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Mapping the surface geomorphology of the Makgadikgadi Rift Zone (MRZ)

Frank D. Eckardt [a, *], Fenton P.D. Cotterill [b], Tyrel J. Flügel [c], Beth Kahle [d], Marty McFarlane [e], Christie Rowe [f]

[a] Environmental and Geographical Science, University of Cape Town, Rondebosch, 7701, South Africa
[b] Geoecodynamics Research Hub, Department of Botany and Zoology, University of Stellenbosch, Matieland, 7602, South Africa
[c] Department of Military Geography, Stellenbosch University, Private Bag X2, 7395, Saldanha, South Africa
[d] Department of Geological Sciences, University of Cape Town, Rondebosch, 7701, South Africa
[e] Marty McFarlane, Bosele Investments (Pty) Limited, Box 66, Maun, Botswana
[f] Earth & Planetary Sciences Department, McGill University, Montréal, QC, H3A 0E8, Canada

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ABSTRACT

The Makgadikgadi basin and wider Middle Kalahari region of Botswana and beyond host landforms which have been attributed to Quaternary environmental change, including palaeolake level fluctuations and aeolian activity. Tectonic processes and landforms on the other hand, have mostly been linked to the Okavango graben and associated rift zone (ORZ) to the west of the Makgadikgadi. In this paper we establish the extent of tectonic surface expression associated with the Makgadikgadi Rift Zone (MRZ). We identify a series of parallel, NNE-SSW, normal faults and scarps, expressing horst and graben structures linked to seven major blocks in the northern Makgadikgadi basin, using both Shuttle Radar Topographic Mission (SRTM) and geomagnetic data. Subtle expression of rifting has controlled endorheic drainage topology, replicated regional dune-field patterns and displaced the 945 m palaoelake contour since lake desiccation. These observations underscore the role of neotectonic "piano key" block movement in shaping surface landforms across a large expanse of the Kalahari region. This paper provides the first detailed map and introduction to the Makgadikgadi Rift Zone (MRZ) and its geomorphology.

1. Introduction

This study is centered on subtle neotectonic landforms in the Middle Kalahari, considered terminal branches of the East African Rift System (Scholz et al., 1976), with the Okavango Rift Zone (ORZ), an alluvial fan, being the most documented example (McCarthy and Ellery, 1998; Modisi, 2000; Gumbricht et al., 2001; Kinabo et al., 2007, 2008; Shemang and Molwalefhe, 2011; Bufford et al., 2012; Podgorksi et al., 2013). In this paper we will particularly focus on the Makgadikgadi Rift Zone (MRZ) to the east of the ORZ (Fig. 1). Research emphasis in the MRZ in contrast, has been on Late Quaternary lacustrine sandy ridges, flanking the perimeter of the current dry lake basin (Grove, 1969; Heine, 1978; Cooke, 1980; Mallick et al., 1981; Helgren, 1984; Shaw and Cooke, 1986; Shaw et al., 1997; Ringrose et al., 1999, 2005; Burrough et al., 2009; Ringrose et al., 2009; Moore et al., 2012; Riedel et al., 2014) as well as fossil dune forms (Stokes et al., 1997). Although the ORZ and MRZ both include recent and ongoing horst and graben development (Baillieul, 1979a and b; Reeves, 1972), and hosted the same regional palaeolake (Cooke, 1980), it is fair to say that the MRZ has remained comparatively understudied. With this in mind, we set out to identify, map and describe faults and related geomorphic landforms, covering a 40 000 km square area of north-eastern Botswana and western Zimbabwe. The results include the identification of seven major fault blocks, control of drainage channels flowing into the basin, the distribution of palaeo dune topography and the vertical displacement of the sandy ridges associated with the paleo 945 m lake level.

2. Methods

Surface traces of faults were mapped using SRTM3 (Shuttle Radar Topography Mission, 3-arc second resolution) version 4 data obtained from the CGIAR-CSI site (Consultative Group on International Agricultural Research – Consortium for Spatial Information,

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[*] Corresponding author.
E-mail address: frank.eckardt@uct.ac.za (F.D. Eckardt).

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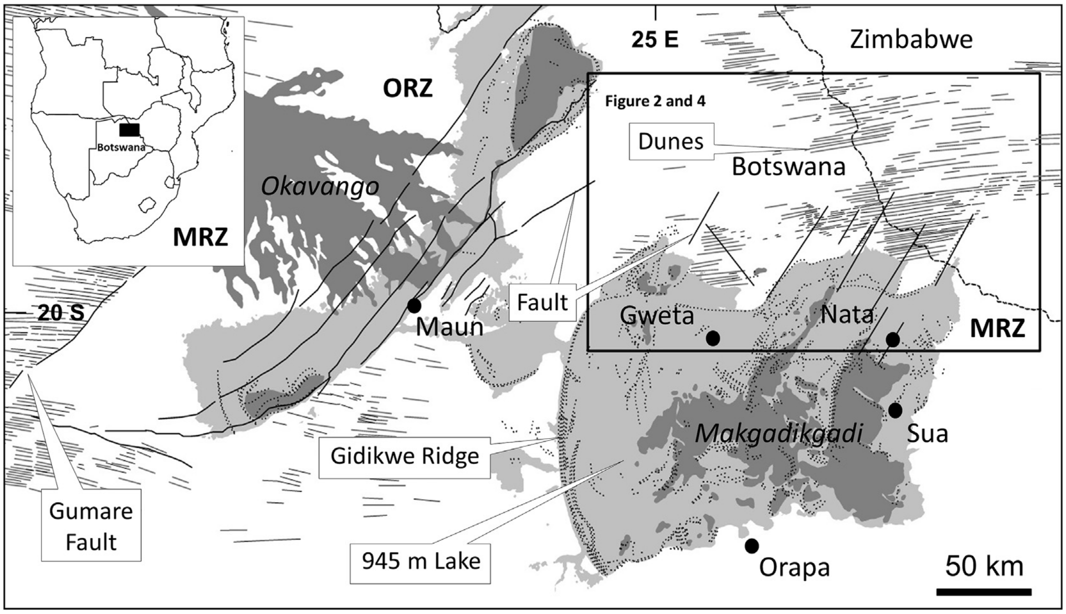

