

# A review of the structural geology of the Cape Fold Belt and challenges towards future research

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## ABSTRACT

This review focuses on our understanding of the structural and tectonic setting of the Cape Fold Belt (CFB) based on contributions made by academics and professional geologists, mainly during the last two decades. Most of the research concentrated on the identification and mapping of thrust faults in the southern arm of the CFB, as well as seismic surveys which provided data for putting forward tectonic models to account for structural and stratigraphic features of the fold belt.

Thrust stacking is a common characteristic in all three stratigraphic sequences of Palaeozoic Cape Supergroup rocks. A complex pattern of ductile and brittle deformation occurs in the Table Mountain Group whereas in the overlying Bokkeveld and Witteberg Groups there is a close association of folding with development of thrust faults. Thin-skinned characteristics are prevalent in the southern arm of the CFB, but give way to thick-skinned features in the southernmost central part of the fold belt where basement rocks have been thrust northwards towards the foreland.

A variety of tectonic models proposed for the CFB have generated some controversy among researchers. Currently popular are the Andean and the strike-slip (transpression) models. The former accounts for the northward vergence of structures in the southern arm of the fold belt, but thicknesses of crustal substrate obtained from recently carried out deep sounding seismic surveys across the fold belt do not entirely corroborate this model. Structural characteristics in cover rocks that favour the transpression model are en echelon folds and faults as well as flower structures which are commonly associated with strike-slip regimes.

**Key words:** thrust faults, thrust stacking, tectonic models

## INTRODUCTION

During the last two decades two factors that have helped researchers the most in gaining a better understanding of the structural and tectonic setting of the Cape Fold Belt are; (i) acquisition of structural data from field studies, and (ii) interpretations of the substrate derived from deep sounding seismic surveys. Recognition and interpretation of thrust faults and their related structural features have given us insight into the geometry of thrust fault systems and the disruptive effect these types of faults have on stratigraphic sequences. The degree to which some sectors of the fold belt have been shortened through thrust stacking and duplexing in Cape Supergroup rocks has drawn attention to the fact that the stratigraphy of the Cape Supergroup (SACS, 1980) is in need of revision.

Examples of structures that show thin-skinned and thick-skinned characteristics are prevalent in the fold belt. There is enough evidence of such structures in a regional context to propose an appropriate tectonic setting for the fold belt during its Late Proterozoic/Early Mesozoic, as well as its extensional history during Recent times (Paton et al., 2006; Bate and Malan, 1992; Goedhart and Saunders, 2009).

## STRUCTURAL GEOLOGY

Outcrops of Palaeozoic Cape Supergroup and Mesozoic Karoo Supergroup rocks, along with structural trends in the fold belt, show an asymmetric pattern where the main west-east trending southern arm of the fold belt swings north-northwesterly in the western extremity of the fold belt, but changes to a south-southeasterly trend at the eastern end of the fold

belt (Figure 1). The syntaxis and antitaxis of the fold belt coincide with these abrupt changes in strike (de Beer, 1992; Johnson, S., pers. com.). In the eastern part of the fold belt at Port Elizabeth, Uniondale and Steytlerville structural features such as fore and back thrusts, wedges, pop-ups and triangle zones have been identified in outcrop (Booth, 1996; 1998). Structures in general show a northward vergence (Booth and Shone 1992; 1999; 2002). In most cases faults have developed in a break-back sequence (Figure 2), and the resulting fault and fold patterns indicate that major thrust stacking has taken place especially in arenaceous units of the Table Mountain and Witteberg Groups of the Cape Supergroup (Booth and Shone, 1992; 2004; Newton et al., 2006).

At Port Elizabeth a complex pattern of early ductile folding indicates the presence of a large recumbent fold (nappe structure?) which is transected by thrust faults that formed in the brittle zone (Booth and Shone, 1992). In the central part of the fold belt estimates of crustal shortening of up to 70% by Hälbich (1992), have been corroborated by de Wit (pers. com. 2009) for the Oudtshoorn area. Paton et al. (2006) propose that the structural setting of the fold belt as a whole can be interpreted in terms of thin and thick skinned characteristics that reflect the Late Proterozoic/Early Mesozoic history of the fold belt.

Current studies of the Kango fault, one of the largest of the normal faults along the southern part of the fold belt associated with the break-up of Gondwana (Bate and Malan, 1992), is aimed at providing an accurate slip rate, as well as an understanding of Neotectonic activity along this fault zone (Goedhart and Saunders, 2009).

