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Extent and Distribution of Individual Proterozoic Orogenic Belts in Southern Africa from Gravity and Magnetic Data

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Abstract

Newly compiled gravity and magnetic datasets, in conjunction with existing geochemical/geochronological data have been able to provide a unique view into the structural evolution of individual Proterozoic mobile belts of southern Africa. Currently there is little actual evidence to support the proposed boundaries for many of the Proterozoic belts that surround the Kaapvaal and Zimbabwe Cratons except for very limited geochemical data and even more limited structural mapping. These newly compiled gravity and magnetic datasets have been able to significantly improve our understanding of the structural geology of these belts and better constrain their evolution and the tectonic interrelationships that control that evolution.

Introduction

Archean cratons comprise only small portions of the modern day continents. However, these portions of the earth's crust represent the oldest cores of the modern day continents and some of the most fertile regions in terms of mineral wealth. One such region is in Southern Africa where the Kaapvaal craton and the Zimbabwe craton collided during the latest Archean (1) and were subsequently surrounded by younger orogenic belts when the rest of Africa accreted to this 'core'. As a natural result of this incredible age, the structural geology of Southern Africa is very complex. Surrounding the Archean cratons that began stabilizing at approximately 3,080 Ma (million years) (2) are several orogenic belts of Proterozoic age. Previously these belts have been poorly constrained due to the fact that they are typically buried under thick blankets of younger sediments (3). The flat topographic profile over much of southern Africa illustrates this fact well, and many of the areas with significant topographic relief still have recent cover that obscures the basement geologies of these areas. Fortunately, geophysics, particularly gravity and magnetic data analysis, provides a unique view into these deeply buried terrains (4). These methods are able to effectively image the deep crustal features that have no surface expression.

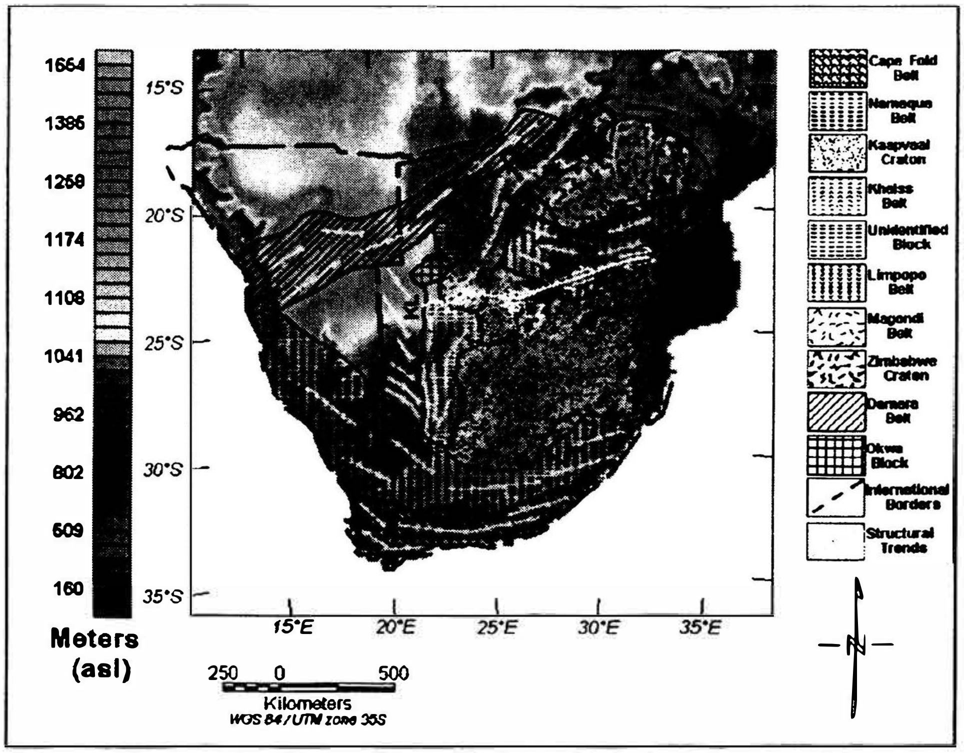

Figure 1: A topographic map of southern Africa with the major tectonic boundaries lay on top. Note that many of these features have very little topographic relief. This has made delineation of these belts very difficult in the past. KL=Kalahari Line; PLZ=Palala-Zoetfontein Shear Zone (Data courtesy of Geosoft)

