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Structural control of fluvial drainage in the western domain of the Cape Fold Belt, South Africa

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ABSTRACT

The purpose of the study was to examine the extent to which drainage morphology has been influenced by faulting, folding and bedrock lithology in the Cape Fold Belt (CFB) of South Africa. This region was formed during Paleozoic–Mesozoic convergence along the south-western margin of Gondwana. An extensive structural geology database, terrain characteristics and stream network data were analysed using Geographical Information Systems (GIS) to examine the possible linkages between structure and fluvial drainage. Results indicated that the contemporary geomorphology of the area reflects the influence of folding and faulting as well as differential erosion. The following drainage anomalies suggestive of strong structural control were identified: orientation of flow direction of major streams corresponding to structural lineaments, abrupt changes in stream direction influenced by anticline fold axes, faults and joints, and fault-aligned streams. Drainage development in the study area responded noticeably to the underlying structure. The study raises questions with regard to the implications of one major or multiple dominant structural controls on drainage morphology and pattern. The findings have relevance with regard to the understanding fluvial drainage development and landform evolution in tectonically deformed regions.

1. Introduction

Structural control on drainage development has been widely investigated (Babault et al., 2013; Bourne and Twidale, 2011; Clark et al., 2004; Eliet and Gawthorpe, 1995; Gelabert et al., 2005; Gunnell and Harbor, 2008; Macka, 2003; Perucca et al., 2014; Raj, 2007; Robolini and Spagnolo, 2008; Twidale, 2004; Zelilidis, 2000). Structural or morphotectonic control embraces the influence of tectonic displacement; strike, dip angles and dip directions on landforms. It also includes the stratigraphic arrangement of rock strata; the pattern of joints, faults, folds and bedding planes and rock mass strength and lithology. It has been established that in regions where rock strata (for example, quartz, sandstone or limestone) are brittle and shallowly buried, compressional stress results in fractures, joints and faults in the rock body. Faults and joints represent zones of weakness in the rock strata often exploited by weathering and erosion leading to preferential opening and enhanced stream erosion. In some cases faults and joints lead to development of narrow linear valleys with little meandering (Raj, 2007). Faulting may also result in vertical and horizontal crustal displacement. The former is related to fault line scarps and juxtaposition of rocks of contrasting erosion resistance (Moon, 1988), thus enhancing differential erosion and the proliferation of knick points on the longitudinal profile of the drainage network. Demoulin (1998), Tebbens et al. (2000) and Sougnez and Vanacker (2011) discussed the interactions between tectonics and longitudinal river profile development. On the other hand, horizontal crustal displacement leads to stream course off-setting, especially where there are active strike-slip faults (Burrato et al., 2003; Raj, 2007). Faulting has also been known to influence the flow direction of streams (Gelabert et al., 2005; Ket-ord et al., 2013; Maroukian et al., 2008; Raj, 2007). Fault-affected landscapes also commonly influence river drainage patterns (Goldsworthy and Jackson, 2000), especially the development of a rectangular pattern.

In regions where the rock strata are ductile, confining deformation is more likely to result in bending or folding of rock strata. Garcia and Hérail (2005), Robolini and Spagnolo (2008) and Twidale and Bourne (2010) found that folded landscapes are commonly characterized by regular patterns of rock strata. This has implications for the development of linear valleys that follow the less resistant strata while the more resistant strata remain as ridges and drainage divides. Where there is active folding (for example, lateral propagation of fold segments) streams may be persistently deflected away from their path (Keller et al., 1999; Ramsey et al., 2008) as they cannot keep up with the rate of lateral propagation of fold segments. However, Holbrook and Schumm

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(1999) warned that sharp deflections do not necessarily reflect tectonic deformation, especially where bedrock control is a factor, or highly resistant materials are present. Garcia and Hérail (2005) investigated the development of drainage network before and after folding and found that folding generated a progressive abandonment and sometimes fossilisation of the initial drainage pattern network in some sectors of the Andes Mountains in South America. They also observed changes in incision rates with the post-folding rate being approximately twice that of the prefolding era. According to Holbrook and Schumm (1999), the influence on the rate of fluvial incision is the most consistent of all the effects of folding on streams.

From the above, it can be concluded that folding and faulting exercise a control on the development and morphology of streams in a given region leading to most streams responding directly to these structural controls. The Cape Fold Belt (CFB) located at the southern margin of South Africa is a well-exposed fold and thrust belt. Various studies have documented the structural geology and tectonic evolution of the CFB (see Booth, 2009; de Wit and Ransome, 1992; Johnston, 2000; Sohnge and Halbich, 1983), particularly in the southern domain of the belt. Very few studies have explored the linkages between the geological structure and fluvial geomorphology in the CFB. For example, Hattingh and Goedhart (1997) examined the neotectonic controls on drainage evolution in the Algoa Basin, Eastern Cape, South Africa. Hattingh (2008) found that basin substrate, orientation and spacing of folds, faults and joints had marked influence on drainage morphology in the southern domain of the CFB. Particular importance was given to documenting the evolution of drainage networks including detailed studies of stream capture between Port Elizabeth and George. These studies have mostly concentrated on the southern domain of the CFB. Because the pattern of deformation in the southern and western domains of the CFB differs considerably (de Beer, 1995), the study offered an opportunity to investigate to what extent the geomorphology in the western domain and the resultant positioning of, development and patterns of the drainage network were influenced by the bedrock lithology and structure. Thus the current study aimed to (a) document the topographic expression of structure in the study area and; (b) identify and explain broad-scale anomalies in stream networks and their potential structural controls in the domain. The investigation was undertaken in a region of known geological deformation, and the results are likely to provide insight as to the relationship between drainage morphology and structural control in similar regions.