The significance of documenting and interpreting thrust faults in the CFB is that it has necessitated a re-interpretation of two anomalies associated with the stratigraphy of the Cape Supergroup, viz. (i) excessively thick sequences of arenaceous rocks and (ii) absence of certain time marker horizons. Examples of the former occur in all three major groups of rocks of the Cape Supergroup (SACS, 1980) whereas an example of the latter is the Cedarberg Shale Formation, which extends as a thin unit across the entire fold belt, but is absent in some parts of the central and eastern part of the fold belt (1:250 000 geological map 3324 Port Elizabeth). These anomalies can now be explained by thrust stacking which has resulted in tectonically thickened arenaceous units in areas of thrust faulting, whereas certain argillaceous units such as the Cedarberg Shale Formation have been exploited by thrust faults to such an extent that they have been eliminated in places. The implications of these findings are that where tectonically thickened strata of the Cape Supergroup occur they need to be re-interpreted as tectonostratigraphic packages.

## GEOPHYSICAL SURVEYS

During the last few years deep sounding seismic surveys (funded through the Inkaba ye Africa programme) have been carried out along north-south oriented sections through the fold belt (Lindeque et al., 2007). These surveys reveal layered patterns in the substrate where structures in the Proterozoic Namaqua basement contrast with those in the overlying Palaeozoic cover rocks (Cape Supergroup). In Palaeozoic rocks structures dip predominantly south, whereas in Namaqua basement structures dip northwards, indicating that seismic data is consistent with outcrop patterns of Cape and Namaqua rocks. Data from seismic sections also show that thicknesses of cover rock sequences do not occur on a scale commonly associated with the Andean model. The magnetic signature related to the Beattie anomaly in the southern part of the fold belt is probably related to a sulphide rich horizon at depth. Southward dipping major faults appear to have a listric geometry which suggests that decoupling along these major discontinuities may be largely in the upper crustal regions. Such an interpretation is supported by thin skinned characteristics seen in cover rocks in the major part of the fold belt.

## TECTONIC MODELS

Some of the tectonic models proposed by researchers explain local structural characteristics, whereas others have been put forward to accommodate the entire fold belt. According to Ransome and de Wit (1992), for example, rotating microplates account for interference structures observed in the syntaxis region (de Beer, 1992). In the eastern part of the fold belt duplexing on a large scale has been proposed by Booth et al. (2004) as the mechanism that accounts for tectonically thickened strata. However, models that best explain overall characteristics of the fold belt are the Andean model (de Wit and Ransome, 1992; Johnson (1991), and the strike-slip (transpression) models (Johnson, S., pers. com; Tankard, A., in prepn.). The former accommodates the structural geometry in the southern arm of the fold belt, in addition to providing an explanation for volcanic horizons in the foreland (Karoo Supergroup rocks).

The transpression model with left-lateral sense of movement explains en echelon fold and fault structures, as well as possible flower structures in the central parts of the fold belt. The latter model is also in harmony with sense of movement in northwesterly trending strike-slip faults in basement rocks of the western part of the fold belt. This interpretation further corresponds appropriately with the transpression model proposed by Jappas (2007) for the Sierra de la Ventana of Argentina, a South American correlative of the CFB.

## FUTURE RESEARCH

Future research should be focused on systematic field studies of Cape and Karoo Supergroup rocks with the aim of providing detailed structural and stratigraphic information. Data should be interpreted, firstly, to accommodate along-strike correlation of thrust sheets and stratigraphic horizons across the fold belt, especially in the central to eastern part of the fold belt. Secondly, future studies should be aimed at providing a viable tectonic model that explains all the characteristics of the fold belt.

It is also necessary to provide structural data on crustal shortening from sections across the fold belt where thrust stacking has occurred. Field evidence, coupled with evidence from deep sounding seismic surveys, should form the basis for interpreting the role that the crustal substrate played in controlling structural development in the cover rocks during compressional events. Chronostratigraphic studies are vital for future research in order to refine a sequence of structural events for the entire fold belt, as well as deciphering the relationship between basement and cover rocks.

Currently the Andean model explains the predominantly northward vergence of the majority of structures, but evidence from recently conducted seismic surveys has thrown doubt on the viability of this model because crustal thicknesses do not corroborate the model.

