The Impact of High Precision Age Controls in Basin Modeling for Tectonic Studies: Karoo Basin, South Africa*

Matthew P. McKay[1], Justin Dean[2], and Amy Weislogel[2]

Search and Discovery Article #10570 (2014)**
Posted January 27, 2014

*Adapted from oral presentation presented at AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 19-22, 2013

[1]Department of Geology and Geography, West Virginia University, Morgantown, WV (matty.mckay@yahoo.com)
[2]Department of Geology and Geography, West Virginia University, Morgantown, WV

Abstract

The Karoo Basin and adjacent Cape Fold Belt of South Africa record tectonism along the western Gondwanan margin from the Carboniferous through the Jurassic dissection of the Pangean supercontinent. Previous studies have suggested that the Karoo Basin may be a retroarc foreland basin created as a result of lithospheric flexure in response to tectonic loading of the Cape Fold Belt. However, paleotectonic reconstructions indicate the distance between the Panthalassan margin and the Karoo Basin may have exceeded 1000 km, making this interpretation suspect, and leading to recently postulated models that link early tectonic subsidence of the Karoo Basin to epeirogenic, mantle-driven dynamic subsidence. We present new results from 1-D basin models that incorporate newly available stratigraphic age controls from volcanic ashes interbedded throughout the Permian Ecca Group within the Karoo Supergroup. Basin subsidence analysis suggests that periods of rapid tectonic subsidence occurred during the intervals of 280-277, 270-257, and 248-243 Ma. These rapid subsidence events are coeval with deformational events in the adjacent Cape Fold Belt as constrained by previously published 40Ar/39Ar ages of syn-metamorphic cleavage micas that record periodic, post-deformational cooling at 298, 278, 258, 247, and 230 Ma (error unspecified). The compatibility between 40Ar/39Ar thermochronology and basin subsidence suggests that the Cape Fold Belt-Karoo Basin may represent a Late Paleozoic-Mesozoic intracratonic foldbelt-foreland basin system. If the age of deformational fabric development in the Cape Fold Belt is robust and not partially reset, then episodic subsidence events within the Karoo Basin could have been coupled with topographic crustal loading driven by Permian-Triassic shortening in the Cape Fold Belt. The variation in tectonic subsidence within the basin modeling results is completely controlled by the age estimates for lithostratigraphic units. Lithostratigraphic age constraints are not always sufficient for generating a robust geohistory model in a basin with highly diachronous filling. Significant risk for major error exists when assessing burial histories using poorly-constrained chronostratigraphy.

References Cited

Alao, A.O., and D. Mikes, 2011, Subsidence analysis of the Permian Tanqua depocentre, southwestern Karoo Basin, South Africa: South African Journal of Geology, v. 114/3-4, p. 325-334.

Catuneanu, O., J.P. Hancox, and B.S. Rubidge, 1998, Geodynamic evolution and stratigraphic consequences for the Karoo Basin of South Africa: AAPG Search and Discovery Article #90937. Web accessed December 31, 2013.http://www.searchanddiscovery.com/abstracts/html/1998/annual/abstracts/116.htm

Catuneanu, O., H. Wopfner, P.G. Ericksson, B. Cairncross, B.S. Rubidge, R.M.H. Smtih, and P.J. Hancox, 2005, The Karoo basins of south-central Africa, *in* O. Catuneanu, R. Guiraud, P. Eriksson, B. Thomas, R.W. Shone, and R. Key, eds., Phanerozoic evolution of Africa: Journal of African Earth Sciences, v. 43/1-3, p. 211-253.

DeCelles, P.G., and K.A. Giles, 1996, Foreland basin systems: Basin Research, v. 8/2, p. 105-123.

Fildani, A., N.J. Drinkwater, A. Weislogel, T. McHargue, D.M. Hodgson, and S.S. Flint, 2007, Age controls on the Tanqua and Laingsburg deep-water systems; new insights on the evolution and sedimentary fill of the Karoo Basin, South Africa: JSR, v. 77/11, p. 901-908.

Greese, P.G., and R. Scheepers, 1993, Neoproterozoic to Cambrian (Namibian) rocks of South Africa: a geochronological and geotectonic review: Journal of African Earth Sciences (and the Middle East), v. 16/4, p. 375-393.

Halbich, I.W., 1983, Geodynamics of the Cape fold belt in the Republic of South Africa, a summary, *in* N. Rast, and F.N. Delany, eds., Geodynamics of orogenic belts: Geodynamics Series, v. 10, p. 21-29.

Halbich, I.W., 1992, The Cape fold belt orogeny; state of the art 1970s-1980s, *in* M.J. de Wit, and I.G.D. Ransome, eds., Inversion tectonics of the Cape fold belt, Karoo and Cretaceous basins of Southern Africa: A.A. Balkema Rotterdam, Netherlands, p. 141-158.

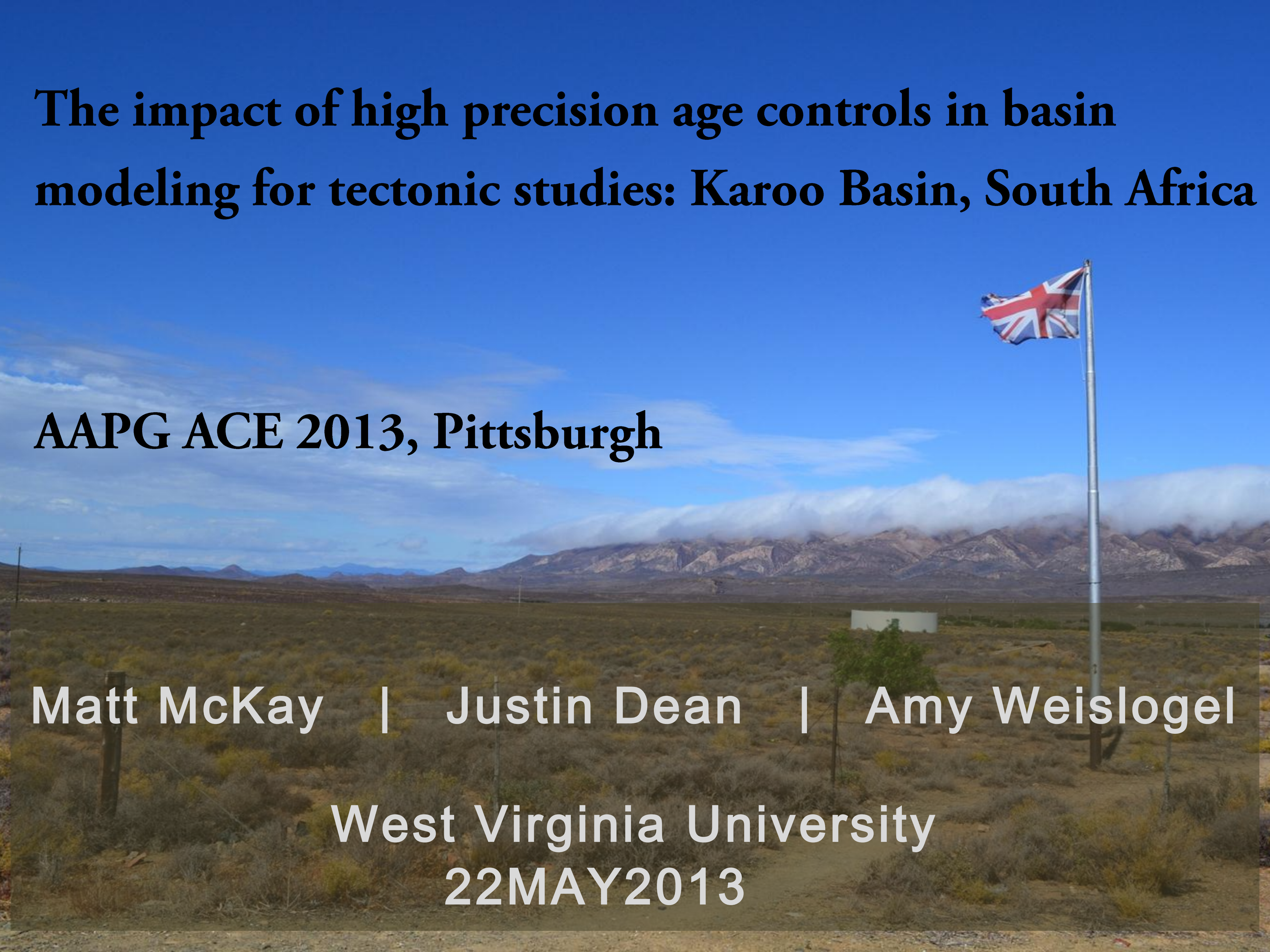
Lopez-Gamundi, O.R., and E.A. Rossello, 1998, Basin fill evolution and paleotectonic patterns along the Samfrau Geosyncline; the Sauce Grande Basin-Ventana Foldbelt (Argentina) and Karoo Basin-Cape Foldbelt (South Africa) revisited: Geologische Rundschau, v. 86/4, p. 819-834.

Newhall, C.G., J.W. Hendley II, and P.H. Stauffer II, eds., 1997, The cataclysmic 1991 eruption of Mount Pinatubo, Philippines: U.S.G.S. Fact Sheet, Report # FS 0113-97.

Veevers, J.J., C.McA. Powell, J.W. Collinson, and O.R. Lopez-Gamundi, 1994, Synthesis, *in* J.J. Veevers, and C.McA. Powell, eds., Permian Triassic Pangean basins and foldbelts along the Panthalassan margin of Gondwanaland: GSA Memoir 184, p. 331-353.

Weislogel, A.L., S.A. Graham, E.Z. Chang, J.L. Wooden, and G.E. Gehrels, 2011, Detrital zircon provenance from three turbidite depocenters of the Middle-Upper Triassic Songpan-Ganzi complex, central China: Record of collisional tectonics, erosional exhumation, and sediment production: GSA Bulletin, v. 123/1-2, p. 384.

The impact of high precision age controls in basin modeling for tectonic studies: Karoo Basin, South Africa



AAPG ACE 2013, Pittsburgh

Matt McKay | Justin Dean | Amy Weislogel

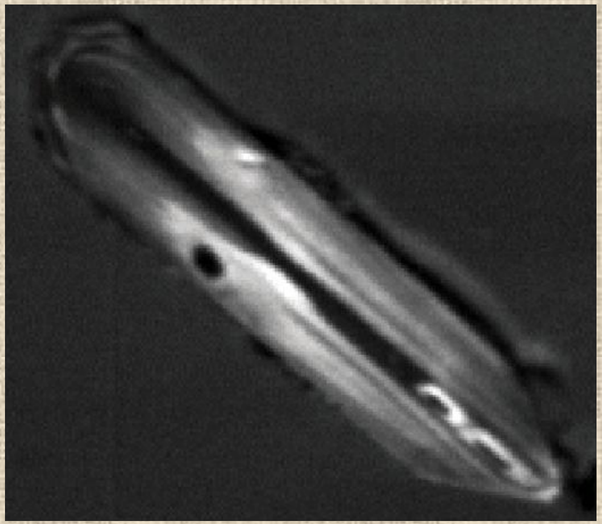
West Virginia University

22MAY2013

How can basin models be used in tectonic studies?

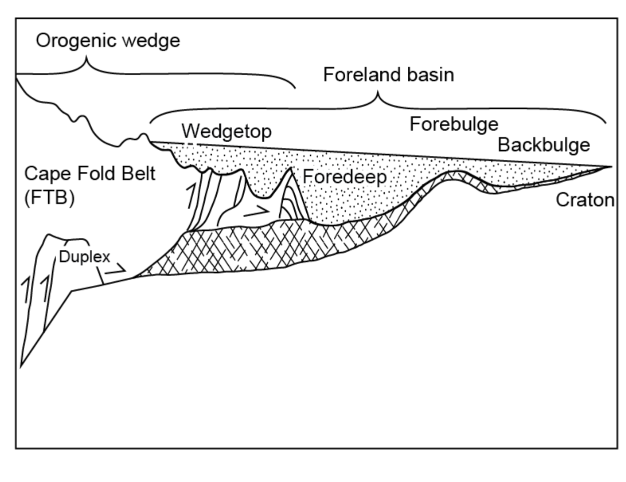
How can high-precision age constraints improve basin models?

