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Late Quaternary active faulting and landscape evolution in relation to the Gowk Fault in the South Golbaf Basin, S.E. Iran

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ABSTRACT

We present ten infra-red stimulated luminescence (IRSL) ages of feldspar grains within lake-bed sediments and alluvial fan gravels displaced by the Gowk Fault, SE Iran. Our results show that lake deposition in the South Golbaf basin was ongoing from at least 13.5 ka (the deepest exposed sediments) until the mid-Holocene. Furthermore, the South Golbaf palaeo-lake is likely to have spilled into the neighbouring Golbaf basin at 6.3 ± 0.2 ka. This event led to a widespread incision of the lake-bed and neighbouring alluvial fan surfaces as the drainage systems adjusted to the new base-level. Our constraint on the age of the South Golbaf palaeolake, combined with measurements of 30 ± 5 m of right-lateral displacement of stream channels incised into the lake-beds, yields a slip-rate of 3.8–5.7 mm/yr. The deposition of alluvial fans around the margins of the South Golbaf depression appears to have largely ended by 12.9 ± 0.7 ka. Right-lateral displacements of up to 60 m are observed in streams cut into the fan surfaces, yielding a second slip-rate estimate of ~4.4–4.9 mm/yr. Much of the widespread incision of the ~12.9 ka fan surfaces does not appear to have taken place until ~6 ka later, when overtopping of the South Golbaf palaeolake and the adjustment of drainage to a lower base-level, promoted widespread drainage incision.

1. Introduction

The Gowk right-lateral strike-slip fault in eastern Iran (Fig. 1) is one of a number of faults that accommodate ~15 mm/yr of the north–south, right-lateral shearing between Afghanistan and the interior of Iran (e.g. Vernant et al., 2004; Walker and Jackson, 2004; Meyer and LeDortz, 2007). It forms the central segment of the Sabzevaran-Gowk-Nayband Fault system, which bounds the western margin of the Dasht-e-Lut depression, and is one of the most prominent active faults in Iran (e.g. Berberian, 1976; Berberian et al., 2001; Walker and Jackson, 2002).

The Gowk Fault has a proven record of generating destructive earthquakes (Fig. 2); parts of it ruptured in 1981.06.11 (Mw 6.6); 1981.07.28 (Mw 7.1); 1989.11.20 (Mw 5.8); 1998.03.14 (Mw 5.4) and 1998.11.18 (Mw 6.6). The high level of earthquake activity in recent decades may be part of a longer sequence of activities; as several historical events on the Gowk Fault (and immediate surroundings) are recorded in the 19th and 20th centuries (e.g. Berberian et al., 2001; Berberian, 2005; Walker et al., 2010). However, the southern ~100 km of the fault — sometimes labelled the Sarvestan Fault (e.g Berberian, 1976; Walker and Jackson, 2002), is not associated with any recent or historical events. There is also a wider seismic hazard in the region around the Gowk Fault, as the Sarvestan Fault segment is close to the epicentral zone of the devastating Bam earthquake (Mw 6.6; e.g. Talebian et al., 2004; Berberian, 2005) of 26.12.2003 and, more recently, a pair of earthquakes south of the town of Rigan, ~120 km SSE of Bam (Fig. 2), in December 2010 and January 2011 (Walker et al., 2013).

The late Quaternary slip-rate of the Sabzevaran Fault – situated south of the Gowk Fault – is constrained at 4.0–7.4 mm/yr from cosmogenic ^{10}Be dating of surface boulders embedded in displaced landforms (Regard et al., 2005) whereas the Nayband Fault – situated north of the Gowk Fault – has a slip-rate of 0.9–1.9 mm/yr determined from the displacement of volcanic rocks with Ar-Ar ages of ~2.2 Ma (Walker et al., 2009). The apparent northward decrease in right-lateral slip-rate probably results from the westward transfer of some of the slip on the Sabzevaran-Gowk-Nayband system to the Rafsanjan and Kuh Banan Faults (Fig. 1C). The Gowk Fault should have a slip-rate somewhere between the 4.0–7.4 mm/yr measured on the Sabzevaran Fault and the 0.9–1.9 mm/yr estimated for the Nayband Fault. However, despite its apparent importance in the regional tectonics, and the hazard that it poses to local populations, the only direct constraint that so far exists on the slip-rate of the Gowk Fault is a bound on the minimum rate, which lies within the range 3.1–4.5 mm/yr (Walker et al., 2010). The maximum possible slip-rate is not constrained. The minimum slip-rate estimate comes from the South Golbaf depression; a small enclosed

