ECONOMIC GEOLOGY

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Johannesburg

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INFORMATION CIRCULAR No. 113

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February, 1978

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THE REGIONAL GRAVITY FIELD OVER SOUTH AFRICA AND SOUTH WEST AFRICA

Although gravimetric methods of geophysical surveying were first systematically employed in mineral exploration in Southern Africa in the late 1930's, their application was essentially to local problems. The first regional gravity survey of the sub-continent was completed by the Geological Survey of South Africa in the second half of the 1950's, and the results were published in 1962 (Smit, 1962). The next regional investigation was undertaken in South West Africa (Kleywegt, 1966). In subsequent years, smaller areas were studied, covering the whole of Swaziland and portions of Botswana, Rhodesia, and Mozambique. In the mid-1970's, there was a resurgence of interest in obtaining total coverage of the gravity field over Southern Africa, and, subsequent to the compilation of the information described here, regional gravimetric data became available for the whole of Zambia, Malawi, and Botswana. The countries of the sub-continent, for which adequate knowledge of the gravity field is still lacking, are Rhodesia, Angola, Mozambique, and Lesotho.

For almost twenty years after the gravimetric information for South Africa was released, little thought was given to the significance of the regional component of the total variation in the field. Contoured maps of the Bouguer and isostatic anomalies were used primarily in the structural analysis of small areas of interest to localized mineral exploration activities. The advent, in the late 1960's and, particularly, the early 1970's, of computer-based, sophisticated methods of filtering areally-distributed, quantitative data permitted, for the first time, the systematic differentiation of the total field into regional, or trend, components and local, or residual, components. The results described in this contribution to the structural framework of Southern Africa were obtained through statistical techniques embracing polynomial and moving-average trend-surface analyses. In general, it was found that the main features of the tectonic fabric were more sharply defined through moving-average methods, employing blocks of data encompassing areas measuring two degrees of latitude by two degrees of longitude, than through polynomial trend-surfaces of up to the sixth order.

Such a moving-average surface is depicted in Figure 1, which includes gravity observations over the whole of South Africa and the southern portion of South West Africa. It can be seen that the regional gravity field over South Africa has a roughly ovoidal shape, with the major axes trending WSW-ENE, from the Cape of Good Hope to the South Africa-Mozambique border, between Swaziland and Rhodesia, and SSE-NNW, from Lesotho to the central part of Botswana. The field reaches its lowest intensity over Lesotho which also represents the topographically highest area in Southern Africa, indicating that the east-central part of South Africa is still undergoing isostatic adjustment. Two minima - the Maseru and Vredefort gravity lows - appear to be off-set portions of the Kaapvaal low which is believed to be a function of comparatively thicker sialic crust, centred under Lesotho. The assumed thinning of such a crust is more gradual towards the southwest continental edge than towards the northeastern and southeastern edges, the gravity