- Greater temporal resolution than biostratigraphy
- Reduces importance of lithostratigraphic correlations



Does geochronology improve basin modeling such that models can be used to:

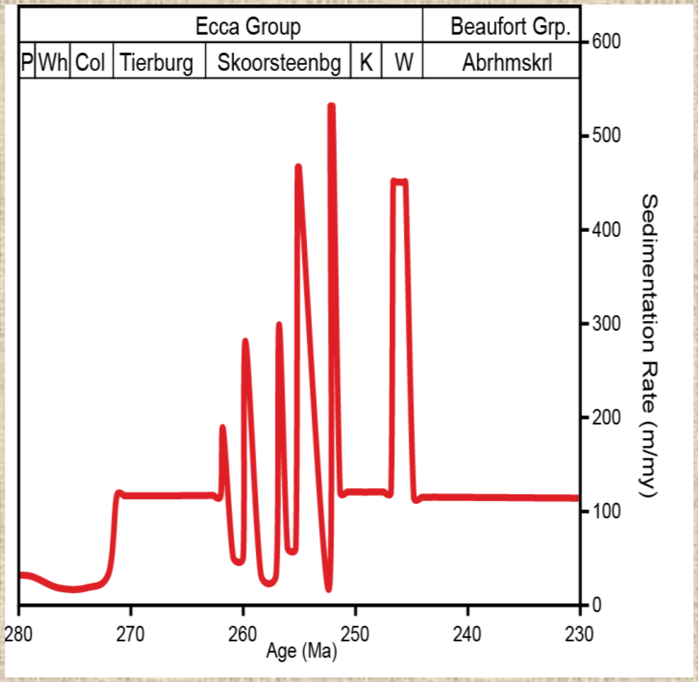
- Understand the relationship between deformation and sedimentation
- Resolve tectonic events



Are mountain building events recorded better in the mountain belts themselves, or in the adjacent basins?

Why is absolute age important in basin models? (for hydrocarbon exploration)

Lithology, compaction properties, and unit thickness can be directly observed/constrained for basin modeling. Age, however, is usually estimated based on biostratigraphic interpretations.



Basin model products that are dependant on age:

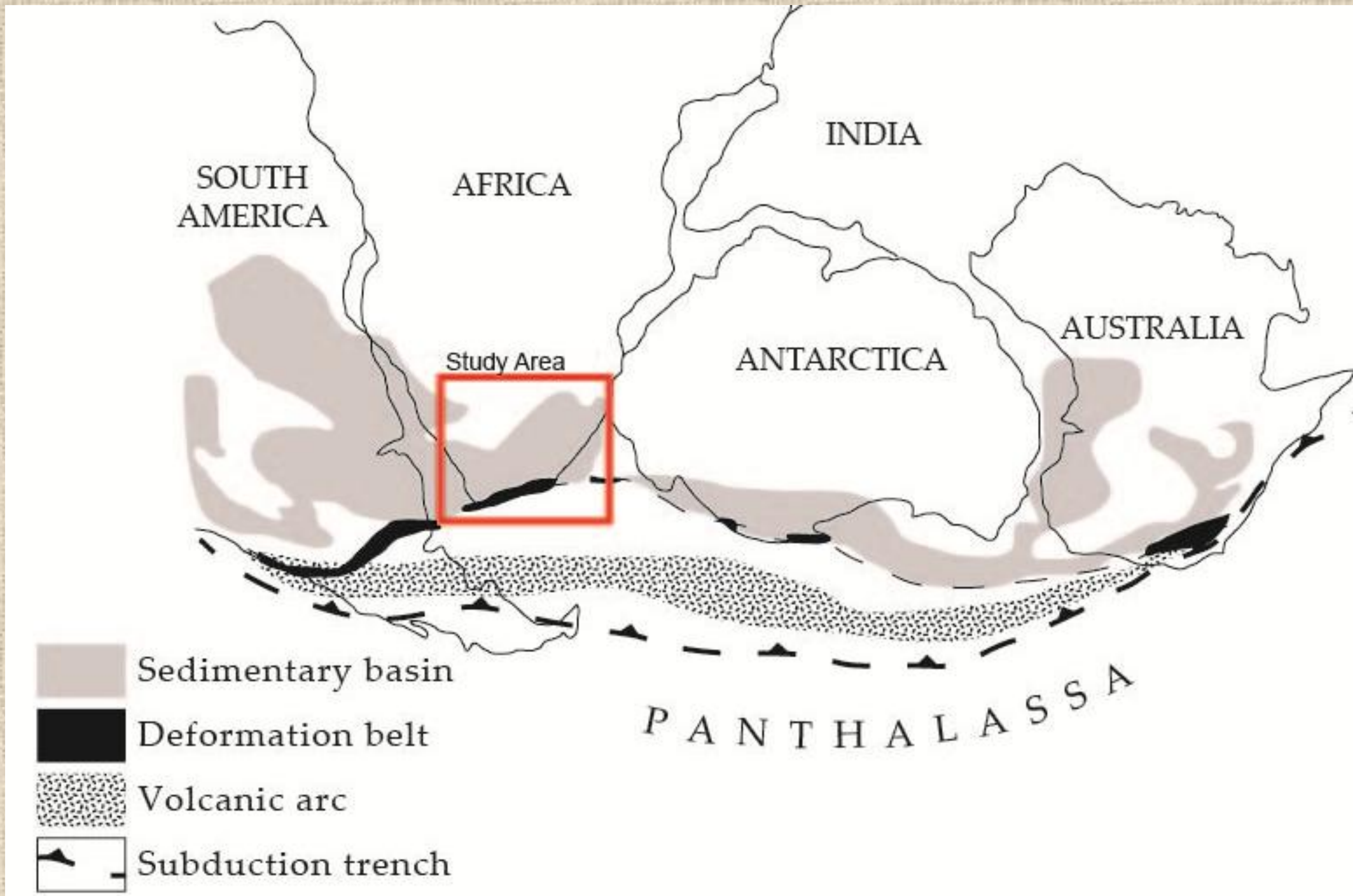
- Sedimentation and subsidence rate
- Compaction rate
- Timing of hydrocarbon maturation
- Timing of HC migration

Possible implications of poor age controls

Examples:

- High sed rate dilutes organic matter
- Migration predates reservoir development
- Seal insufficient to retain HC's over time

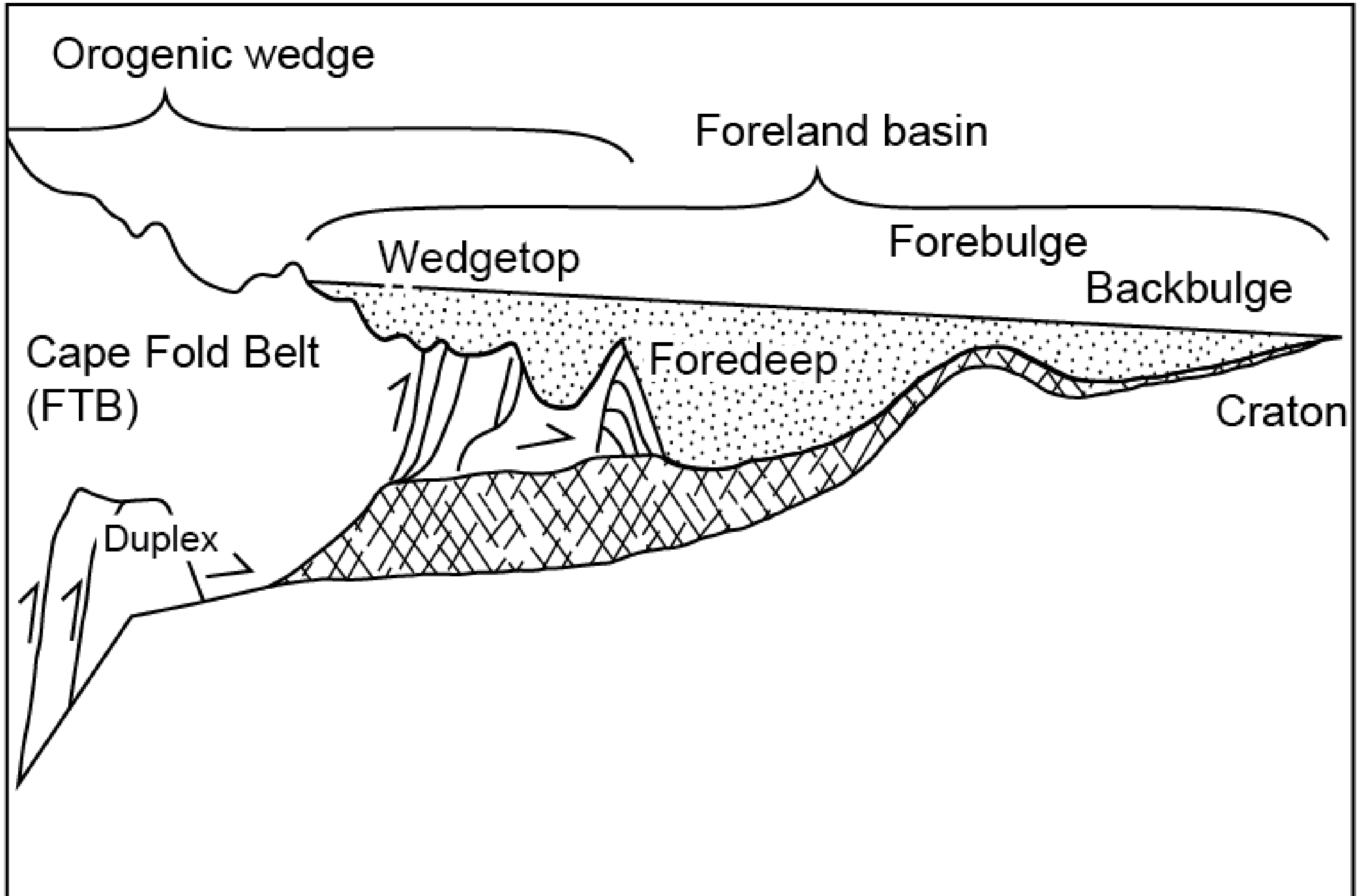
C-Tr Tectonism Along the Gondwanan Margin



The Karoo Basin and Cape Fold Belt record the Carboniferous-Triassic evolution of Gondwana.

