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Early Holocene extensional tectonics in the South-Eastern Cape Fold Belt, South Africa

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ABSTRACT

The current seismo-tectonic model for South Africa depicts the south-eastern Cape Fold Belt as a tectonically stable intraplate-type environment, where earthquakes are relatively infrequent to rare, particularly large surface-rupturing events. The closest surface rupture recorded by the SANSN, which underpins the model, is the extensional Mozambique 7.2M event on 22 February 2006, related to southward propagation of the East African Rift. A similar 84km-long extensional surface rupture has been found along the Kango fault within the southern Cape Fold Belt, 50km east of Oudtshoorn. Optically stimulated luminescence dating indicates it occurred around 10,620 ± 509, at the start of the Holocene. This fault, together with the adjoining Baviaanskloof and Coega faults, and other nearby adjacent faults, is the subject of a palaeoseismic investigation to determine the Quaternary tectonic history of the south-eastern continental margin. This region of South Africa has little seismic information, and the record is too short to include the long recurrence intervals of large, surface damaging earthquakes typical of intraplate regions. The data reported includes the location and extent of the surface rupture, the local stress direction, the date and magnitude of the most recent event, the minimum recurrence interval, and maximum slip rate. The earthquake environmental effects are also evaluated according to the new Environmental Seismic Intensity Scale (ESI 2007), to provide an independent assessment of seismic intensity. A potential local tectonic driver, the Cape Isostatic Anomaly (CIA) is also discussed, as well as a possible trigger mechanism leading to the rupture. Results should facilitate PSHA of several new critical facilities planned for the province.

Key words: Cape Fold Belt (CFB), intraplate, palaeoseismic, Kango fault, Baviaanskloof fault, South African National Seismography Network (SANSN), Cape Isostatic Anomaly (CIA), Environmental Seismic Intensity scale (ESI), Probabalistic Seismic Hazard Assessment (PSHA).

INTRODUCTION

The palaeo-earthquake near Oudthoorn reactivated an eastern 84km segment of the 320km long east-west striking, southward-dipping Kango fault. This normal Cretaceous-basin boundary fault is a deep-seated (>10km) crustal-scale zone of weakness (Harvey *et al.*, 2001, Stankiewicz *et al.*, 2007, Lindeque *et al.*, 2007), and so should respond to regional tectonic stresses in the crust. Together with the adjoining Baviaanskloof and Coega faults, as well as the adjacent Kouga and Gamtoos faults, it is being investigated to determine the Quaternary tectonic history of the south-eastern continental margin (Goedhart, 2005, 2006). This region of South Africa has little seismic information (Kjiko, *et al*., 2003, Brandt, *et al.*, 2005), and the record is too short to include the long recurrence intervals of large, surface damaging earthquakes typical of intraplate regions (Goedhart and Saunders, 2009). Ongoing field reconnaissance of potential neotectonic faulting is being assessed using international guidelines (e.g. Hanson, *et al*. 1999, McCalpin, 1996). Assessment of uncertainties associated with the deterministic methods of investigation, and the results obtained, have recently been formalized to assist the population of a logic tree to be used in a revised PSHA of the region (Midzi and Goedhart, 2009).

METHOD AND RESULTS

Results from a palaeoseismic trench investigation, aimed at characterizing and dating the surface rupture, has indicated that the fault was active between 12,206 ± 723 and 8,878 ± 452 years ago, and most probably around 10,620 ± 509, at the beginning of the Holocene. An 80m long x 6m deep trench, excavated N-S across the fault trace (Figure 1) exposed a 32 m-wide graben in which twenty-one lithological units, six soil horizons, and nineteen fault strands were mapped, correlated and interpreted within the local geological setting. The uppermost fault strands all terminated in the same horizon, indicating a single most recent event (MRE). In total, 52 OSL samples were collected, 12 of which were selected for analysis. Three samples near the base of the trench yielded ages of ~115 ka, while the remaining samples were all of early- to late-Holocene age. Using the age of the oldest bed exposed in the trench, the minimum recurrence interval for the fault is 106.8 ± 5.5 ka, typical of intraplate regions (100-150ka). Vertical displacement at the trench was estimated at 2.0m, slightly less than the average vertical displacement of 2.18±2.68m measured by levelled scarp heights along the fault trace. These indicate the Kango fault has a maximum slip rate of 0.0187-0.0208mm/yr. Using published relations for surface rupture length, as well as both average and maximum displacement methods (Wells and Coppersmith, 1994, McCalpin, 1996), the event is estimated to have had a moment magnitude of between 7.18±0.01 and 7.43M±0.23.