Gravity and magnetic data on the cratonic and continental scales are typically collected by airplanes or helicopters. These aircraft are fitted with specialized equipment that is able to measure the acceleration due to gravity and the intensity of the total magnetic field to a high degree of accuracy (5). The databases with this information can then be compiled to generate regional gravity or magnetic databases for interpretation. One such database of recently compiled data, provided by the South African Council for Geoscience, was the source of the geophysical data used in this study.

With the aid of geochemical analysis from boreholes in several of these Proterozoic belts it is possible to constrain the tectonic history of one of the oldest regions of the earth. In addition, it is possible, with the aid of gravity and magnetic data from this region, to create two-dimensional profiles of the subsurface structures that define these Proterozoic belts. This combination of structural analysis from geophysical data, geochronological dating, and modeling provide a unique view of the structure and evolution of the crust in Southern Africa.

Methods

The data provided by the South African Council for Geoscience was processed using Geosoft's Oasis Montaj suite for the analysis of potential field data. The data, comprised of thousands of individual data points, was displayed on a two-dimensional grid and color contoured. By using a local datum transform it was possible to geo-reference the data and project in on a lat-long map. Various mathematical filters were applied using processing algorithms built into Oasis Montaj, namely a Fast Fourier Transform algorithm to convert the data from the space into the frequency domain. The data was then manipulated mathematically primarily by taking the first vertical derivative to heighten vertically controlled changes in the data and by removing the higher frequency components a process known as upward continuation. The data is then converted back into the space domain to be displayed for interpretation (6). These processes make deeper features more pronounced and easier to interpret. In addition, it is possible to better delineate structural trends within the basement geology. This was done by carefully comparing the newly available gravity, magnetic and the previously published geochemical/geochronological data.

A profile was extracted from the data using GM-SYS, a two-dimensional (vertical and one horizontal direction) modeling package, which allowed me to model the structure of a Late Archean orogenic belt, the Limpopo Belt, from the surface to the crust-mantle boundary. This is done by matching a calculated model to the data extracted from the dataset. GM-SYS and Oasis Montaj are integrated in such a way as to make the extraction process very simple. In addition constraints were placed on the crust-mantle depths by seismic data from the Kaapvaal Seismic Project (7). The basic crustal structure was assumed to be that proposed by Kampunzu and Rangani (8).

Data and Discussion

A basic tectonic reconstruction as defined by geophysics and geochemistry is shown in figure 2. The oldest structures, the Kaapvaal and Zimbabwe cratons, collided at the very end of the Archean in a Himalayan type orogenic event creating the Limpopo Belt. Throughout the Proterozoic there were several orogenic events on the western and southern margins of the assembled block that can be easily discerned in the geophysical data. There may have also been belts on the eastern margin of the Zimbabwe and Kaapvaal cratons, but they were destroyed by the breakup of Gondwanaland during the Mesozoic, and there was poor data coverage to the north of the Zimbabwe craton. The age of the Proterozoic belts decreases with distance from the Archean cratons.