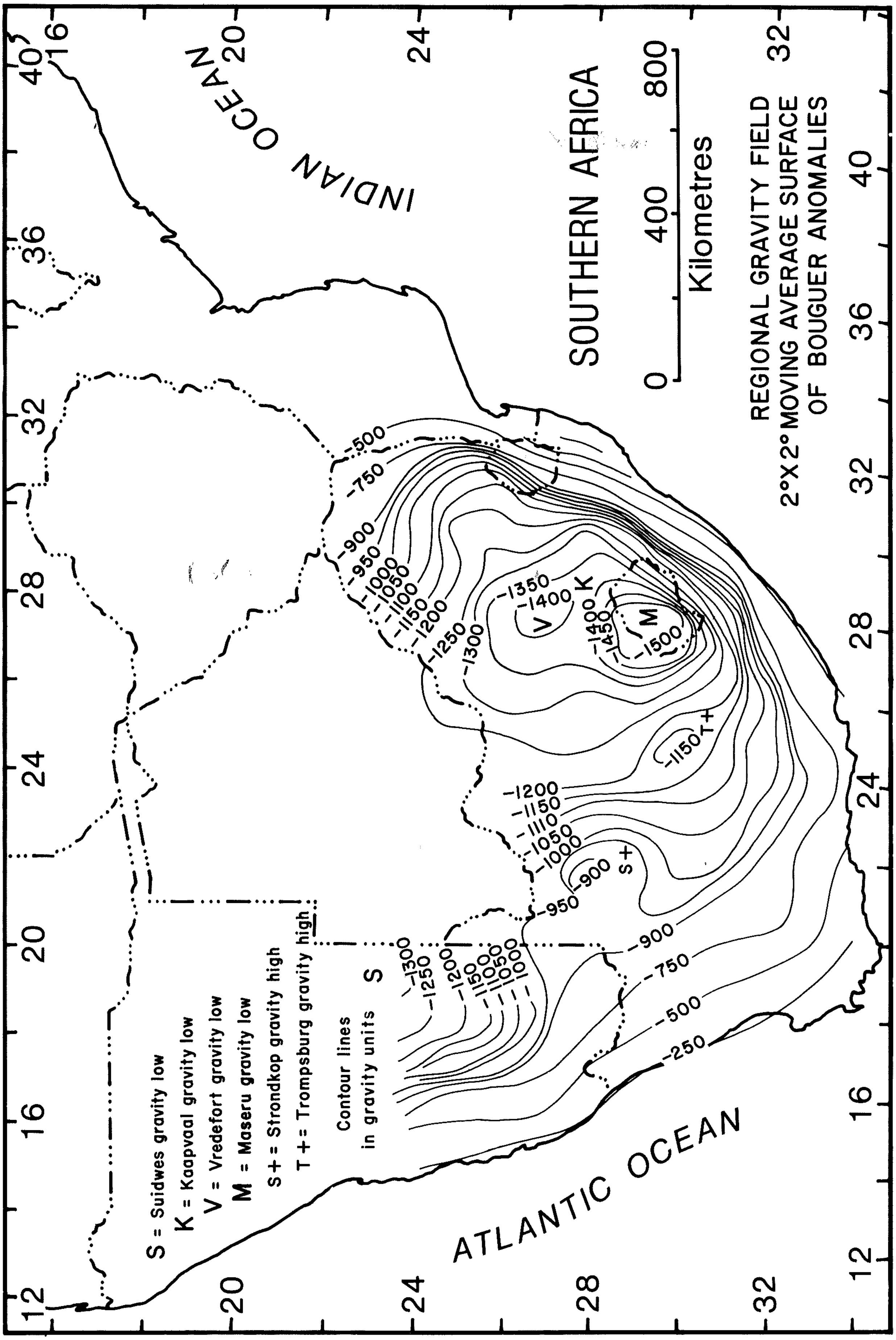
SOUTHERN AFRICA
0 400 800
Kilometres
REGIONAL GRAVITY FIELD
2°X2° MOVING AVERAGE SURFACE
OF BOUGUER ANOMALIES
INDIAN OCEAN
ATLANTIC OCEAN
S = Suidwes gravity low
K = Kaapvaal gravity low
V = Vredefort gravity low
M = Maseru gravity low
S+ = Strondkop gravity high
T+ = Trompsburg gravity high
Contour lines
in gravity units

Figure 1

gradient in the last-mentioned direction being particularly steep. In the southeastern portion of South Africa, the coastal effect on the gravity field extends 150 km inland, while, in Mozambique, the effect is still discernible 250 km inboard from the coast. Oceanic crust and the upper mantle might thus be at a shallower depth under Mozambique than under South Africa.

Two small, but conspicuous, gravity highs are detectable in the regional gravity field on the southwestern side of the dominating Kaapvaal gravity low. The Trompsburg high is known to be associated with a major, differentiated, late-Proterozoic igneous complex of circular shape, concealed beneath a thick cover of Phanerozoic rocks. The geological feature responsible for the Strondkop high has not yet been clearly established, but it would seem likely that it might also be indicative of a concealed igneous intrusion of major dimensions, possibly blanketed by late-Proterozoic strata.

The field over the southern part of South West Africa points to the presence of the Suidwes gravity low in the central part of the border area between that country and Botswana. Because of the absence of adequate data for the latter territory, at the time of preparing this contribution, it was not possible to determine whether the Suidwes gravity low could be regarded as a westwards displacement of the Kaapvaal gravity low, or whether it constituted a discrete crustal feature, unrelated to the areas of thicker sialic crust in South Africa. It is considered that the latter is the more likely possibility, indicating the presence of at least two focal points of crustal thickening in the region covered by Figure 1.