For the strike-slip (transpression) model to be accepted it would require proving the existence and development of flower structures in strata of the Cape and Karoo Supergroups. Additional structural features characteristic of transpression, e.g. en echelon folds and faults, supported by evidence from seismic surveys, would have to be mapped and interpreted in the light of strike-slip regimes.

Ongoing studies of normal faults, particularly along the coastal regions of the fold belt will provide insight into Neotectonic activity along the southern margin of the African continent, to help us arrive at a better understanding of the extensional history related to Gondwana break-up.

## CONCLUSIONS

Field studies of the structural geology of the CFB carried out during the last two decades have highlighted the necessity to identify and document thrust faults and their related structural features in the field, because this type of faulting has a disruptive effect on lithological sequences. As a result, interpretation of the stratigraphy in places is certainly incorrect. Thrust stacking of predominantly arenaceous

units has produced tectonostratigraphic packages which have to be interpreted correctly.

Controversial tectonic models put forward to explain the structural evolution of the CFB include the Andean model and the strike-slip (transpression) model. Both models have merit, but more field studies are necessary before all the structural and stratigraphic features of the fold belt are taken into account, so that an appropriate tectonic model for the fold belt can be put forward.

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## REFERENCES

- Bate, K. J. and Malan, J. A., 1992, Tectonostratigraphic evolution of the Algoa, Gamtoos and Pletmos Basins, offshore South Africa. In: de Wit, M. J. and Ransome, I. G. D. (Eds.), *Inversion tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of Southern Africa*. Balkema, Rotterdam, pp 61-73.
- Booth, P.W.K., 1996, The relationship between folding and thrusting in the Floriskraal Formation (upper Witteberg Group), Steytlerville, Eastern Cape. *South African Journal of Geology*, 99, 235 – 243.
- Booth, P.W.K., 1998, The effect of thrusting on fold style and orientation, Weltevrede Formation (Cape Supergroup), Steytlerville, Eastern Cape. *South African Journal of Geology*, 101, 27 – 37.
- Booth, P.W.K. and Shone, R.W., 1992, Structure of the Table Mountain Group in the Port Elizabeth area. *South African Journal of Geology*, 95, 29 – 33.
- Booth, P.W.K. and Shone, R.W., 1999, Complex thrusting at Uniondale, eastern sector of the Cape Fold Belt, Republic of South Africa: structural evidence for the need to revise the lithostratigraphy. *Journal African Earth Sciences* 29, 125 – 133.
- Booth, P W K and Shone, R W., 2002, A review of thrust faulting in the eastern Cape Fold Belt, South Africa, and the implications for current lithostratigraphic interpretations of the Cape Supergroup. *Journal African Earth Sciences* 34, 189 – 200.

- Booth, P.W.K., Brunson, G. and Shone, R.W., 2004, A duplex model for the eastern Cape Fold Belt?: Evidence from the Palaeozoic Witteberg and Bokkeveld Groups (Cape Supergroup), near Steytlerville, South Africa, *Gondwana Research*, 7, 211 – 222.
- De Beer, C.H., 1992, Structural evolution of the Cape Fold Belt syntaxis and its influence on syntectonic sedimentation in the SW Karoo Basin. In: de Wit, M.J. and Ransome, I.G.D. (Eds.), *Inversion Tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of Southern Africa*. A.A. Balkema, Rotterdam, pp. 197 – 206.
- De Wit, M.J. and Ransome, I.G.D., 1992, Regional inversion tectonics along the southern margin of Gondwana. In: de Wit, M.J. and Ransome, I.G.D. (Eds.) *Inversion tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of Southern Africa*. Balkema, Rotterdam, pp 15 – 21.
- Goedhart, M. L., and Saunders, I., 2009, Review of Seismicity and fault reactivation in the south-eastern Cape Fold Belt, South Africa, and proposals to improve the SANSN catalogue for use by non-seismologists. Abstract, International Association of Seismology and Physics of the earth's Interior IASPIE, Cape Town.
- Hälbich, I.W., 1992, The Cape Fold Belt Orogeny: State of the art 1970's'- 1980's' In: de Wit, M.J., Ransome, I.G.D., (Eds). *Inversion Tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of Southern Africa*. A.A. Balkema, Rotterdam, pp. 141- 158.
- Jappas, M. S., 2007, The Late Paleozoic Gondwanide Orogen: the Sierra de la Ventana Transpressional Foldbelt. In: *Problems in western Gondwana geology. 1 Workshop "South America – Africa correlations: du Toit revisited"*. Gramado–RS- Brazil, 78-85.
- Johnson, M. R., 1991, Sandstone Petrography, provenance and plate tectonic setting in Gondwana context of the southeastern Cape-Karoo basin. *South African Journal of Geology*, 94, pp 137-154.
- Lindeque, A. S., Ryberg, T., Stankiewicz, J., Weber, M., and de Wit, M. J., 2007, Deep Crustal Seismic Reflection experiment across the southern Karoo basin, South Africa., *South African Journal of Geology*, 110, 419-438.
- Newton, A. R., Shone, R. W. and Booth, P. W. K., 2006, The Cape Fold Belt. In: Johnson, M. R., Anhaeusser, C. R. and Thomas, R. J., (Eds.) *The Geology of South Africa*. Geological Society of South Africa, Johannesburg/Council for Geoscience, Pretoria, 521-530.
- Paton, D.A., Macdonald, D.I.M., Underhill, J.R., 2006, Applicability of thin or thick skinned structural models in a region of multiple inversion episodes; Southern South Africa. *Journal of Structural Geology*, 28, 1933 – 1947.
- Ransome, I.G.D. and de Wit, M.J., 1992, Preliminary investigations into a microplate model for the South Western Cape. In: De Wit, M.J. and Ransome, I.G.D. (Eds.) *Inversion tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of Southern Africa*, Balkema, Rotterdam 257 – 266.
- SACS (South African Committee for Stratigraphy), 1980, *Stratigraphy of South Africa. Part 1. (Compiled by L.E. Kent). Lithostratigraphy of the Republic of South Africa, South West Africa/Namibia, and the Republics of Bophuthatswana, Transkei and Venda. Handbook 8, Geological Survey, South Africa, 690p.*