Figure 1. View ENE along the bush-covered trace of the Kango fault separating the pre-Cape and Palaeozoic rocks of the Swartberg Mountains at left, from Mesozoic basin fill and thin Quaternary to Holocene cover sediments, at right. The trench at left foreground was excavated across a locally-developed, elongate, 32m wide graben that truncated the proximal reach of a southward-draining coarse-grained alluvial fan.

According to the new Environmental Seismic Intensity scale (ESI 2007), used to evaluate faults in areas with surface deformation that are currently inactive, or where seismic records are absent, the local Environmental Earthquake Effects indicate that the epicentral intensity was devastating (ESI I_o = XI). These data suggest that the 5.6-6.3M m_{max} for the Eastern Cape should be reviewed, as well as the highest m_{max} for South Africa, which is currently between 6.3 - 6.7M for the Ceres area of the Western Cape (Bejaichund, M., *et al*., 2004, *pers comm*., Nov 2008).

DISCUSSION

Slow isostatic rebound along the Cape Isostatic Anomaly (CIA), an east-west trending gravity trough extending from Port Elizabeth towards Willowmore, is the closest possible tectonic driver. This trough, whose axis lies 50-60km north of the Kango-Baviaanskloof fault trace, probably reflects the root of the former fold belt, estimated to be at least 1.5 times higher than at present (Smit, *et al.*, 1962; Pitts *et al.*, 1992). Coulomb stress transfer along strike suggests crustal instability could be expected in the Baviaanskloof-Kouga region, where the current seismo-tectonic model (Du Plessis, 1996a,b, and Partridge, 1995, Hartnady, 1996, Brandt, 2008, Singh, *et al*., 2009), based mainly on sparse SANSN data, suggests maximum stability (Kjiko, *et al*., 2003). It is therefore essential to determine if the larger faults in the region are capable, and if any of the existing seismic data can be linked directly with these faults (Aitkinson, 2007). New low-level seismicity (2001, 3.4-3.7M; 2006, 2.7M) has recently been recorded on the Kouga and Baviaanskloof faults, suggesting they are under strain, and potentially capable. In the absence of long-term GPS strain data for the Eastern Cape region, long-term anelastic strain modelling suggests a NW-SE extension could be expected in the southern to south-eastern coastal region of South Africa (Bird, *et al*., 2006). Other methods are also being tested to investigate the potential uplift effects of the CIA in the Kango-Baviaanskloof region (Engelbrecht and Goedhart, 2009). These must discount the effect of local groundwater abstraction schemes that target the fault (e.g. for the town of Willowmore).

The trench stratigraphy displayed a major basal disconformity, corresponding to regional aridification related to the last ice age between MIS5e and MIS1. There is also strong correlation between the age of the MRE and the end of a continuous, very rapid, eustatic sea-level rise towards MIS1 (+108m, from 15,000-11,000BP). It is therefore tempting to suggest that crustal instability on the south-eastern continental margin may have been accentuated by rapid hydrostatic loading, possibly triggering the event. Future aacceleration of instability across faults bordering the CIA to the east may also be expected from increased under-plate heating associated with the southward propagating EAR system under southern Africa and the Indian Ocean (Simmons *et al*., 2007).

The most recent fieldwork suggests the eastern arm of the reactivated segment, east of the Skilpadbeen thrust near Willowmore, may have experienced more than one surface rupturing event in the Quaternary. This is because a second potential fault scarp has been found a few hundred metres north of the MRE. Dating the older ruptured surface poses a challenge, due to the expected age of the silcretized and ferruginized Quaternary-aged sediments.

CONCLUSIONS

The new pre-historic data comes at an opportune time as the CGS is currently reviewing the SANSN catalogue for completeness, according to international standards. In this process, several historical events in the Eastern Cape are also being scrutinized individually, including their location accuracy. The revised catalogue will be accompanied by new metadata, reported per event in some cases. As in several European databases, ranking the quality of listed events will improve the understanding of the uncertainty around individual events, and their use in PSHA or in identifying potentially capable faults.

With further investigation, should an older Penultimate Event be determined, a closed seismic cycle will increase the recurrence interval, while the slip rate will be reduced. Should the SRL be shortened, the magnitude will be reduced. In contrast, should younger events be found along the Kango fault, for example new seismites, they may reduce the recurrence and possibly increase the slip rate.

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