The main elements in the tectonic fabric, as revealed by the regional component of the gravity field, are shown in Figure 2. Two axial directions of minimum gravity are coincident with two axes of crustal upwarping. Whether the upwarping is a product of a thicker sialic crust along the central portion of the Kaapvaal crustal fragment or whether more sial developed where upwarping and updoming, on a sub-continental scale, took place remains to be ascertained. On all scales of folding, these two axial directions can be detected as having controlled the geometry of deformation. The configuration of outcrops and suboutcrops of strata of varying ages reflects the "vosfi"-pattern - the Vaal-Orange-superimposed-fold-interference pattern, with the Vaal trend being that orientated WSW-ENE and the Orange trend NNW-SSE. Regional plunges, on the sub-continental scale, are away from the Maseru and Vredefort gravity lows, towards the coastlines and under the Kalahari area of Central Botswana.

The dominant fracture lineaments are parallel, or sub-parallel, to the Vaal and Orange trends. Elongation of the gravity highs at Trompsburg and Strondkop is in the NNW direction, providing evidence that the localisation of emplacement of prominent igneous complexes is lineament-controlled. On the Trompsburg lineament, in addition to the late-Proterozoic intrusion, a number of significant diamond-bearing kimberlites, of possible Cretaceous age, having been injected, pointing to longevity of activity of, at least, some of the major Vaal- and Orange-trend fractures. That the ENE lineaments might have acted as transcurrent faults, with substantial horizontal movements, is suggested by the apparent right-lateral displacement of the Vredefort and Maseru portions of the Kaapvaal gravity low. The projection of this fracture to the northeast coincides with what might be a right-lateral displacement of the coastline of Mozambique.

The geometry of the regional gravity field over South Africa is a large-scale portrayal of the areal and local tectonic fabrics, favouring the