Paleogeography modified from *Lopez-Gamundi and Rossello* [1998] and *Fildani et al.* [2007]

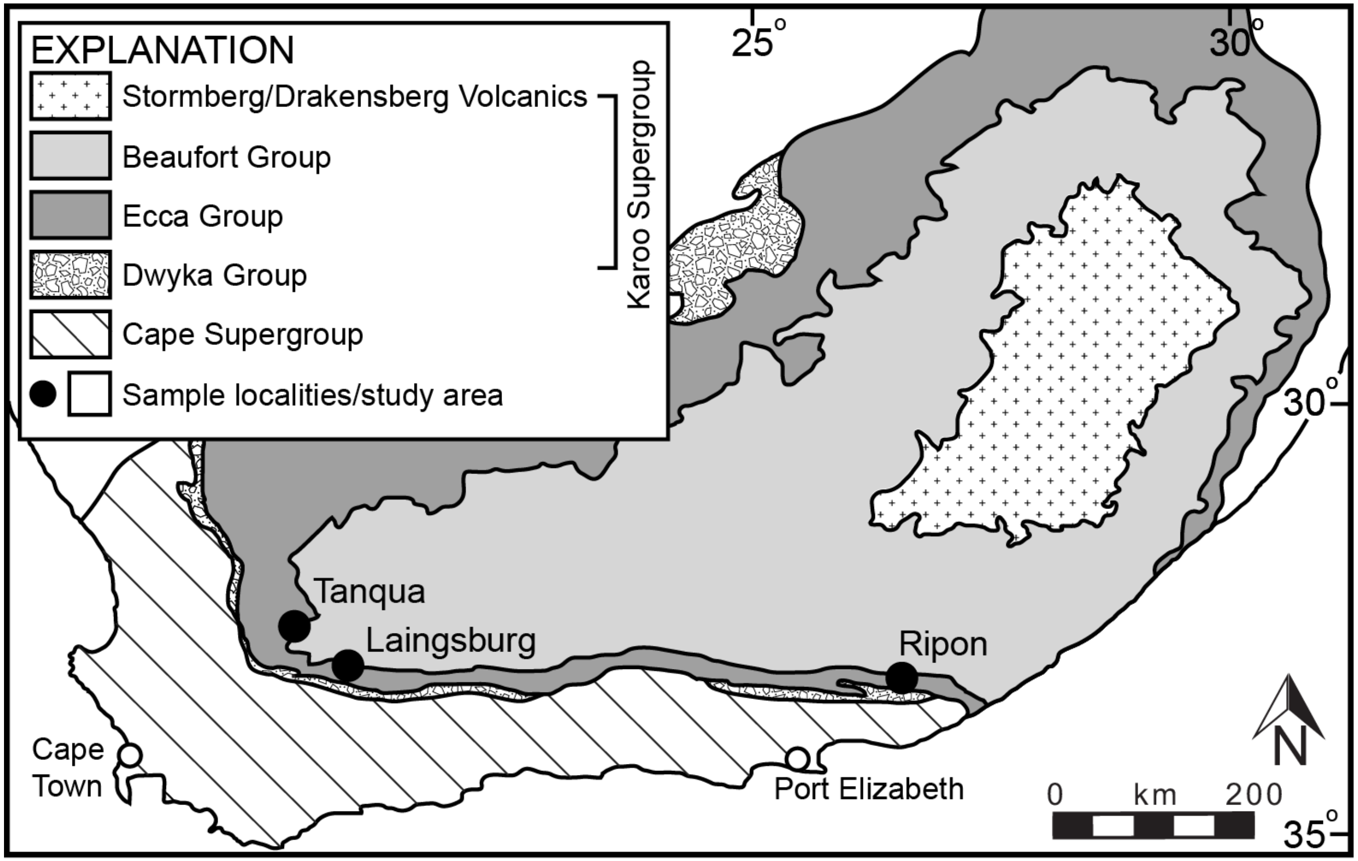
Foldbelt-foreland basin model

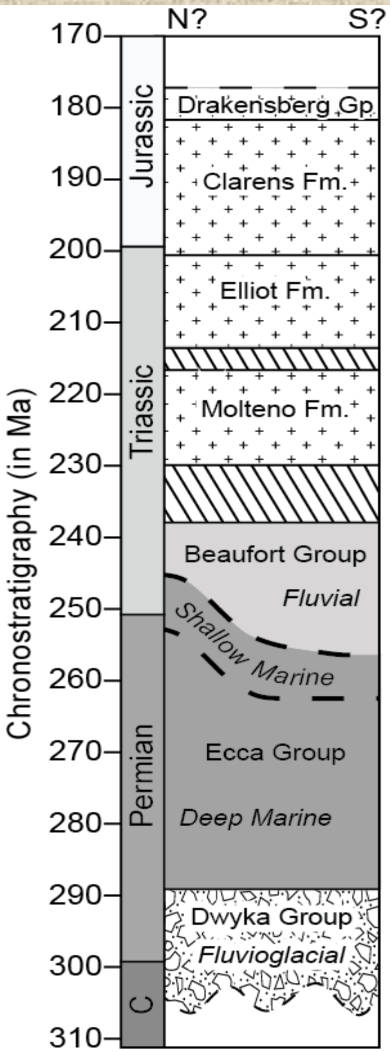


Modified from DeCelles and Giles, 1996

The Karoo Basin has been suggested to be a foreland basin in response to the Permian-Triassic Gondwanide Orogeny. Does the Karoo Basin record the relationship between **deformation** and **sedimentation**?

Geologic Overview of South Africa

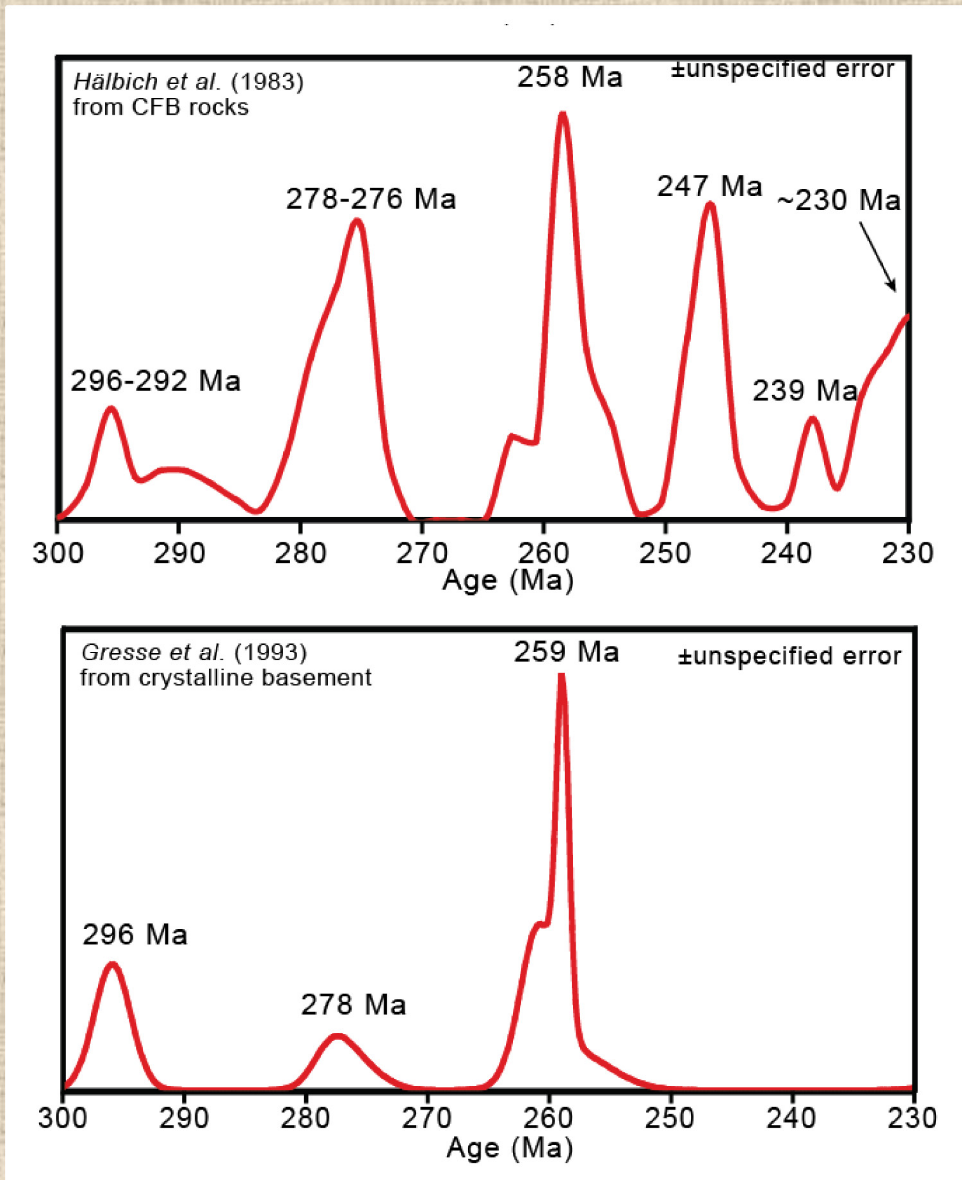


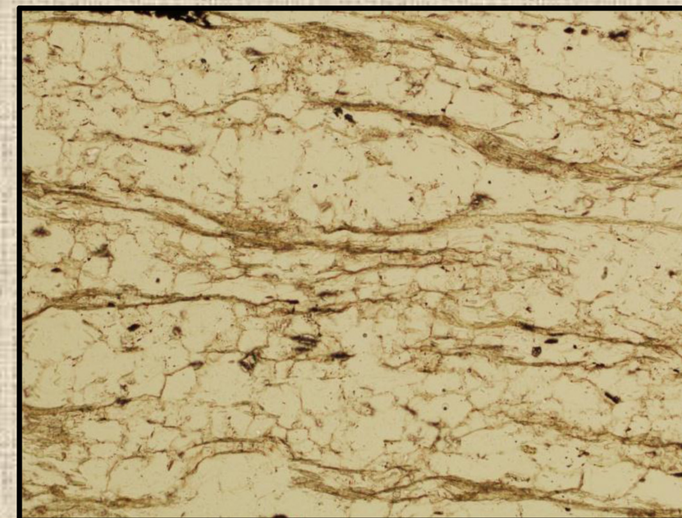


The Karoo Basin and Cape Fold Belt record the Carboniferous-Triassic evolution of Gondwana

Modified from Veevers et al., 1994; Catuneanu et al., 2005; Fildani et al., 2007

Dating the Cape Orogeny





Contentious $^{40}Ar/^{39}Ar$ ages of "mica" exist for deformation of the Cape Fold Belt.

Ages were interpreted to represent the growth of syndeformational metamorphic mica.

How can absolute ages be obtained for sedimentary rocks?

Volcanic ashes can be used to produce a radiometric age for the surrounding strata

Plinian eruption of
Mt. Pinatubo, Philippines
Photo from: Newhall et al. (1997)

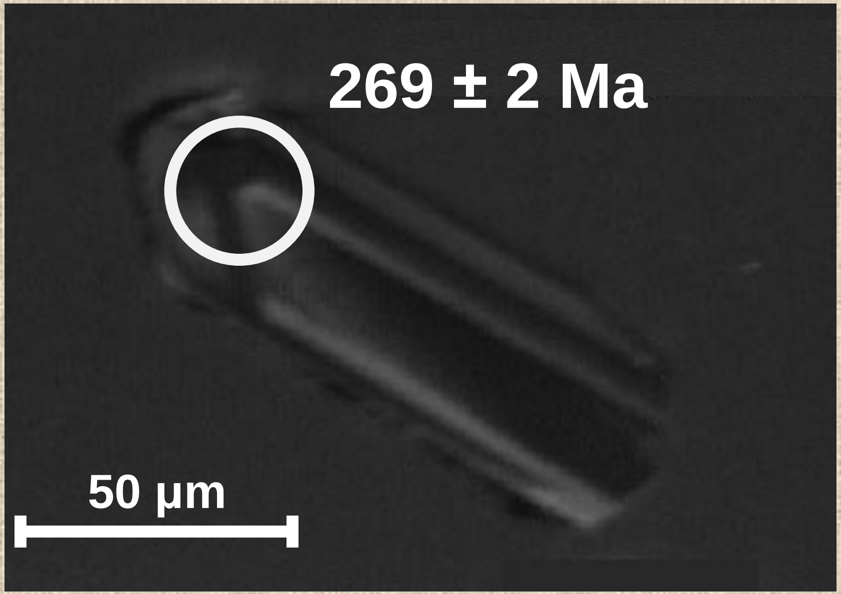
Ashes record geologically instantaneous events, where deposition occurs hours or days following an eruption.

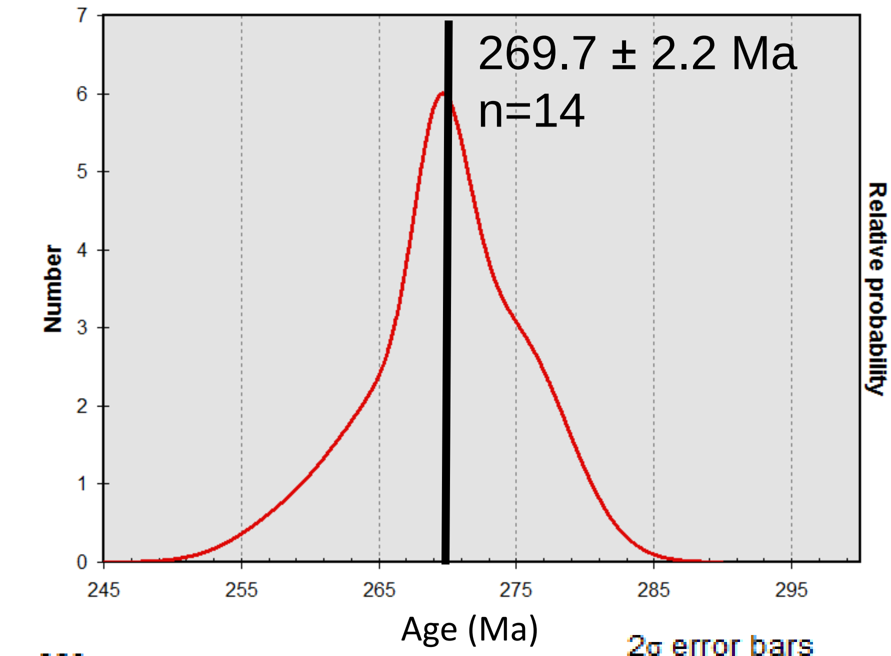
Ash can travel 1,000's of km from the volcanic source.