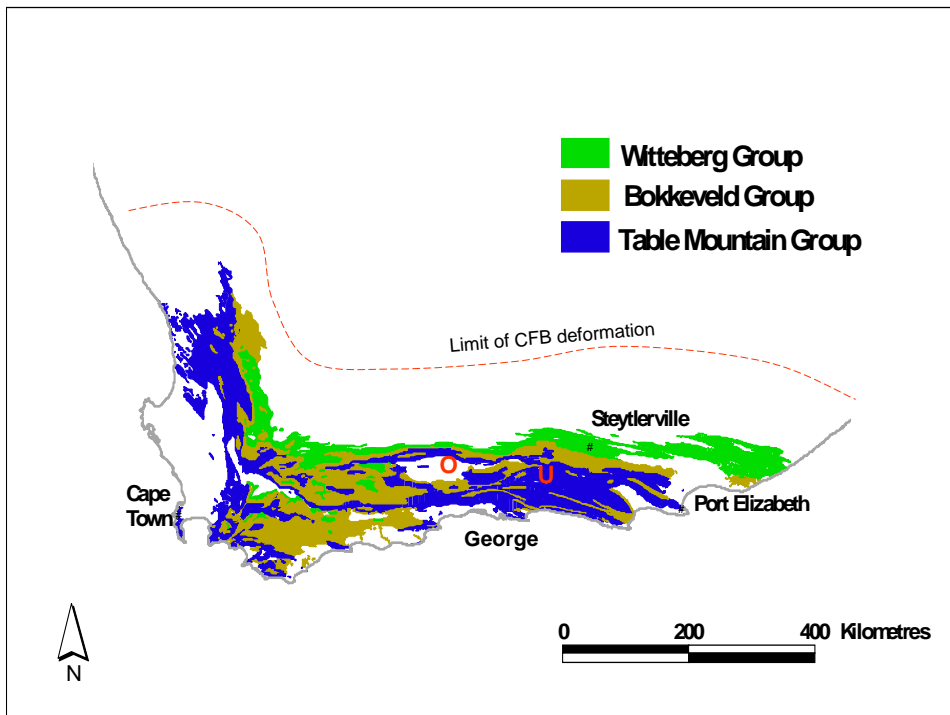


Figure 1. The Cape Supergroup (Table Mountain, Bokkeveld and Witteberg Groups) outlines the asymmetric shape of the Cape Fold Belt. Dotted line indicates limit of Cape Fold Belt deformation. The syntaxis region lies just east of Cape Town, the antitaxis at Port Elizabeth. O = Oudtshoorn, U = Uniondale.



Figure 2. Thrust stacking of quartzite beds of the Table Mountain Group at Target Kloof, Port Elizabeth.