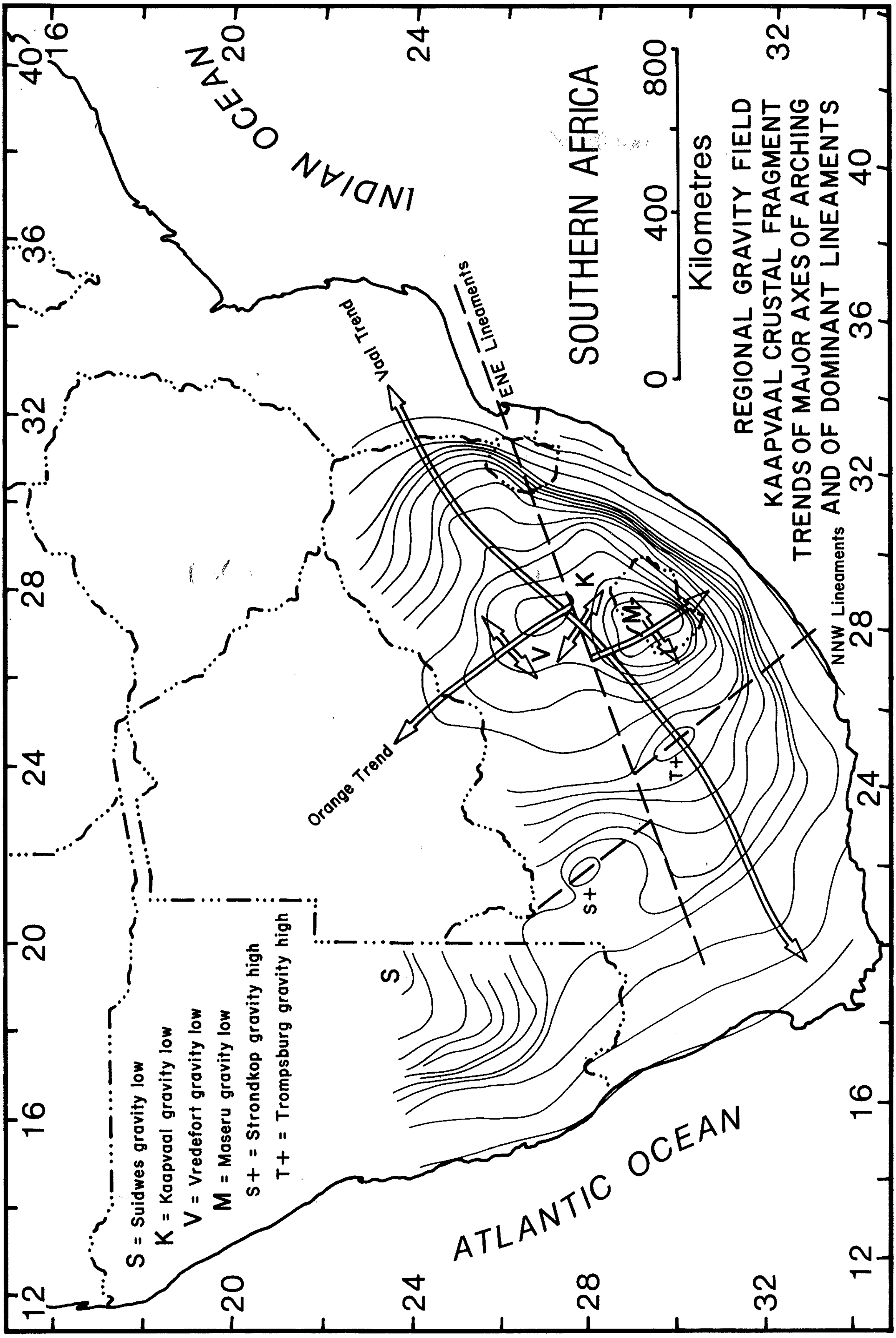
SOUTHERN AFRICA
0 400 800
Kilometres
REGIONAL GRAVITY FIELD
KAAPVAAL CRUSTAL FRAGMENT
TRENDS OF MAJOR AXES OF ARCHING
AND OF DOMINANT LINEAMENTS
INDIAN OCEAN
ATLANTIC OCEAN
Vaal Trend
Orange Trend
ENE Lineaments
NNW Lineaments
S
K
V
M
S+
T+
S = Suidwes gravity low
K = Kaapvaal gravity low
V = Vredefort gravity low
M = Maseru gravity low
S+ = Strondkop gravity high
T+ = Trompsburg gravity high

Figure 2

concept that the parts of the Kaapvaal crustal fragment have not reacted to the processes of deformation in a style different to that which shaped the gross structural morphology of the whole. The principal fold and fracture trends follow the same two general directions, the interaction of which has produced an interference pattern which is the key to understanding the configuration and areal distribution of the various sequences which make up the total stratigraphic assemblage of South Africa.

The local, residual components of the gravity field show a spatial array of parallel or sub-parallel zones of alternating high and low gravity values which, for the most part, can be seen to be coincident with synclines and anticlines, respectively. The residual trends on the Kaapvaal crustal fragment are aligned roughly west-east in the eastern portion of the fragment and north-south in the western segment, thus defining a major regional flexuring over the Kaapvaal gravity low. This low reflects crustal upwarping and thickening of the sial along the Molomari arch, a NNW-trending structural feature which dominates the fabric of the Kaapvaal crustal fragment (Figure 3). The pattern of the array is disturbed in the north, where the Limpopo gravity high is developed, and in the southwest, where the Karasburg gravity high is present. In the southeast, the possible presence of another gravity high is masked by the steep gradients of the coastal effect. At the time of the investigation, the absence of gravity data for Botswana and Mozambique did not permit any conclusions regarding the nature of the gravity field at the northwestern and eastern extremities of the Kaapvaal crustal fragment.

In South West Africa, two different patterns of gravity residual alignments are apparent. In the south, there is a concentric arrangement of alternating highs and lows about the Suidwes regional gravity low. In the north, a second array would seem to be related to what, if gravity data were available for Angola, might emerge as the Ondasha regional gravity low. Changes in the direction of concavity of the curvilinear residual trends are strongly suggestive of the presence of different focal points of concentric configurations of alternating highs and lows on areal and local scales. This concentricity of gravity trends about regional gravity lows, also seen, partially, in the case of the Kaapvaal crustal fragment, and the well-established younging of successive Proterozoic stratigraphic sequences radially away from the central zones of the regional gravity lows are evidence of these lows representing foci of maximum crustal updoming and maximum sialic thickening. The two crustal fragments in South West Africa are separated by the Spitzkoppe gravity high.

