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Earthquake-induced soft-sediment deformation structures in Late Pleistocene lacustrine deposits of Issyk-Kul lake (Kyrgyzstan)

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ABSTRACT

This paper discusses the composition and distribution of soft-sediment deformation structures induced by liquefaction in Late Pleistocene lacustrine terrace deposits on the southern shore of Issyk-Kul Lake in the northern Tien Shan mountains of Kyrgyzstan. The section contains seven deformed beds grouped in two intervals. Five deformed beds in the upper interval contain load structures (load casts and flame structures), convolute lamination, ball-and-pillow structures, folds and slumps. Deformation patterns indicate that a seismic trigger generated a multiple slump on a gentle slope. The dating of overlying subaerial deposits suggests correlation between the deformation features and strong earthquakes in the Late Pleistocene.

1. Introduction

To better understand the earthquake history of an area, it is important to study evidence for paleo-earthquakes. Seismites are layers deformed by seismic shaking that triggered liquefaction and associated upward movement of fluid and sediment (Seilacher, 1969; Sims, 1975; Allen, 1970, 1986; Obermeier, 1996; Montenat et al., 2007 and many others). At the surface they can be represented by mud or sand ejections from ground fissures, mud volcanoes, gryphons, etc. The widespread occurrence of seismites makes them an important indicator for seismic hazard assessment and they have been reported from most seismically active regions throughout the world (Hempton and Dewey, 1983; Anand and Jain, 1987; Green et al., 1991; Mohindra and Thakur, 1998; Jones and Omoto, 2000; Moretti, 2000; Rodríguez-Pascua et al., 2000; Bowman et al., 2001; Monecke et al., 2004; Obermeier et al., 2005; Povolotskaya et al., 2006; Moretti and Sabato, 2007; Perucca et al., 2007; Deev et al., 2009, 2012, 2013, 2015; Moernaut et al., 2009; Reddy et al., 2009; Gibert et al., 2011; Taşgın, 2011; Mishra et al., 2013; Korzhenkov et al., 2014; Lunina et al., 2014; Sissakian et al., 2014; Toro et al., 2015; Zheng et al., 2015; and others). Analysis of the spatial distribution and dating of seismites allows for accurate estimations of the parameters of known seismogenic structures and the identification of previously unknown epicenters of paleoearthquakes (Mc Calpin, 2009; Allen, 1986; Obermeier et al., 2005; Rodríguez-Pascua et al., 2000; Lunina and Gladkov, 2015; and others). However, it remains a challenge to differentiate between earthquake-induced deformation and deformation structures of other origins (Mc Calpin, 2009; Owen et al., 2011).

This work is focused on the recognition of seismites amongst deformation structures in the deposits of Issyk-Kul Lake (Kyrgyzstan). Issyk-Kul Lake is located in the Northern Tien Shan, which is an active continental orogenic zone and part of the Himalayan mountain belt that formed as a result of the collision between the Indian and Eurasian plates (Fig. 1). The region is characterized by frequent seismic activity and is known for strong earthquakes. Previously reported seismites from the northern shore of Issyk-Kul Lake (Korjenkov, 2000; Bowman et al., 2004; Povolotskaya et al., 2006; Korzhenkov et al., 2015; and others) demonstrate that Middle Pleistocene and Holocene lacustrine deposits are susceptible to intensive seismic shaking. We study sedimentary deposits on the southern shore of Issyk-Kul Lake, near Tossor Village, where fieldwork in 2013–2014 identified horizons with soft-sediment deformation features of inferred seismic origin.