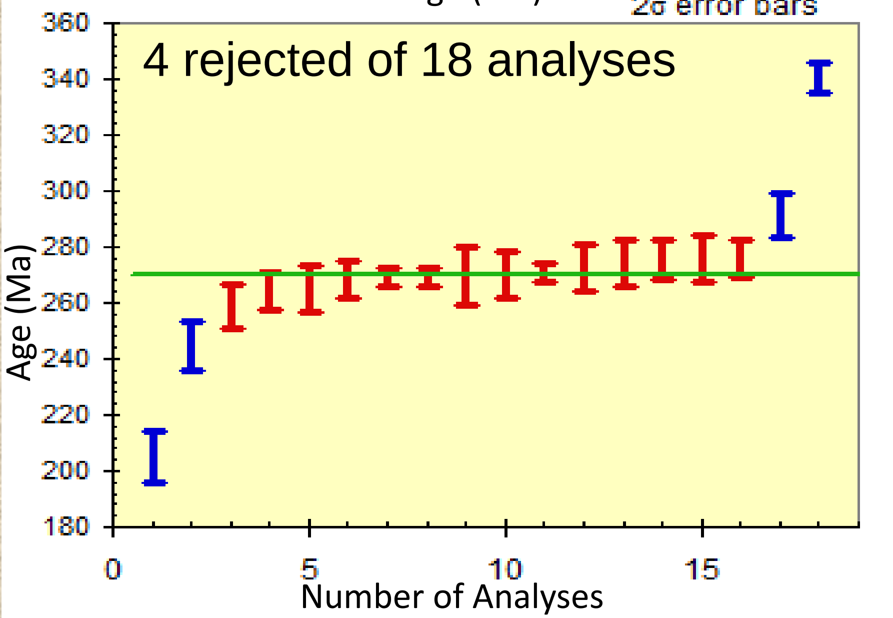
U-Pb zircon geochronology to date the eruption of volcanic ashes

Multiple zircon grains are analyzed using the Sensitive High Resolution Ion Microprobe (SHRIMP) at the USGS-Stanford Geochronology Center at Stanford University.

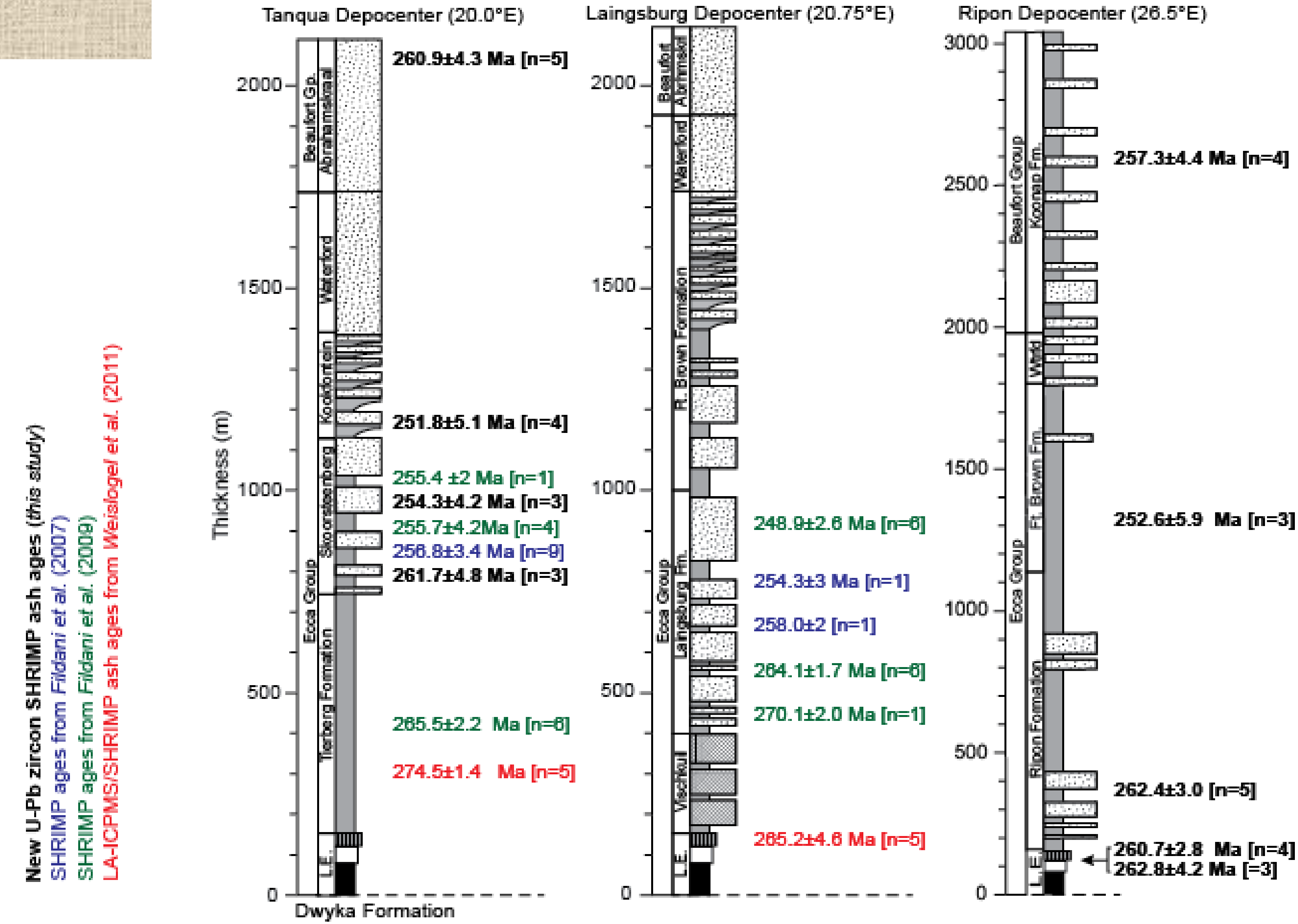
Ash ages are derived from weighted mean average of the youngest, coherent age population (from ^{207}Pb corrected $^{238}U/^{206}Pb$ age).







Geochronological age constraints on the Karoo strata



Basin modeling methodology

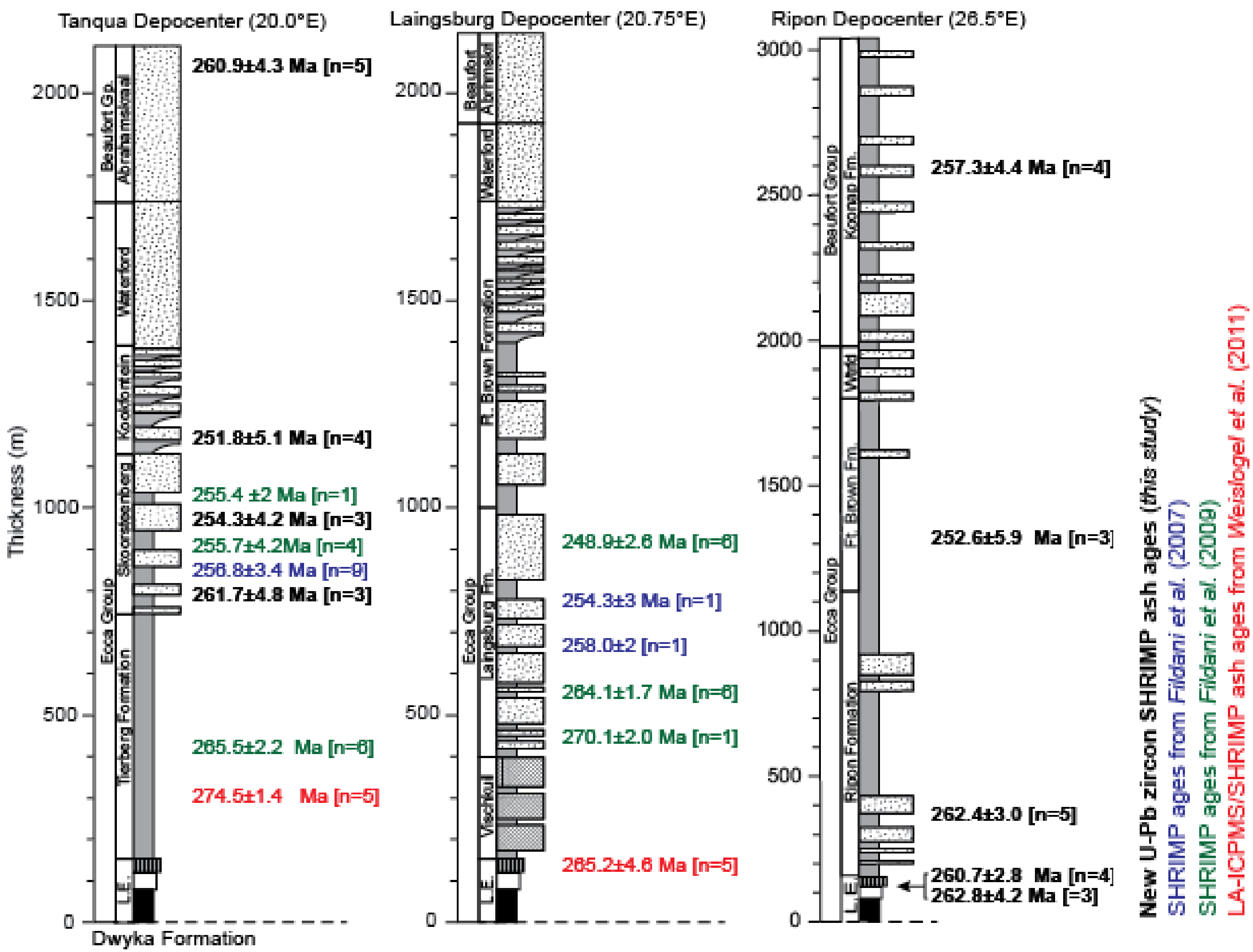
Variables for basin modeling:

•Unit thickness

•Lithology

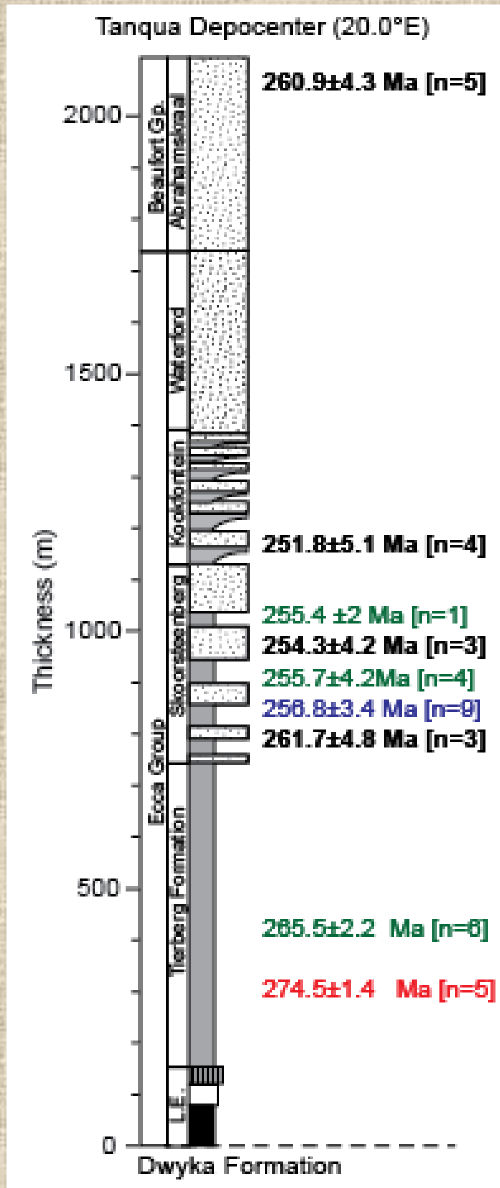
•Age

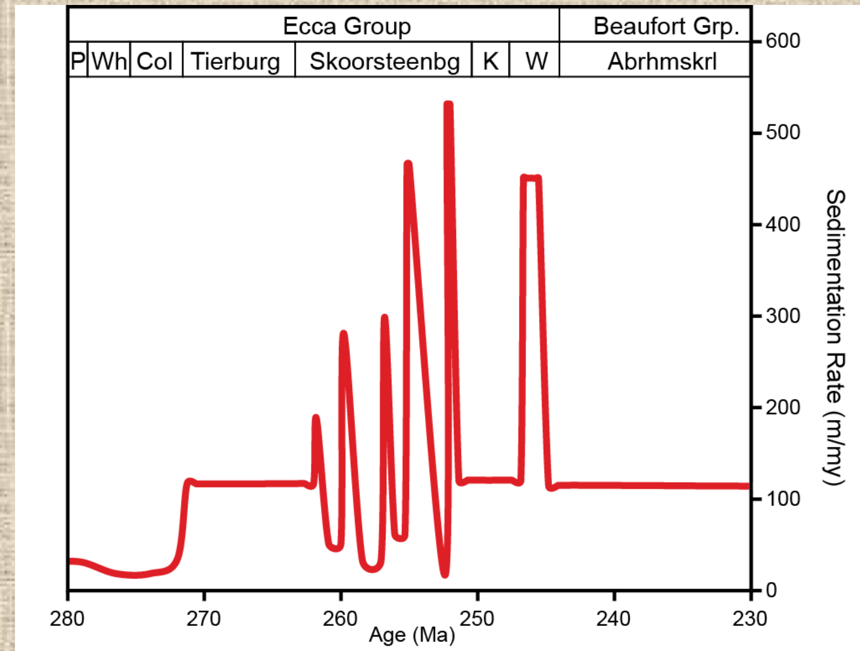
Using PRA's BasinMod

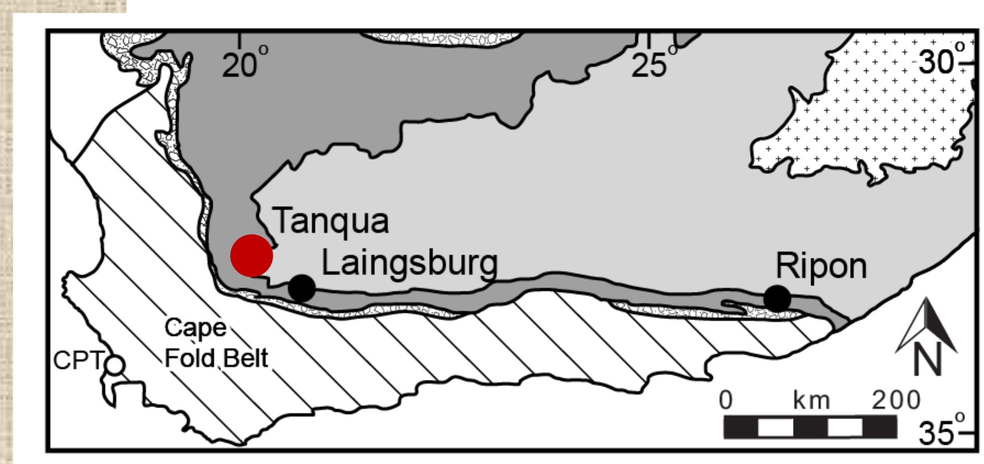


Introduction of high-precision age reduces reliance on bio/lithostratigraphic correlation

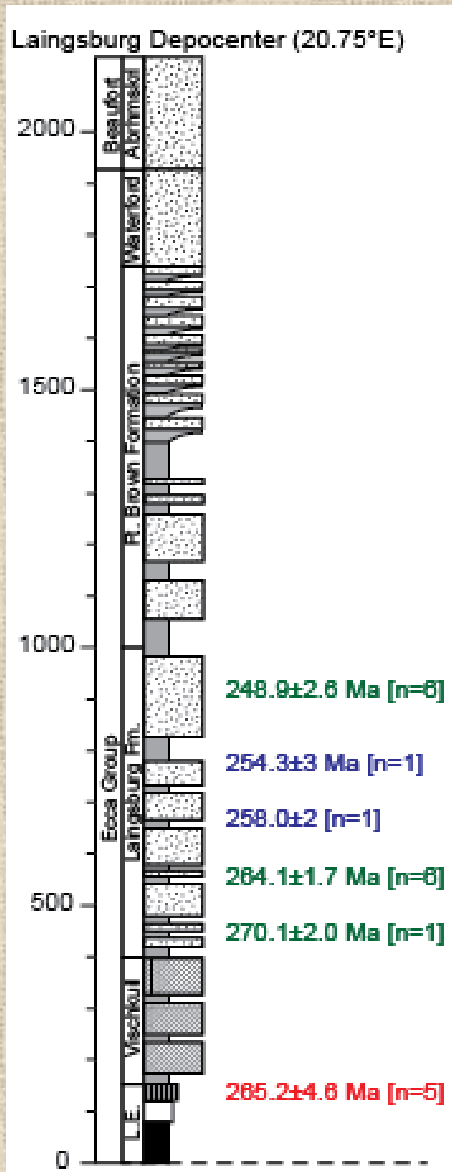
Dating basin filling using U-Pb zircon from ashes and basin models-Tanqua

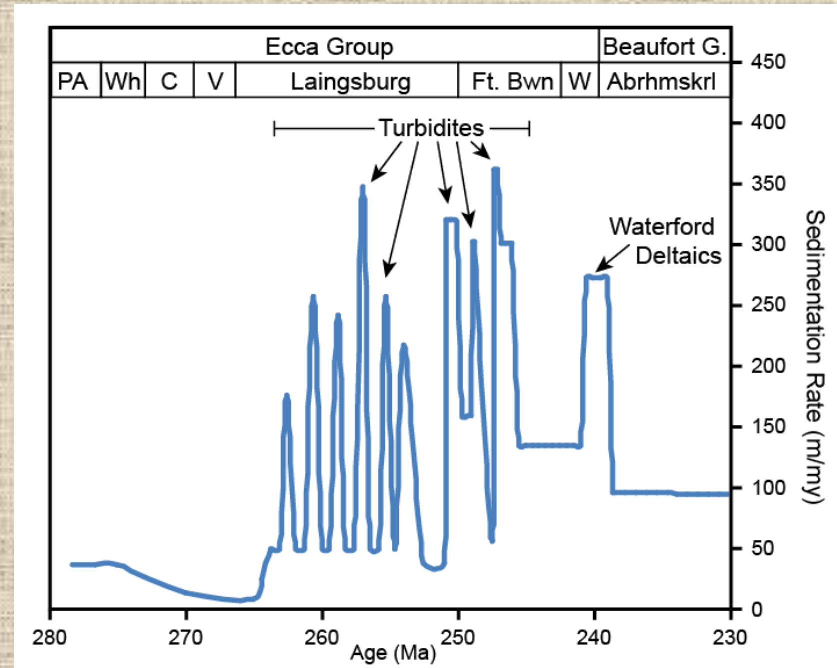


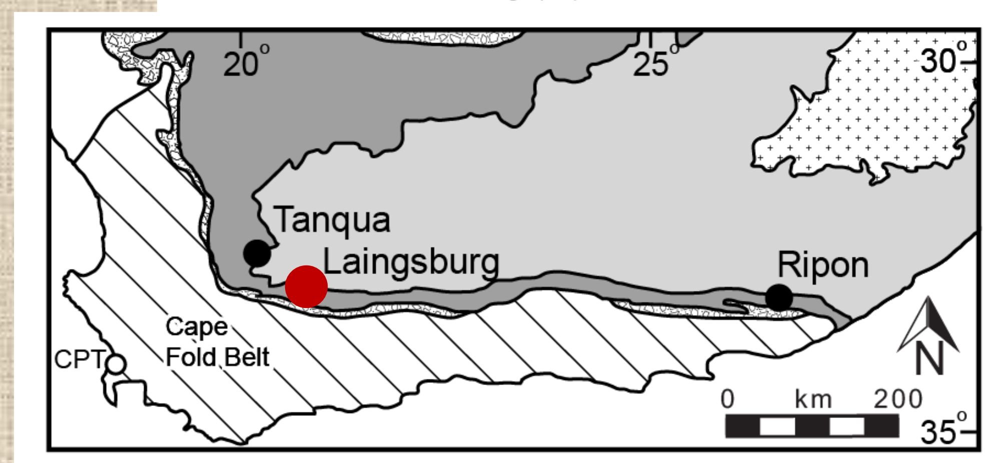




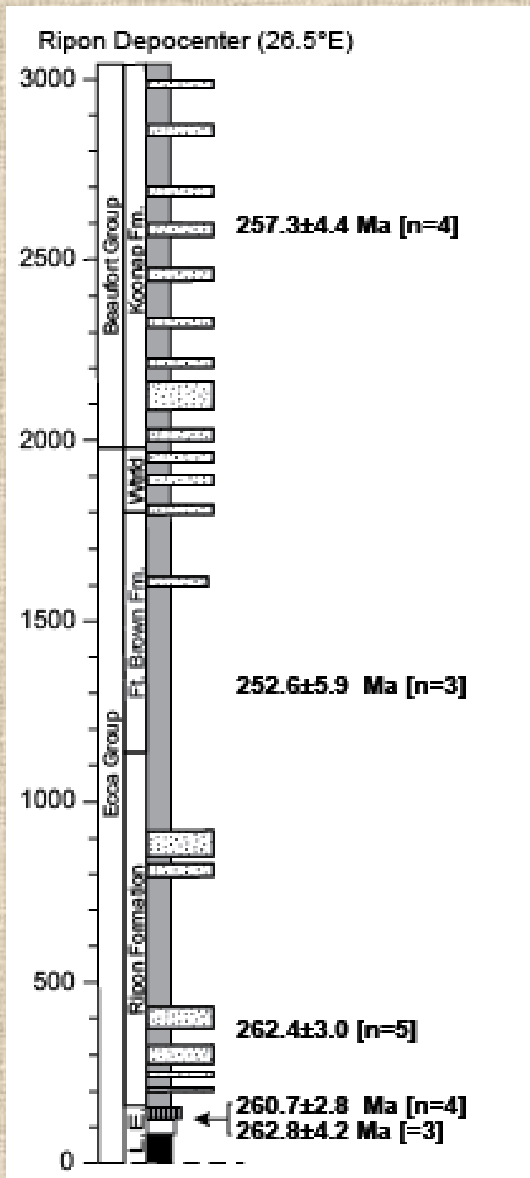
Dating basin fill using U-Pb zircon from ashes and basin models-Laingsburg