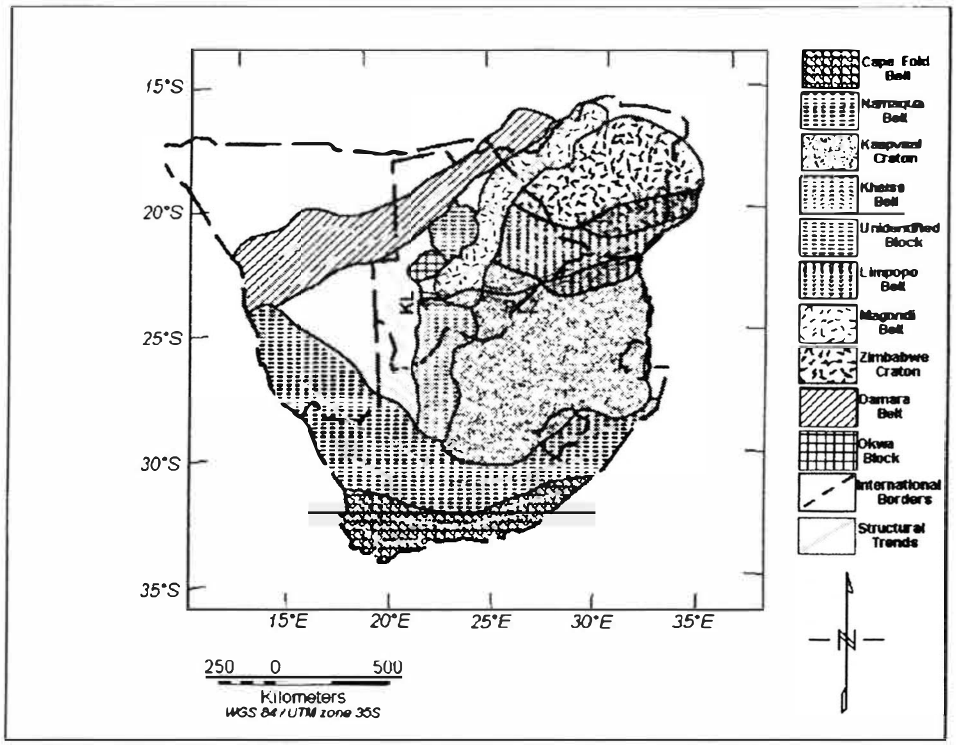

Figure 2: Tectonic interpretation of the basement geology in southern Africa. PLZ=Palala-Zeitfontein Shear Zone; KL=Kalahari Line

The Limpopo Belt

The Limpopo Belt is one of the first major Himalayan type orogenic belts in the world (1). It occurred at the end of the Archean Eon as a result of collision between the Zimbabwe and the Kaapvaal craton and has been dated to at approximately 2595 Ma (9). This collision created a mountain belt that, according to seismic data has a crustal thickness slightly greater than that of the cratons themselves (7). It is defined by not only a thickening of the crust, but also appears to override portions of the cratons. The southern marginal zone marks a location where the Limpopo Belt covers the Kaapvaal craton at shallow crustal level, and the northern marginal zone represents the same phenomena in the Zimbabwe craton (3). It is possible to extract a gravity profile across the Limpopo Belt using the GM-SYS modeling package and generate a model for the subsurface structure of the Limpopo Belt. Figure 3 shows the location of the extracted profile, and figure 4 displays the model that was generated using constraints provided by geochemistry and seismology (7,9).

