of substantial debris-flow control structures. These appear sufficiently robust to halt, or at the very least slow down, large future debris flows in this valley and provide a measure of protection for the town of Zhouqu (Figs 5 and 6). However, elsewhere in the region, poorly constructed dams still exist and these continue to pose a potential danger for those living downstream, both in terms of a complacency creep (i.e. a gradual loss of awareness of geohazards occurrence when small events are successfully captured upstream) and impact magnification (as deposits of small debris-flow events accumulate in upland catchments; one large event may mobilize much of this stored material). In a broader context the question needs to be addressed whether an approach to constrain or even halt the progress of natural processes in such a dynamic terrain is a sustainable long-term strategy.

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Fig. 5.

The main discharge channel of the Zhouqu debris flow in October 2010 (top) and September 2012 (bottom) (photographs T. Dijkstra).

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Fig. 6.

Engineered interventions in the discharge channels of the Sanyangyu valley where the Zhouqu debris originated; October 2010 (left) and September 2012 (right) (photographs T. Dijkstra).

The thematic set on Geohazards in Central China

In recognition of the severe impact that geohazards have on lives and livelihoods in the mountainous regions of Central China much research has been carried out at a large number of research institutions and universities. In September 2012, the first symposium on new techniques for geohazards research and management was held at Lanzhou University. At this meeting it was decided to facilitate the publication of a thematic set of papers addressing geohazards research in the Central China region. There is much valuable research undertaken in this region and, through publication in the *Quarterly Journal of Engineering Geology and Hydrogeology*, it is hoped that these research outcomes will reach an important additional target audience. To design appropriate geohazard management strategies (in terms of reducing the potential for hazards to occur, and reducing the vulnerability and enhancing the resilience of local communities) requires an understanding of geological structures and tectonic activity, hydrogeology and drainage, geomorphology and geotechnics. This needs to be put into an environmental context that is strongly influenced by socio-economic development. The understanding of weather impacts and long-term trends of climate change is still developing, but the importance of rainfall triggering major geohazards is clearly recognized, particularly in an area where seismic activity provides an additional driver to heighten the susceptibility of landscapes to generate marginally stable slopes (e.g. Tang *et al*. 2011*b*). In this dynamic environment the key characteristics of landslides, debris flows and associated landforms are often removed rapidly by the very instability that causes them. Mostly, our understanding of the processes is derived from small-scale laboratory experiments, requiring upscaling that may affect the relevance of the observations. However, this region of Central China provides a unique field laboratory that is gradually being explored to gain a better understanding of the risks posed by geohazards.

This first instalment of the thematic set covers two contributions representative of geohazard aspects in the two main regions discussed above: one on the effect of pore water chemistry on undrained shear behaviour of saturated loess (Zhang *et al*. 2014) and one on debris-flow analysis using a stepwise discriminant analysis and extension theory (Niu *et al*. 2014).

Zhang *et al*. provide a detailed account of ring-shear tests on saturated loess with various NaCl concentrations in the pore water to achieve a better insight into the behaviour of irrigation-induced loess landslides.

Niu *et al*. provide an analysis of debris-flow hazards in south Sichuan-north Yunnan, where some 27 debris-flow prone valleys have been identified that could potentially cause a serious threat to a hydropower station, and establish an approach to determine the degree of hazard that each of the 27 debris-flow prone valleys poses.

These first two papers form the start of a series of contributions on Geohazards in Central China that will appear in subsequent issues of the QJEGH. It is hoped that this will provide a showcase for the research currently being carried out on this topic in China.