In summary, the regional gravity field over South Africa and South West Africa reveals that this part of the sub-continent is built-up of at least four crustal fragments, generally ovoidal in shape, which are separated from each other by regional gravity highs that flank the fragments concentrically on all sides. The fragments, more-or-less the equivalents of what have been called cratons previously, are characterized by a central portion of gravity minima which are taken as indicating the presence of relatively thicker sialic crust under areas of maximum tectonic upwarping and doming. The intervening zones of high gravity have been labelled as mobile belts which have hallmarks of high-grade metamorphism and plastic deformation. The increase in the gravity field suggests an attenuation of the sialic crust beneath the mobile belts, with associated downwarping and rift-faulting. The relatively narrow widths of the regional gravity highs between the crustal fragments renders it unlikely that the whole of the western segment of South Africa, southwest of the Kaapvaal fragment, is a

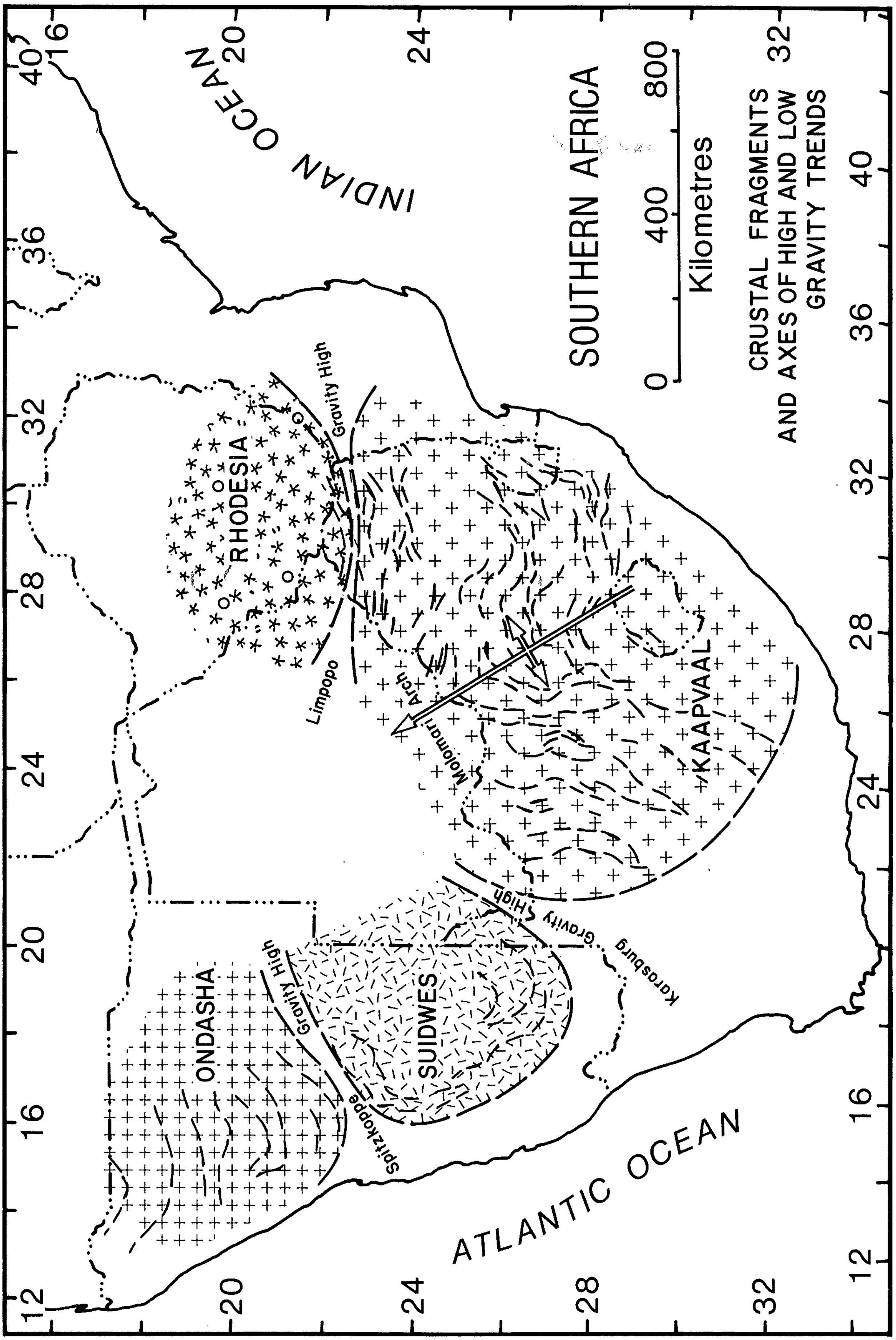
SOUTHERN AFRICA
0 400 800
Kilometres
CRUSTAL FRAGMENTS AND AXES OF HIGH AND LOW GRAVITY TRENDS
INDIAN OCEAN
ATLANTIC OCEAN
RHODESIA
KAAPVAAL
SUIDWES
ONDASHA
Gravity High
Limpopo
Arch
Gravity High
Karasburg
Gravity High
Spitzkoppe