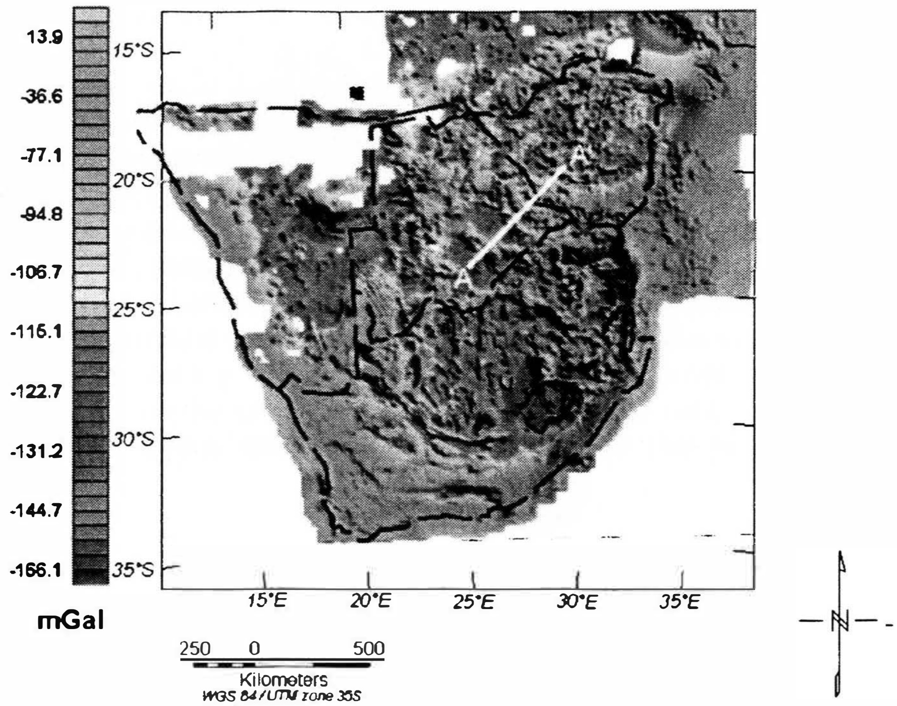

Figure 3: Color shaded relief of gravity data showing the location of the extracted gravity profile, A-A', from southwest to northeast. Dashed lines represent national borders

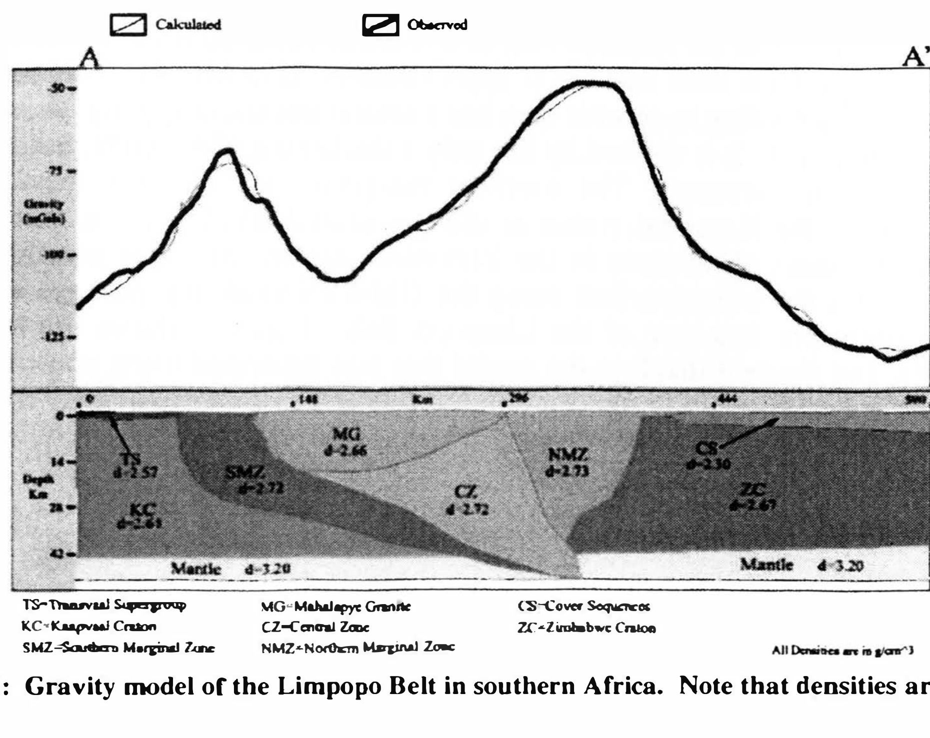

Figure 4: Gravity model of the Limpopo Belt in southern Africa. Note that densities are in g/cm^3.

The model of the gravity anomaly over the Limpopo belt displays three unique shear zones sandwiched between the Archean cratons. The densities used represent averages for the rock-types that comprise each unique tectonic unit (5). The Southern Marginal Zone (SMZ) represents a thrust front is exposed at the surface. It is bounded in the northeast by the Mahalapye Granite (MG) that overlies the Central Zone (CZ) of the Limpopo Belt in this area. This granite is a post tectonic event that is bounded by the Northern Marginal Zone and completely covers central zone (4). The general shapes of the cratonic blocks indicate the SMZ and the CZ were thrusted onto Kaapvaal craton and the NMZ was thrusted backward on to the Zimbabwe craton. This is consistent with the pop-up structures seen in the Himalayan Mountains today (1).