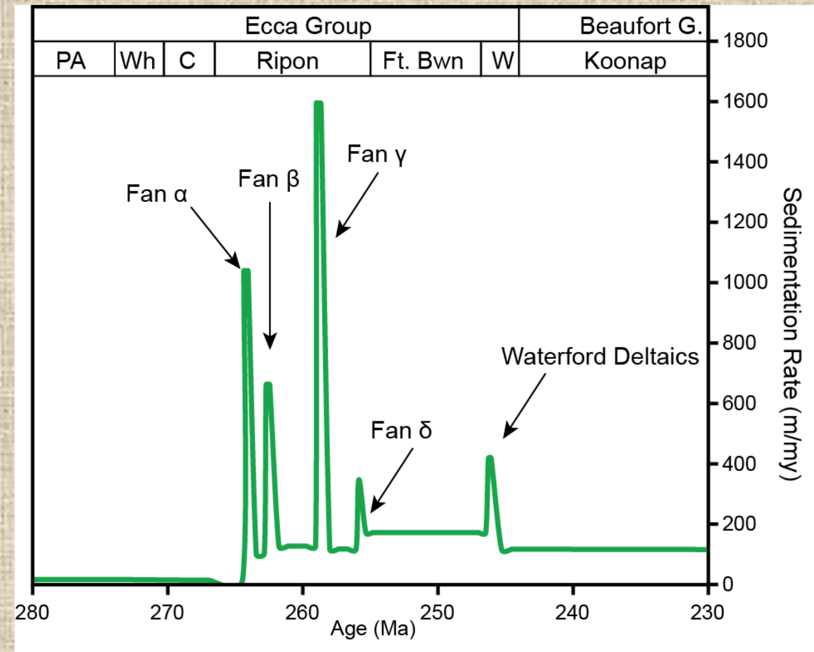


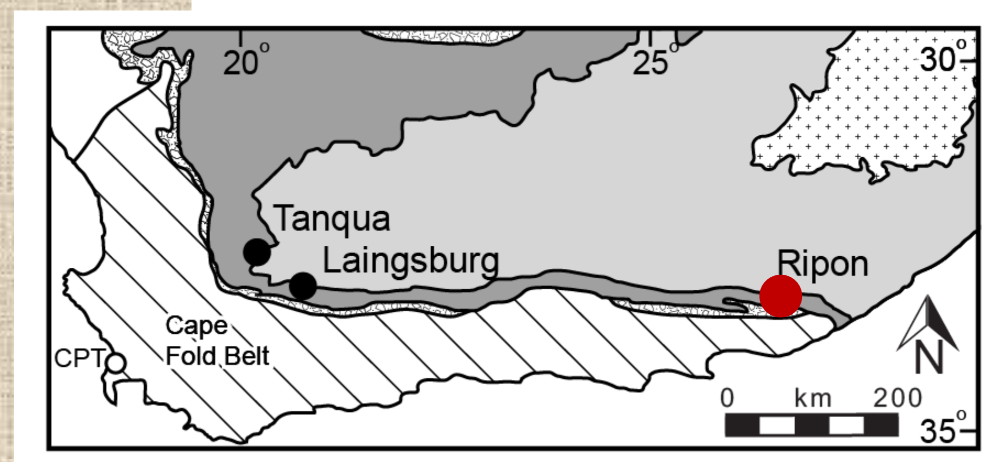




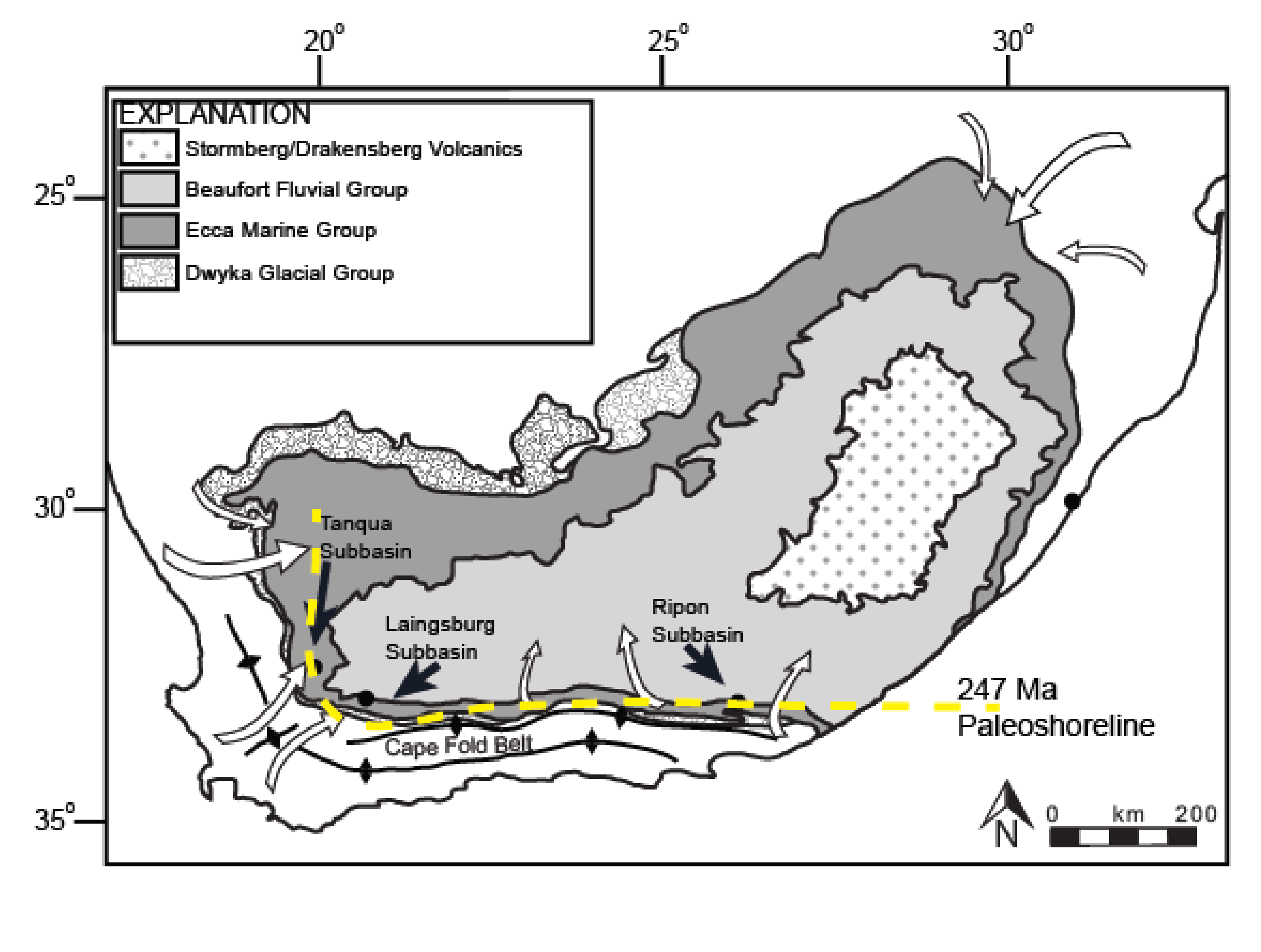
Dating basin filling using U-Pb zircon from ashes and basin models-Ripon