2. Study area

2.1. Regional tectonic setting

The CFB extends across the southern tip of Africa between latitude 31° and 35° South and longitude 18° and 27° East (Fig. 1). The belt extends for about 1400 km between Vanrhynsdorp and Port Alfred (Booth and Shone, 2000). It is believed to have formed in response to subduction-related compression during Paleozoic–Mesozoic convergence along the south-western margin of Gondwana (Tankard et al., 2009; Trouw and de Wit, 1999). Thus, the CFB is part of the greater Gondwanide orogenic belt, which prior to the breakup of Gondwana, extended west into South America, and east through the Falkland Islands and into Antarctica (Johnston, 2000).

Several studies have examined the regional tectonic setting of the CFB. Söhnge (1983) examined its geodynamics. De Wit and Ransome (1992) synthesized the belt's inversion tectonics and de Beer (1992) and Booth (2009) reviewed its structural geology and structural evolution. Despite all these studies the structure and evolution of the CFB is a matter of considerable debate among geologists (see Booth, 2011; de Wit and Ransome, 1992; Shone and Booth, 2005; Shone et al., 1990) and the belt still lacks fully integrated studies (Mielke and de Wit, 2009).

The orogen of the CFB is commonly separated into three tectonic domains. Firstly, a western domain stretches 300 km from Vanrhynsdorp to Ceres parallel the Western Cape coast, secondly, a syntaxis located around the town of Worcester, and finally, a southern domain extending some 900 km east along the south coast from Touwsrivier to Port Elizabeth. The current study focuses in the western domain.

2.2. Geological deformation in the CFB

It is necessary to review to what extent the sedimentary rocks of the CFB have been deformed as this forms the basis for understanding the fluvial drainage implications. Rocks deform when applied stress exceeds their strength and rock deformation manifests through rock bending/ folding and fracturing/faulting. The type of deformation depends on the temperature of the rock at the time of deformation, the depth of the strata, the type of force involved and the dominant mineral in the rock (Plummer and Carlson, 2012). According to Fagereng (2012), folding in the exposed sections of the CFB occurred within a relatively cold and shallow brittle regime making the occurrence of faults common. Folding occurs at various scales and in an array of different fold

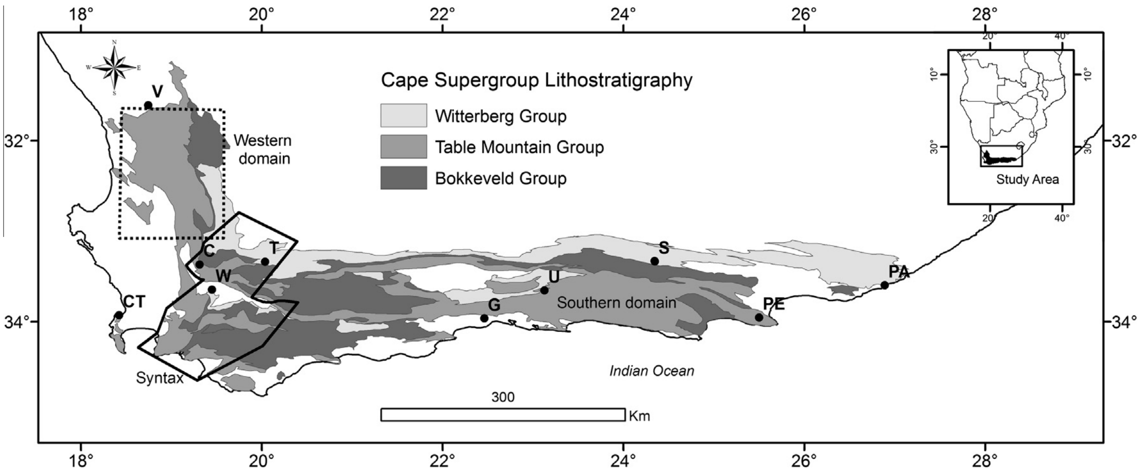

Fig. 1. The lithostratigraphy of the Cape Supergroup rocks corresponding to the Cape Fold Belt. The dotted box shows the area investigated. The letters show the areas mentioned in this paper; C = Ceres, G = George, PA = Port Alfred, S = Steytlerville, T = Touwsrivier, U = Uniondale, V = Vanrhynsdorp, W = Worcester. Source, Council of Geosciences, Geology map, 1:1,000,000 scale.