The Kheiss and Magondi Belts

The region directly to the west of the assembled cratonic cores is comprised of two Proterozoic orogenic belts; the Kheiss Belt and the Magondi Belt. Argument has raged over whether these belts were of a contemporaneous age, but recent geochrological evidence suggests that the Magondi Belt predates the Kheiss. Dating of the Kheiss and Magondi Belts is difficult due to the lack of exposed bedrock. As a result, little geochemical and geochronological work has been done on the Kheiss Belt. More has been done on the Magondi Belt therefore its age and evolution is better understood. The conclusion that the Magondi Belt predates the Kheiss is supported by the interpretations drawn in this report as the Kheiss Belt butts up against the Magondi Belt and the structural trends in both belts are non-parallel.

The southern belt, the Kheiss Belt, defines the western margin of the Kaapvaal craton and is defined by a north-south structural trend, indicating an east west stress direction, and a large magnetic and gravity high on the east and west edge. It represents an orogenic event in the Early Proterozoic that is loosely constrained between 1928 Ma and 1750Ma (10). The north-south trend that defines the belt is truncated in the south by the Namaqua-Natal belt and on the north by the Palala-Zeitfontein Shear Zone (PLZ). But the Kalahari Line which defines the western extent of the Kheiss Belt extends north to the Okwa Block, a small crustal block of uncertain origin, suggesting that the Kheiss belt may extend further north and connect directly to the Okwa Block and simply be obscured due to reactivation along the PLZ. It is also interesting to note that the structural trends within the Kheiss Belt closely mirror that of deeper mantle structures as defined by shear wave anisotropy (11). This may be another line of evidence supporting the idea that the Kheiss Belt extends north of the PLZ as the seismic anisotropy along the PLZ is dominantly east-west and it would be difficult for a crustal feature to eradicate such a deep seated structural lineation.

The new datasets provided for this survey also help to constrain the westward extent of the Kheiss Belt. Previously it was thought that the extreme southwestern section of the belt extended to the west of the location mapped in figures 5 and 6 (12). However, the structural trends mapped within both the gravity and magnetic datasets support the conclusion that the Kalahari Line extends further south than previously thought and that it defines the western boundary of the Kheiss Belt along its entire length.

The structural trends indicated along the southwestern margin of the Kheiss Belt are drawn from both the gravity and the magnetic data. The gravity data shows several parallel to sub-parallel structures further north of this area that closely mirrors this dominant trend. However, there is no evidence for this in the magnetic data and without geochemical or other structural data from the area it is impossible to comment on what the structure may be.

The Magondi Belt is an Early Proterozoic orogenic belt that is curved around the northwest boundary of the Zimbabwe craton and has been dated to between 2000 Ma and 1900 Ma (13). It is bordered on the northwest by the Damaran Belt and on the south by the Okwa Block (figures 5 and 6). In addition, there is a newly defined round structure that is as yet unidentified directly to the west of the Magondi belt. This block appears on both the gravity and the magnetic datasets, and yet is ill-defined in terms of geochemistry and geochronology. It may be an anomalous crustal block similar in origin to the Okwa Block on its southwestern boundary. The dominant structural trends within this belt are southwest-northeast and indicate a primary stress direction of northwest-southeast. Much like the Kheiss Belt to the south the edges of the Magondi Belt are defined by the large positive gravity and magnetic gravity anomalies. Based on recently published geochronological data (14) and the structural analysis within this paper it is reasonable to conclude that the Magondi Belt predates the Kheiss Belt and defines the extreme northeast corner of the Kheiss Belt.