Fig. 1. Introduction of the MRZ. The Middle Kalahari of northern Botswana, home to the Makgadikgadi Rift Zone (MRZ) to the east and the Okavango Rift Zone (ORZ), (Kinabo et al., 2007) to the west, as well as the former 945 m palaeolake outline (light grey shading), extracted from SRTM data. Gidikwe Ridge and associated ridge lines (dotted lines) were obtained from Mallick et al., 1981. Preliminary MRZ faults (thick solid lines) depicted here are taken from Baillieul (1979a and b). Dunes ridges (thin solid E–W lines) were mapped from vegetation stripes in Landsat 7 (Image Source: Global Land Cover Facility).

Jarvis et al., 2008), The unenhanced 90 m DSM (Digital Surface Model) data was side shaded and illuminated with threefold vertical exaggeration, using variable azimuths including 0, 45, 90, 125, 180, 225, 270 and 315° and applying sun elevation of 45 °. Faults appeared as continuous or discontinuous straight features, indicative of tectonic fault block movement (Figs. 2 and 3).

Fault traces were also delineated using national aeromagnetic data, supplied by the Department of Geological Surveys, Botswana (Fig. 4). The survey was flown at a height of 80 m with a line spacing of 200 m and the data converted to a 50 m grid. A range of derivative and trigonometric filters were applied in order to enhance the shallow and subtle features in the magnetic dataset. Mapping of faults from this datasets relies on a magnetic contrast between units on opposite sides of the fault, or between the fault itself and the rocks that it displaces. A fault may appear as a magnetic anomaly in its own right, presumably as a result of fluid flow and precipitation or stripping of magnetic minerals. While it may be difficult to separate dykes and faults with a high degree of confidence, the mapped faults do not coincide with the prominent Karoo-age swarm dykes (NW–SE) in the extreme SW of the dataset. Approximate Kalahari thickness data was also depicted in Fig. 4. This contour data by Haddon and McCarthy (2005) is suitable for mapping regional trends of Kalahari depth but lacks the resolution to identify relative uplift and subsidence of underlying horst and graben structures.

Additionally SRTM was used to generate the 945 m contour, point heights for sandy ridges, resolve stream topology, identified fossil dune ridges and provided the topographic cross-sections (Fig. 3) and terrain view (Fig. 5). It is important to note that while SRTM generally overestimates absolute elevation in southern Africa by approximately 5 m, its relative accuracy however is better than 5 m (Rodriguez et al., 2005). For additional validation purposes we also compared SRTM elevation data against the ICESat (Ice, Cloud, and land Elevation Satellite) laser altimeter points, which has a much greater absolute vertical accuracies (Global elevation data product (GLAH06), Level-1B, laser campaigns: L1A, L2A, L2A, L2C, L3A, L3B, L3C, L3D, L3E, L3F, L3G. L3H, L3I and L3J, release 33) (Schutz et al., 2005) for the Makgadikgadi basin specifically (spatial domain: Latitude −20.17 to −21.46, Longitude +24.72 to +26.61). While ICESat laser coverage is not dense enough to produce digital elevation models, it is well suited for validation purposes, since the 65 m diameter laser altimeter footprints, separated by 172 m at ground level, have returned a vertical accuracy of <2 cm (Fricker et al., 2005). For comparative purposes we ensured that all elevation data used here conformed to the WGS 84 ellipsoid.

Fossil dune distribution patterns for the middle Kalahari have traditionally been inferred from the vegetation patterns detectable in Landsat satellite imagery (Mallick et al., 1981). However the vegetation continues to reveal the past dune forms, even after the dune ridges have been degraded or even substantially flattened. While mapping fossil dunes near the Gumare Fault (Fig. 1, McFarlane and Eckardt, 2007) and comparing the vegetation stripes in Landsat imagery against SRTM data, actual dune topography appeared most pronounced at the margins of, or within down-faulted graben and along incised streams, essentially in areas of lowered local base level. It was proposed that the action of water is the key to the development of linear forms visible in SRTM data, a process that was termed “dune replication”. The striking contrast between actual dune topography (“replication”) detectable in SRTM data and vegetation patterns (“ghosting”) visible in Landsat 7 (Red, Green, Blue/Bands 7, 4 and 2) data, is also observed in the MRZ.

3. Results and discussion

We identified a series of normal faults to the east of the ORZ. A rose diagram indicates that the majority strike from the NNE to SSW in both the SRTM (approx. 30°, Fig. 2) and geomagnetic (approx. 35°, Fig. 4) datasets. Secondary, west to east faultsets are identifiable in the geomagnetics (90°) that have lesser manifestion in SRTM data, where ENE to WSW faults are better expressed (70°). Detailed microseismic studies by Scholz et al. (1976) demonstrated the current activity of the north-northeast striking faults. Focal mechanism solutions indicate that earthquake slip is mostly