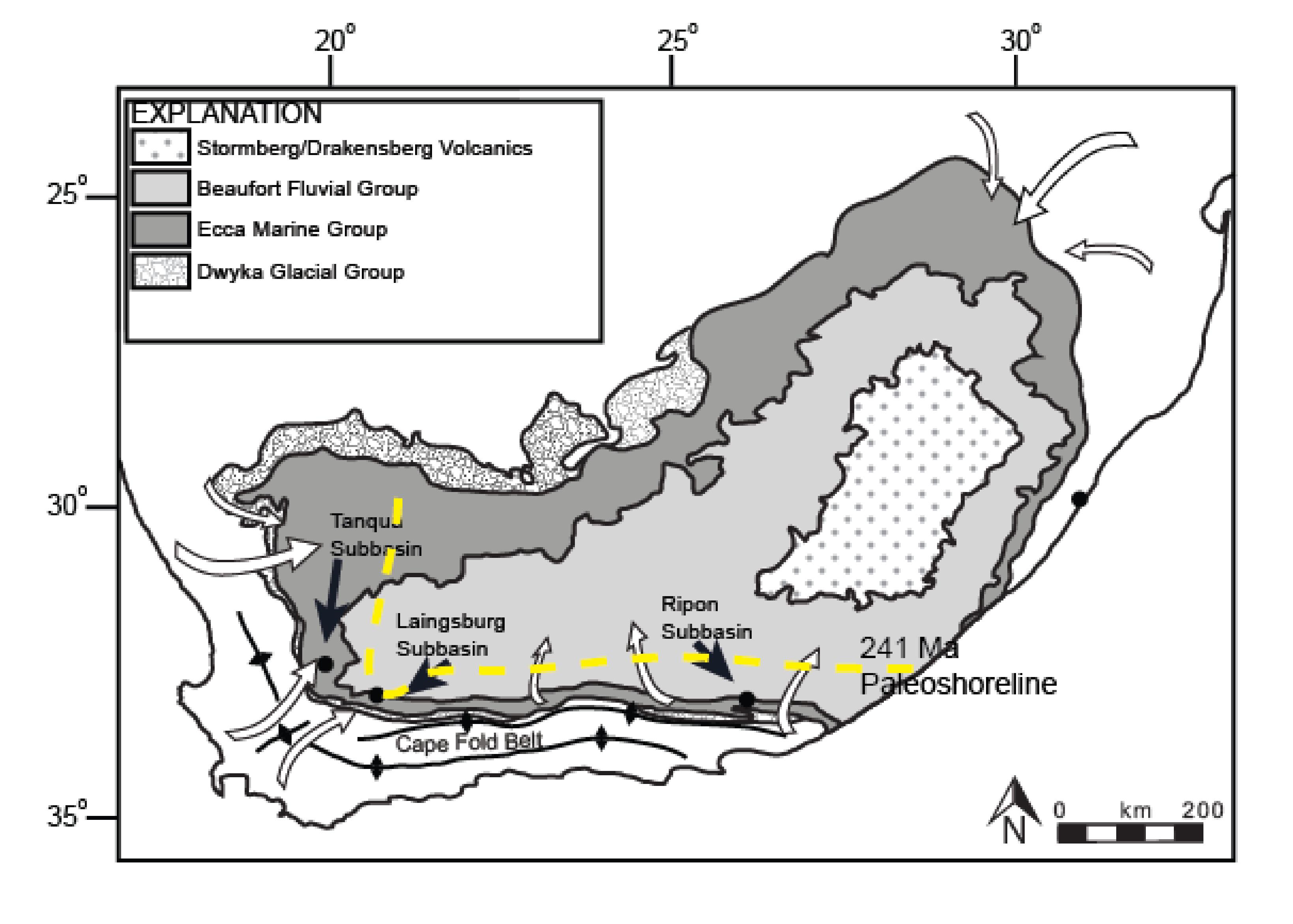




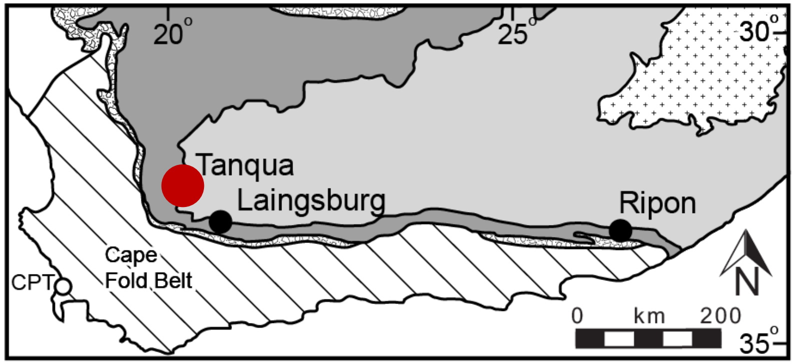
Basin Filling ~247 Ma



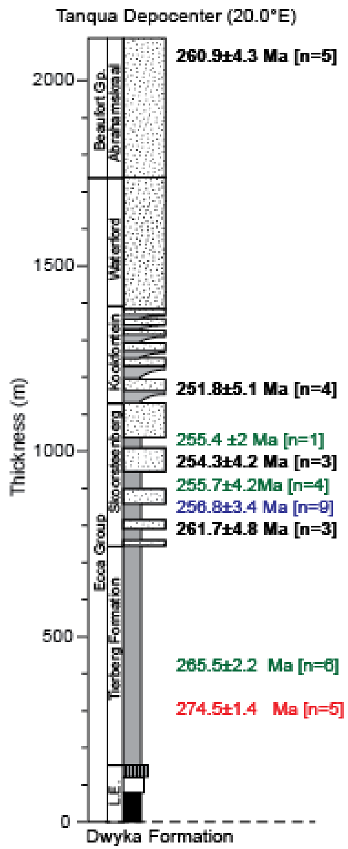
Basin Filling ~241 Ma

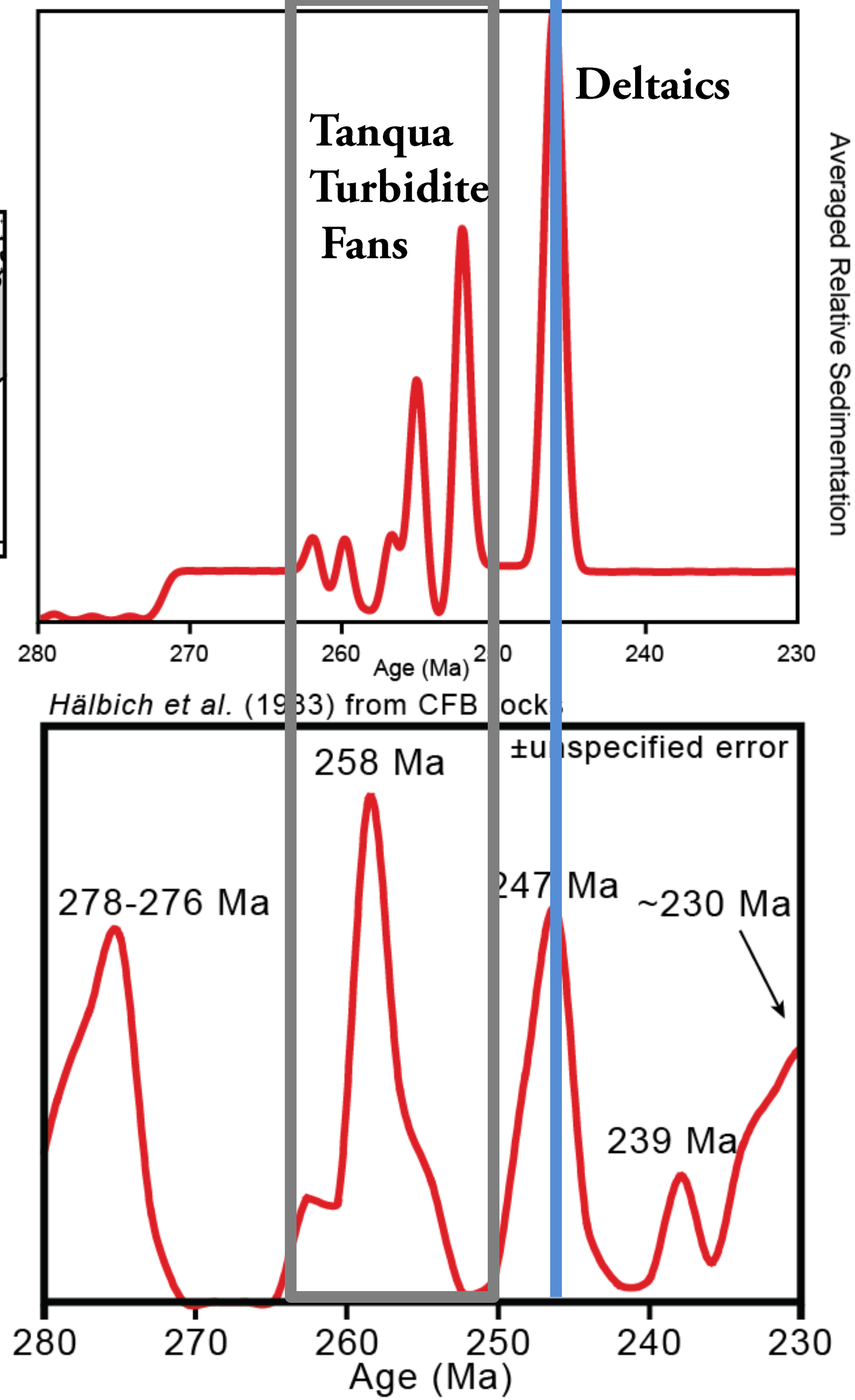


Comparison

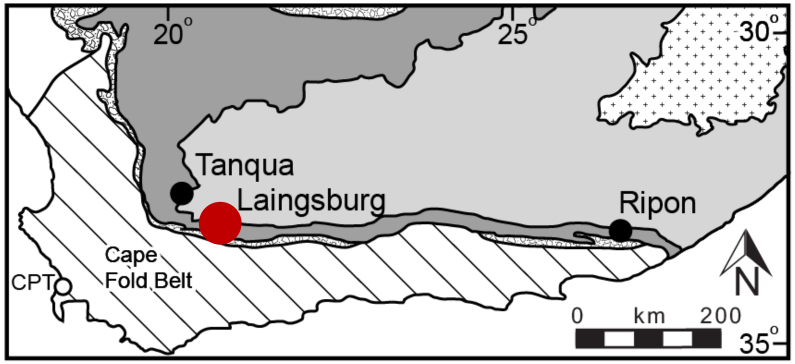


Tanqua

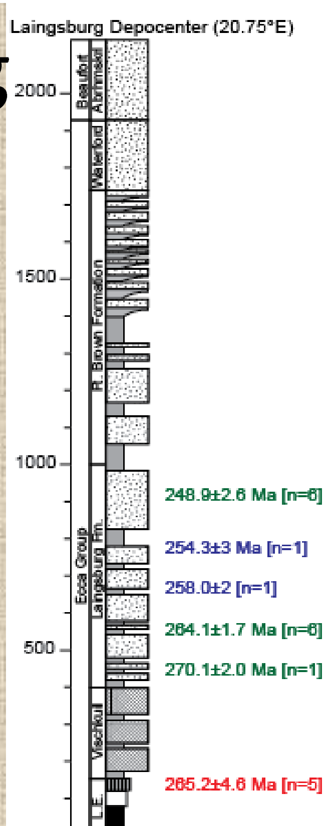


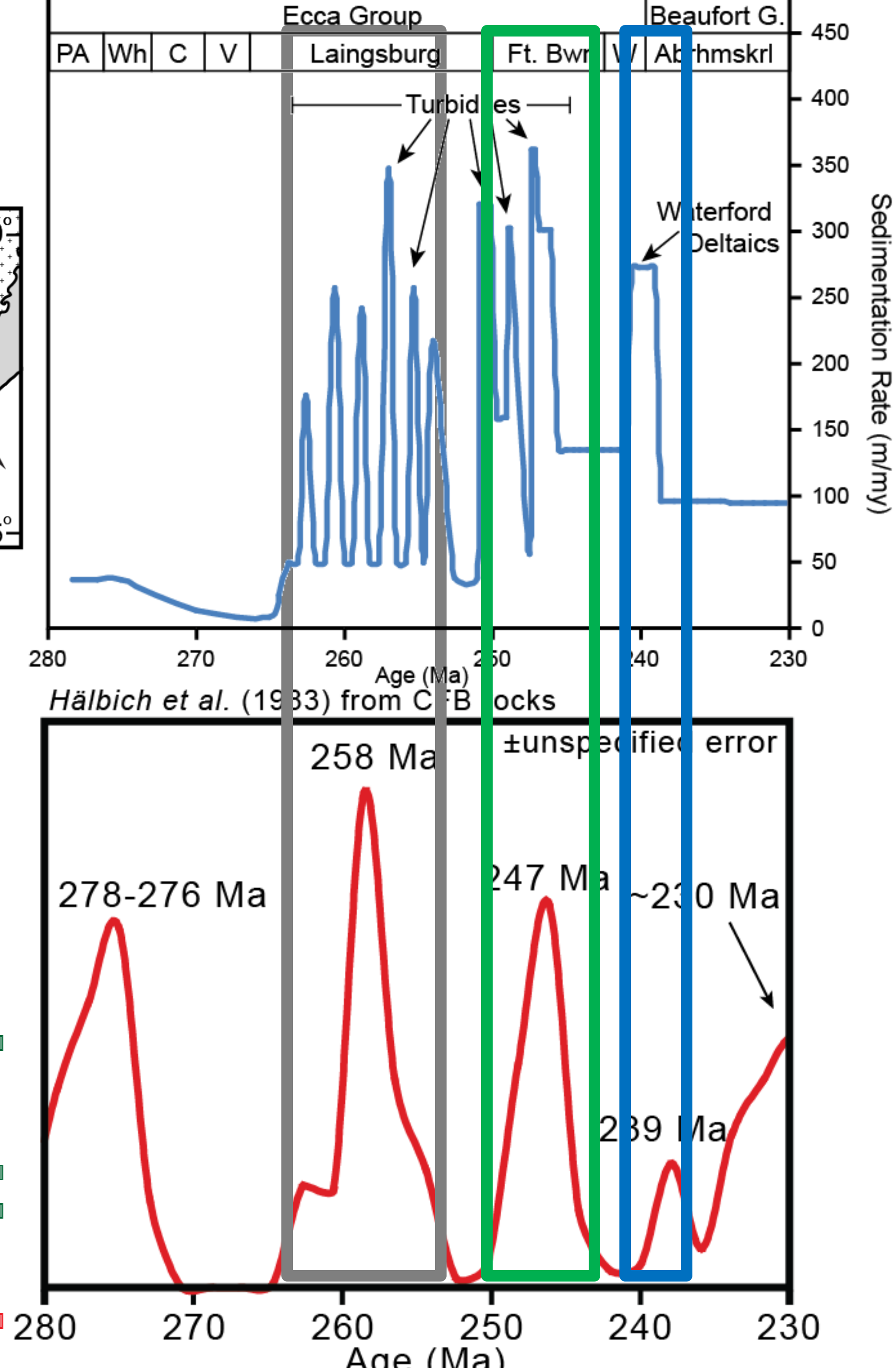


Comparison

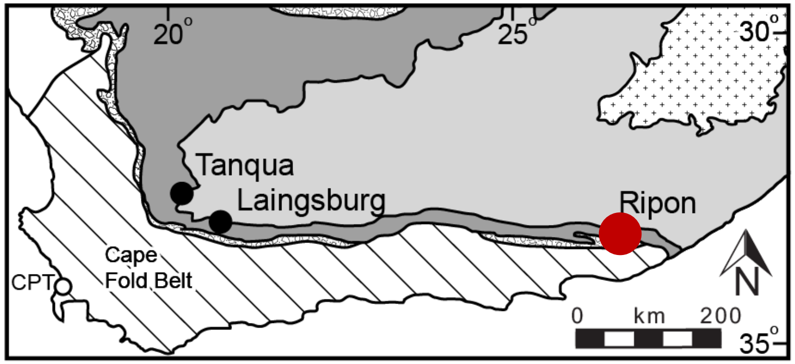


Laingsburg

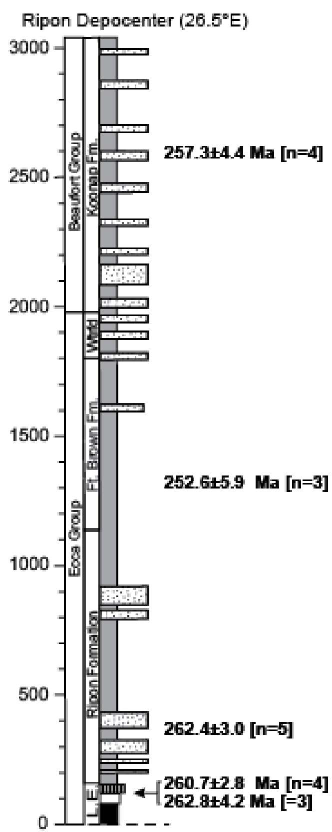


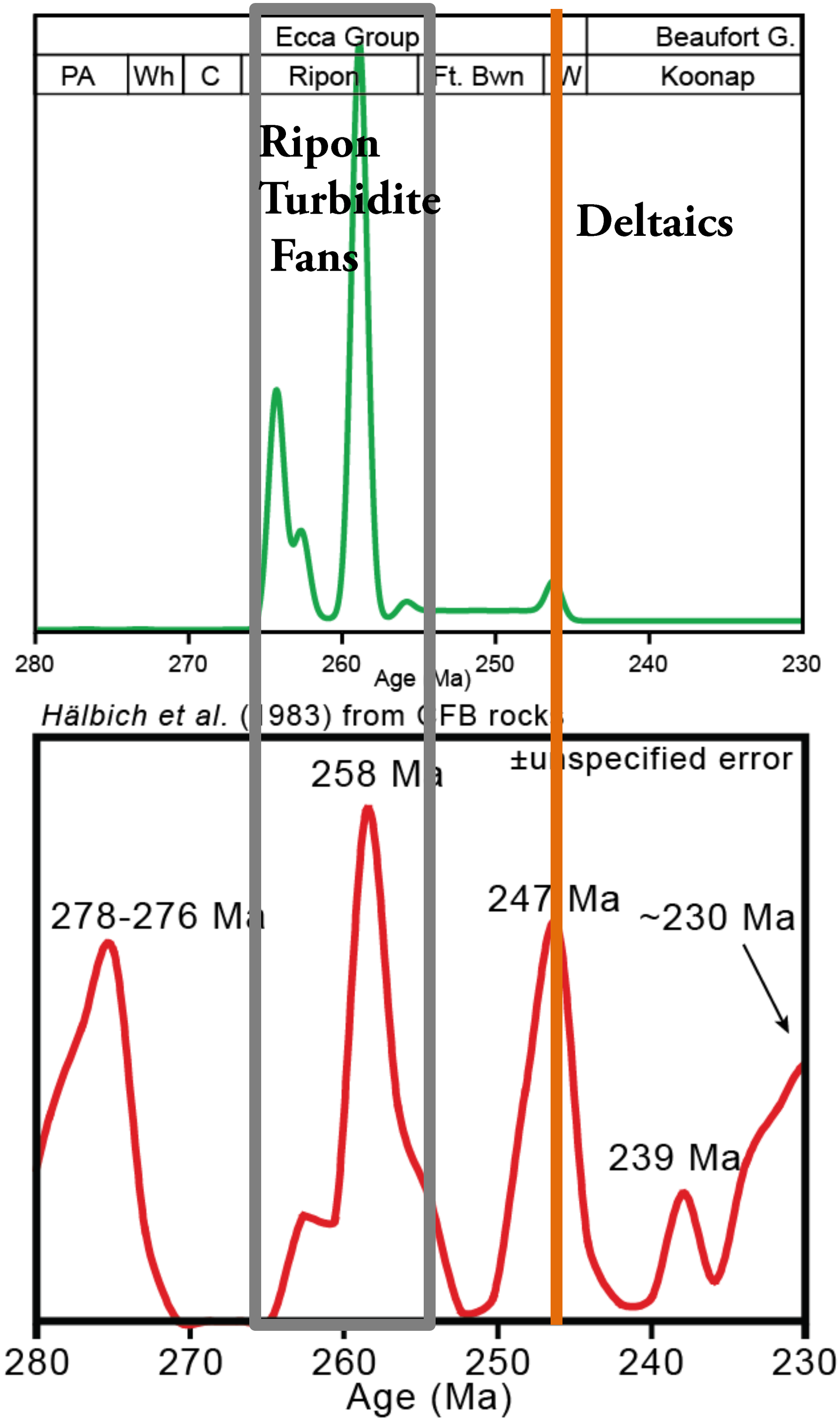


Comparison



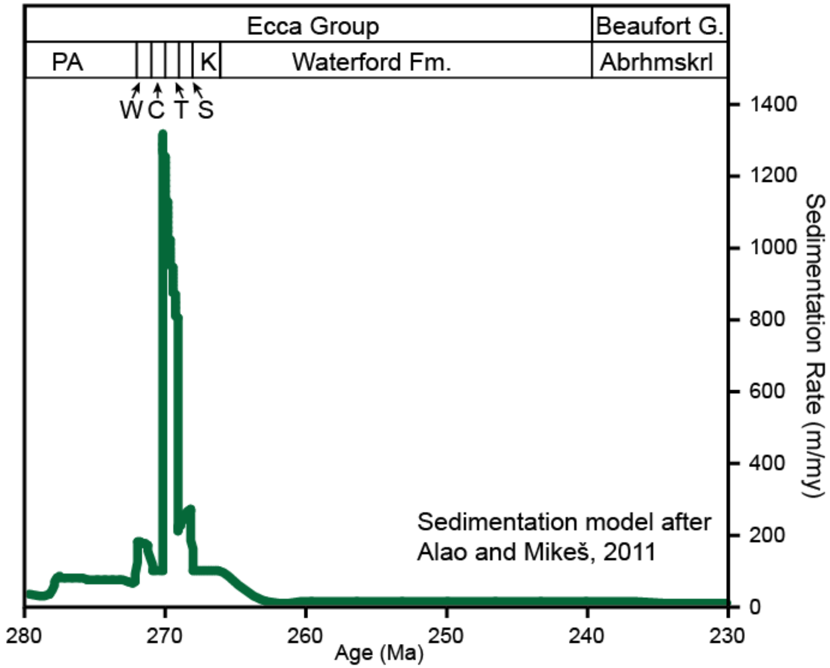
Ripon



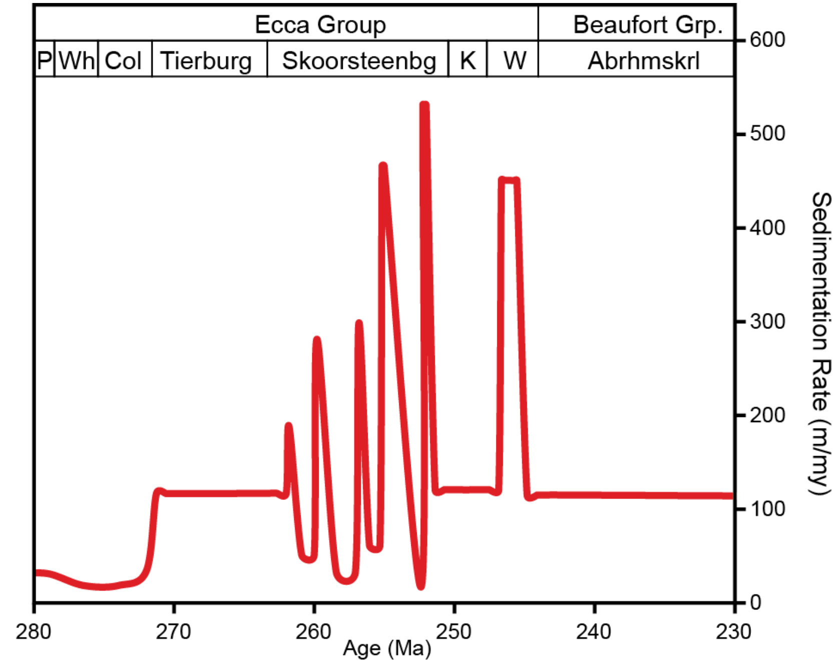


Implications for Basin Modeling-Tanqua Depocenter

Litho/biostrat. based



Geochron. based



Using age controls from biostratigraphy and correlated based on lithostratigraphy can potentially lead to models with less reasonable sedimentation rates and rapid accumulation.

Improved age controls lead to models with more moderate sedimentation rates.

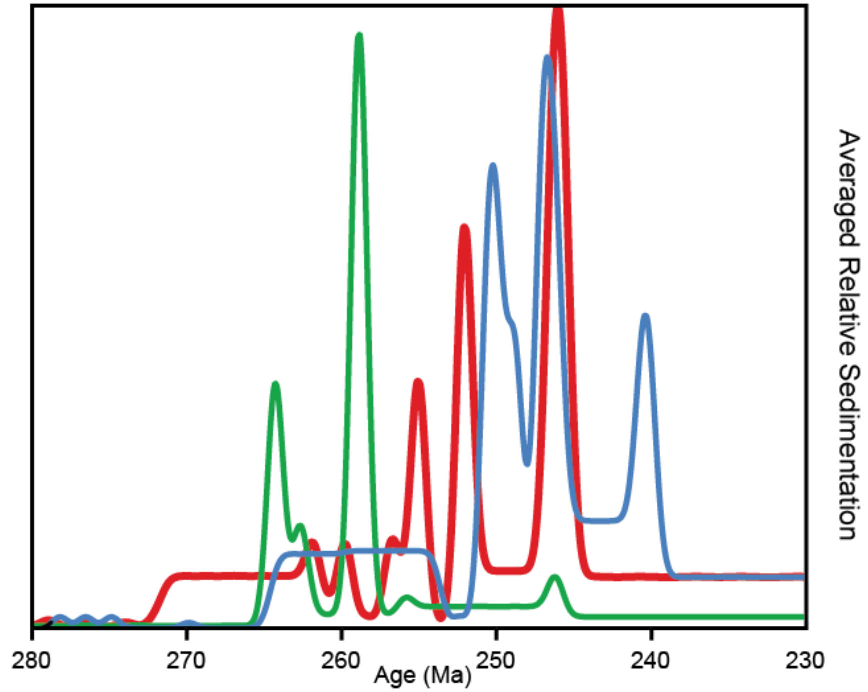
Conclusions

- Sedimentation in the Karoo Basin shows some temporal correlation with estimates for the timing of deformation.

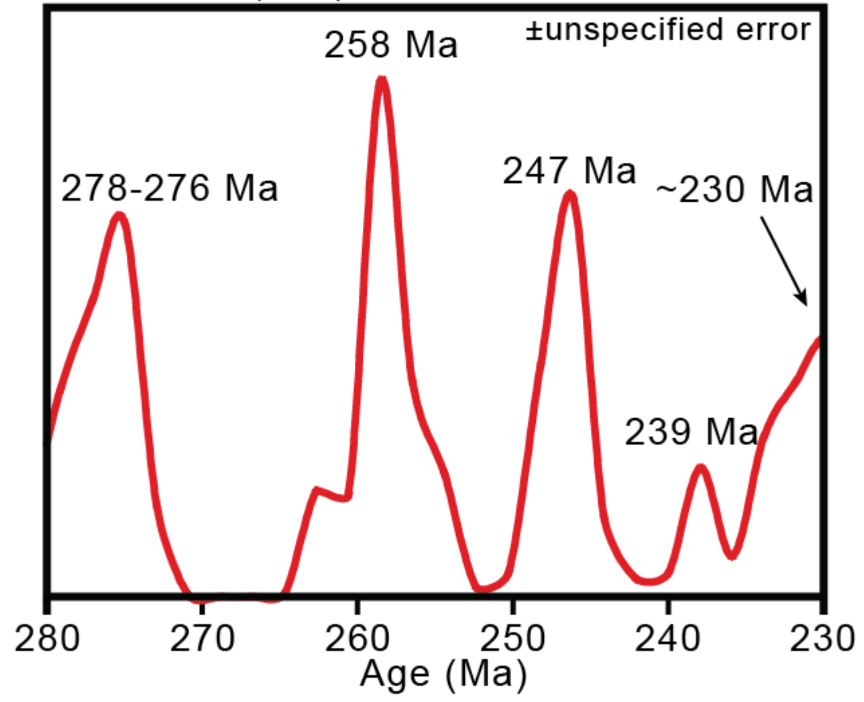
- These models suggest an in-phase model for sedimentation-deformation may be valid