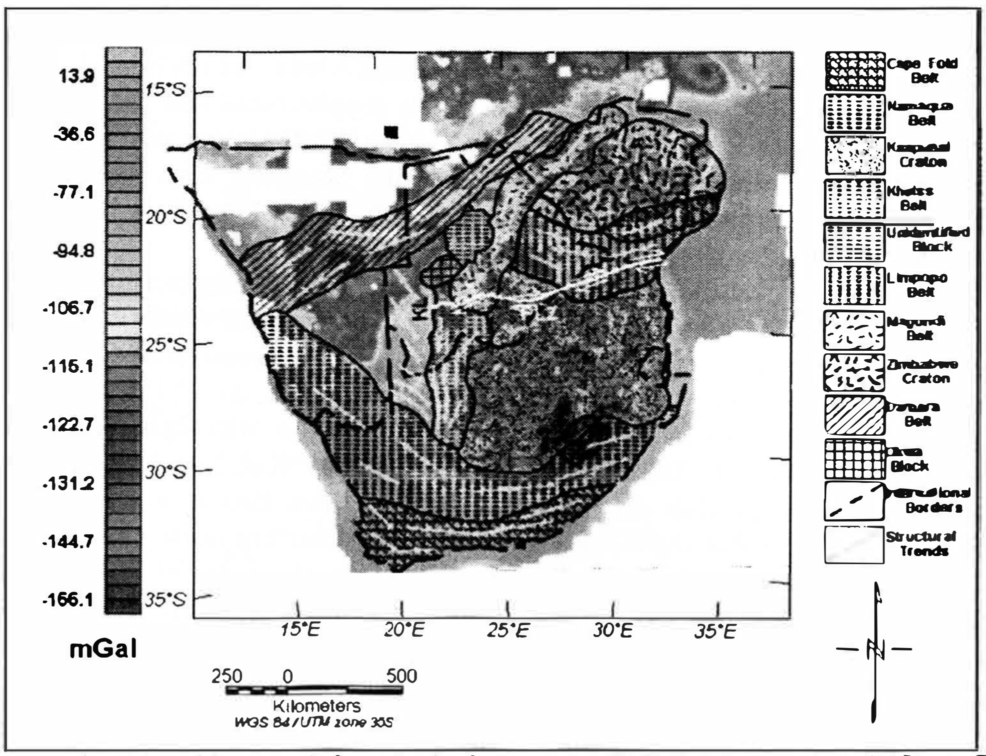

Figure 5: Raw gravity data with tectonic boundaries lay on top. PLZ=Palala-Zoetfontein Shear Zone; KL=Kalahari Line