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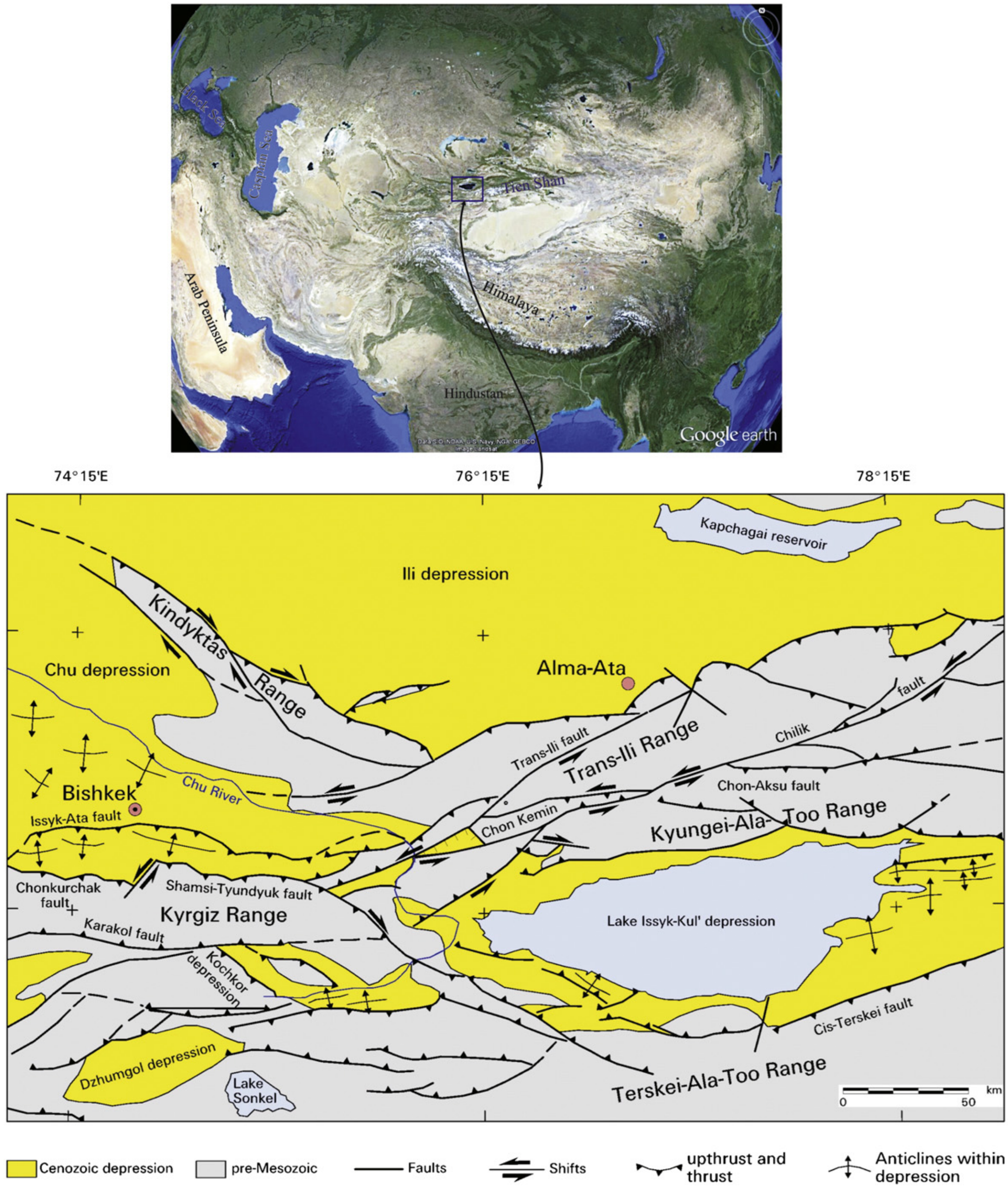

Fig. 1. Neotectonic structures of the Issyk-Kul depression, Kyrgyz Range and eastern Chu depression. (After Delvaux et al., 2001.)

2. Geological setting

The modern Tien Shan Range is an active intracontinental mountain belt in Central Asia (Delvaux et al., 2001) that has been developing between the Tarim and Kazakhstan plates since the Miocene (Abdrakhmatov et al., 1996). It is characterized by intense seismic and tectonic activity.

The Tien Shan was intensely reactivated in the Tertiary, following the India–Eurasia collision (Tapponnier and Molnar, 1979; Cobbold and Davy, 1988). Sedimentation, compressional deformation, and unroofing started in the Late Oligocene (Chediya, 1986; Cobbold, 1996) or Middle Miocene (Hendrix et al., 1994; Avouac et al., 1993). Preliminary paleostress investigation indicated that the Paleogene and Neogene deformation was the result of a compressive stress field with N–S horizontal principal compression (Chediya, 1986; Cobbold et al., 1996). The present-day stress field is still characterized by N–S compression (Gushchenko, 1979). A map of active faults of the Kyrgyz Tien Shan has been compiled by Abdrakhmatov et al. (2001). The present rate of N–S overall shortening across the Tien Shan is estimated at −20 mm/year on the basis of GPS measurements in Kazakhstan, Kyrgyzstan (Abdrakhmatov et al., 1996), and China (Michel et al., 1997).

The Issyk-Kul lake area in the northern Tien Shan (Fig. 1) is a tectonic ramp depression bordered by convergent thrust faults dipping in opposite directions (Chediya, 1986). In the north, the Issyk-Kul depression is bounded by the Kungey ridge and a set of en echelon thrust faults — the west Toguz-Bulak, Kultor, northern Aksu and Taldy-Bulak faults. The Terskey ridge bounds the depression in the