- With enough detail, basin models may be complimentary to structural/deformation studies in tectonic investigations

- High-precision, geochronologic age controls greatly improve the usefulness of basin models



Hälbich et al. (1983) from CFB rocks



Acknowledgements

West Virginia University
DEPARTMENT OF
GEOLOGY AND GEOGRAPHY

Field work would have been impossible without logistical support from Dr. R. Brunt (Univ. Manchester), Dr. D. Hodgson (Univ. Leeds), and Chevron ETC.

We would like to thank Dr. R. Brunt, Dr. A. Fildani, Dr. A. Tankard, Dr. D. Hodgson, M. Jessee, Dr. M. Coble, Dr. J. Hourigan, Dr. O. Catuneanu, Dr. S. Buettner, Dr. K. Benison, Dr. J. Toro, and Dr. T. Kammer for meaningful discussion and feedback.
Patience and comments from K. Kingry are also greatly appreciated.

Lab assistance was provided by Dr. M. Coble (Stanford Univ.) and K. Flowers.

We appreciate funding that was generously provided by the following organizations and individuals:

West Virginia Univ. Faculty Senate
Chesapeake Energy
American Association of Petroleum Geologists
Society for Sedimentary Geology
Geological Society of America
West Virginia Univ. Dept. of Geology and Geography
Dr. and Mrs. Robert Shumaker
Hess Corp.

Sedgefield, Western Cape, ZA