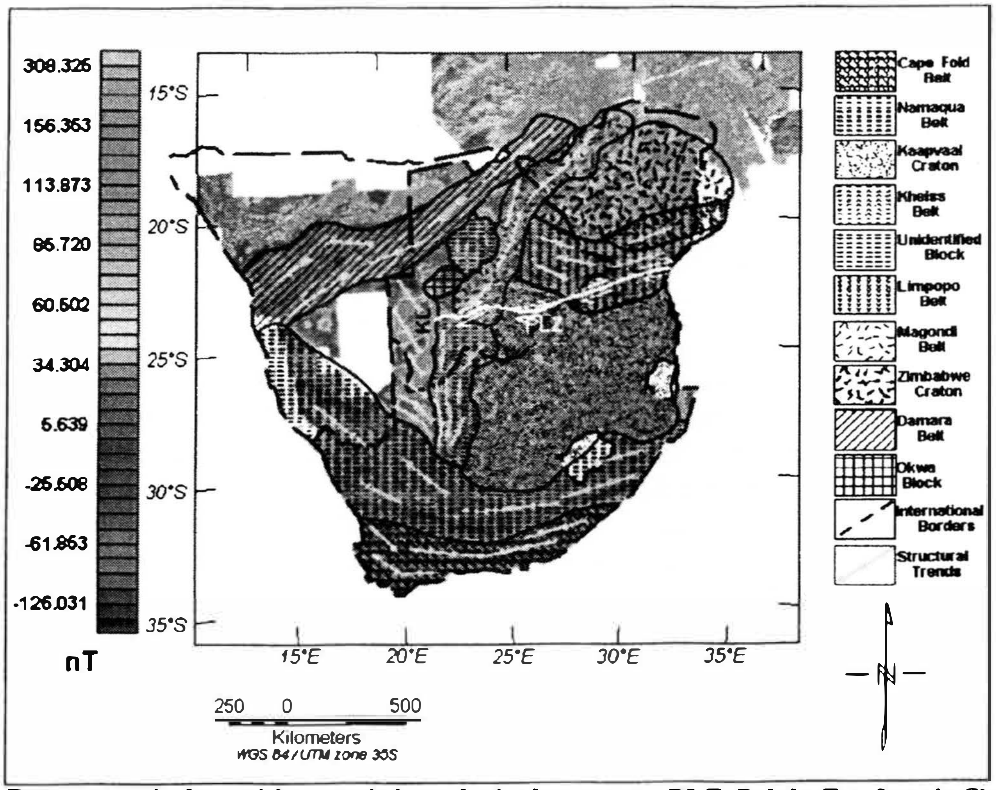

Figure 6: Raw magnetic data with tectonic boundaries lay on top. PLZ=Palala-Zoetfontein Shear Zone; KL=Kalahari Line

The Namaqua-Natal and Damaran Belt

The Namaqua-Natal Belt is a Middle Proterozoic orogenic belt that defines the southern boundary of both the Kaapvaal craton and the Kheiss Belt. It is defined by a structural lineament that is curved sympathetically with the southern boundary of the older structures. It has been dated to between approximately 1200 Ma and 1000 Ma (15). This belt is defined once again by high gravity and magnetic values on its edges and structural trends that are perpendicular to the primary stress directions. The crust that composes the Namaqua-Natal Belt is composed of many dissimilar crustal blocks that were all deformed at approximately the same time. Many of these blocks are believed to be crustal terrains that developed elsewhere and accreted to the edge of the growing continent (10). The structural strength of these terrains was low so they curved to accommodate the shape defined by the much older, well constructed crust of the Archean craton (16) (see figures 5 and 6).

The Damara Belt is a Middle Proterozoic belt that corresponds to the northerwestern border of the Magondi belt. It is essentially coeval with the Namaqua-Natal Belt and shows many of the same characteristics as its southern counterpart. The Damaran and the Namaqua-Natal Belts combine in the western portion of Namibia. Unfortunately the gravity and magnetic data coverage for this area is rather poor, but it does appear that the Namaqua-Natal Belt serves as a structural stop for the Damaran Belt. This suggests that the Namaqua-Natal Belt is the older of the two, at least in the limited area in which there is data coverage (15,16).

The Cape Fold and Thrust Belt

The Cape Fold and Thrust Belt of South Africa is an orogenic belt of Late Proterozoic age that is linked to the creation of Gondwanaland. It has a low gravity and magnetic structure and is primarily defined by a minor high that defines the boundary between it and the Namaqua-Natal Belt to the north. It has been dated to approximately 578 Ma (10) and is composed mostly of folded and thrusted sedimentary units and a minor granite component in the Cape of Good Hope region.

Conclusions

Existing geochemical/geochronological data, when compiled with the structural insights gained from the analysis of the newly compiled gravity and magnetic datasets is able to give unique insights into the structure of the crust in southern Africa. This is important in that many of the rocks that may be dated in boreholes or from small samples at irregular outcrops may now be correlated to the larger crustal structure of which they are a part. This allows for the large scale mapping of individual orogenic events even though they may lie under large columns of cover sediments and have little or no surface expression. In addition, it is now possible to better constrain the evolution of these individual orogenic belts. Whereas previously our understanding of the evolution of these large belts with complex interrelationships was restricted to our limited knowledge of their upper and lower age dates, we are now able to bring to bear the tools of structural geology such as cross cutting relationships and preferential structural trends to better define their evolution.

Acknowledgements

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