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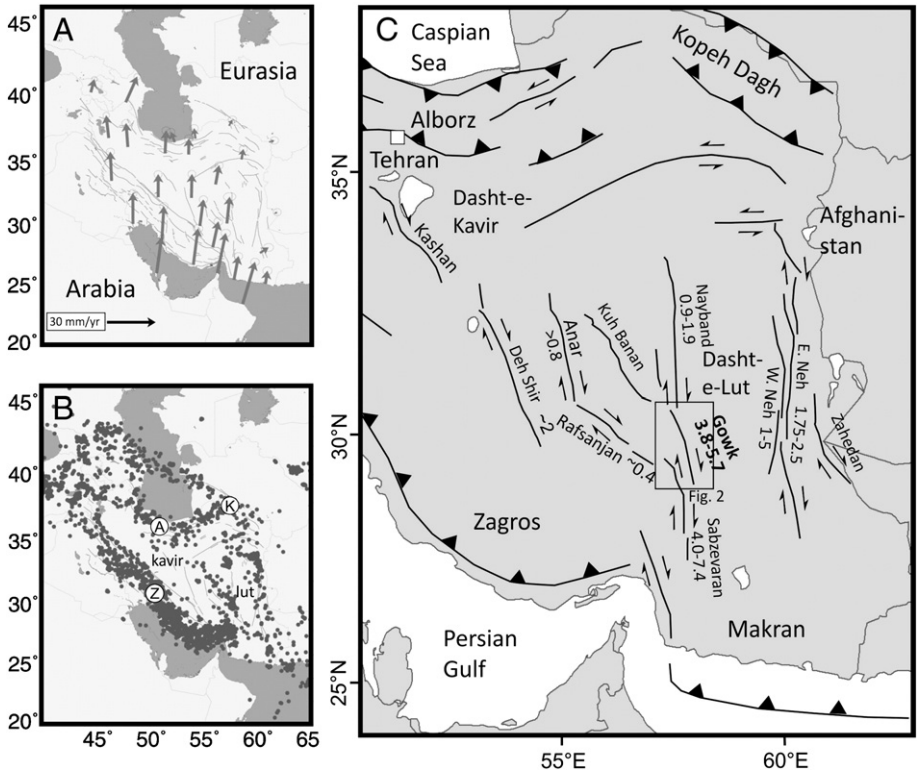

Fig. 1. (A) GPS velocities measured relative to Eurasia from Vernant et al. (2004). The GPS velocities show 16 ± 2 mm/yr of right-lateral shear across eastern Iran. (B) Epicentres of earthquakes in Iran from the catalogue of Engdahl et al. (1998). Arabia-Eurasia shortening is accommodated in the Zagros (Z), the Alborz (A) and the Kopeh Dagh (K). North–south, right-lateral shearing in eastern Iran is accommodated on faults around the Dasht-e-Lut (lut). (C) Map of Iran showing the locations and estimated slip-rates (in mm/yr) of the major strike-slip faults (from Regard et al., 2005; Meyer and Agard, 2006; Meyer and LeDortz, 2007; Le Dortz et al., 2009; Walker et al., 2009; Fattahi et al., 2011). The Gowk Fault is shown in bold.

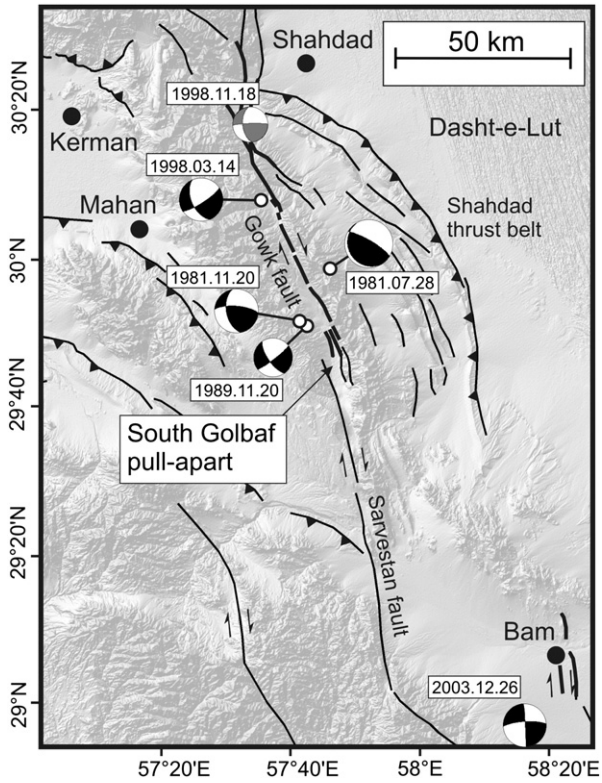

Fig. 2. Shaded relief topography of the Gowk right-lateral fault (from Walker et al., 2010). The South Golbaf pull-apart is labelled. Fault-plane solutions of the five destructive earthquakes on the Gowk Fault – which together ruptured the segments north of the South Golbaf pull-apart – and the 2003 Bam earthquake are shown (ruptured fault segments are marked by thickened lines). The Sarvestan fault segment has no record of earthquakes on it.

basin that has formed at a right-stepping segment boundary situated approximately half-way along the length of the >150 km-long fault (Fig. 2).

In this paper, we present luminescence ages from ten sediment samples from two sites in the South Golbaf depression where late Quaternary landforms have been displaced by the Gowk Fault (Fig. 3). These ages allow us to constrain both the minimum and maximum slip-rates on the Gowk Fault. But our ages are also important because they allow us to describe the last ~20,000 yrs of palaeo-environmental changes that have occurred in the South Golbaf depression; both in terms of constraining the duration and timing of alluvial aggradation at the margins of the basin and of lake deposition in its centre. At present, the region experiences a relatively arid climate, with a mean yearly total precipitation of 142 mm that arrives in rare rain storms almost entirely during the winter and spring months (data from the World Meteorological Organisation for Kerman city and averaged over the period 1961–1990; http://www.worldweather.org/). The sedimentological evidence for year-round standing water in the recent geological past hence indicates that the regional climate has undergone significant changes. In the following sections we first describe the overall geomorphology of the South Golbaf basin. We then describe the two study sites in detail, along with the protocols for sample collection, preparation and analysis. We then investigate the implications of our age constraints for the rates of faulting and the timing of landscape evolution.

2. Geomorphology and sedimentology of the South Golbaf basin

The geomorphology of the South Golbaf basin has been described by Walker et al. (2010) and Walker and Fattahi (2011). Within the South Golbaf basin the Gowk Fault is composed of three main strike-slip segments arranged in a right-stepping pattern (Fig. 3A). The central segment ruptured, with slip of up to 10 mm vertical and 4 mm horizontal, in the 1989 M_w 5.8 South Golbaf earthquake (Berberian and Qorashi,