Figure 3

mobile belt - the Namaqualand-Bushmanland metamorphic terrane - as is presently accepted to be the case. The gravity field would preferentially favour the presence of another crustal fragment - the Sanama fragment - in the northwestern Cape Province, separated from the Suidwes gravity low by the Karasburg gravity high and from the Kaapvaal gravity low by a similar, narrow, mobile belt-gravity high which has yet to be defined and named. Figure 3 shows that the central portion of Botswana, beneath the Kalahari sand-cover, could be a most interesting geological region in that it acts as host to the conjunction of four cratons - the Kaapvaal, the Rhodesia, the Suidwes, and the Ondasha crustal fragments.

THE REGIONAL GRAVITY FIELD OVER SOUTHERN AND CENTRAL AFRICA

Despite the fact that, at the time the present contribution was compiled, there were only scattered data available on the nature of the gravity field in the rest of Southern Africa, beyond the boundaries of South Africa and South West Africa, an attempt was made to extrapolate the trend-surface analyses into Botswana, Rhodesia, and Zambia. The results are shown in Figure 4.

The portion of the sub-continent south of Angola-Zaire-Tanzania shows the presence of three first-order gravity lows - Luwama in Zambia, Suidwes in South West Africa, and Kaapvaal in South Africa. Higher regional gravity values, on average, make the other known crustal fragments - Rhodesia in Rhodesia, Ondasha in South West Africa, and Sanama in South Africa - of second-rank, such a classification to be regarded as of a tentative nature only, in view of the paucity of data considered outside of South Africa and South West Africa. Even on the very broad scale depicted in Figure 4, it is apparent that the configuration of contours clearly shows zones of relatively high gravity values wrapping themselves round the peripheries of the crustal fragments-cratons defined by low regional gravity values.

A profile has been drawn of the gravity field from the Tanzanian-Zambian border to the southern coast of South Africa (Figure 5). This shows that the gravity highs-mobile belts are coincident with the more pronounced drainage features intersected along the line of section - the Lake Rukwa rift valley, the Zambesi River valley, and the Limpopo River valley. The gravity minima occur over the most topographically-elevated sections of the gravity lows-cratons - the Mbala-Kasama high country of the Luwama crustal fragment, the Salisbury-Fort Victoria high country of the Rhodesia fragment, and the Lesotho high country of the Kaapvaal fragment. There is thus a good degree of correlation between regional gravity lows, the central portions of cratons, thick developments of sialic crust, maximum uparching and doming, and topographically elevated country, as well as between regional gravity highs, the peripheral portions of cratons, the inter-cratonic areas, attenuations of the sialic crust, maximum downwarping and rift-faulting, and topographically depressed country.

The order of values in the various regional gravity lows might be a measure of the status of isostatic imbalance and the extent of vertical uplift and consequent erosion of cover-rocks of each of the crustal fragments. If this is the case, then, of the three first-rank crustal fragments, the Luwama craton is the one showing the youngest onset of uplift and the least amount of resultant erosion. The Suidwes craton would have suffered the

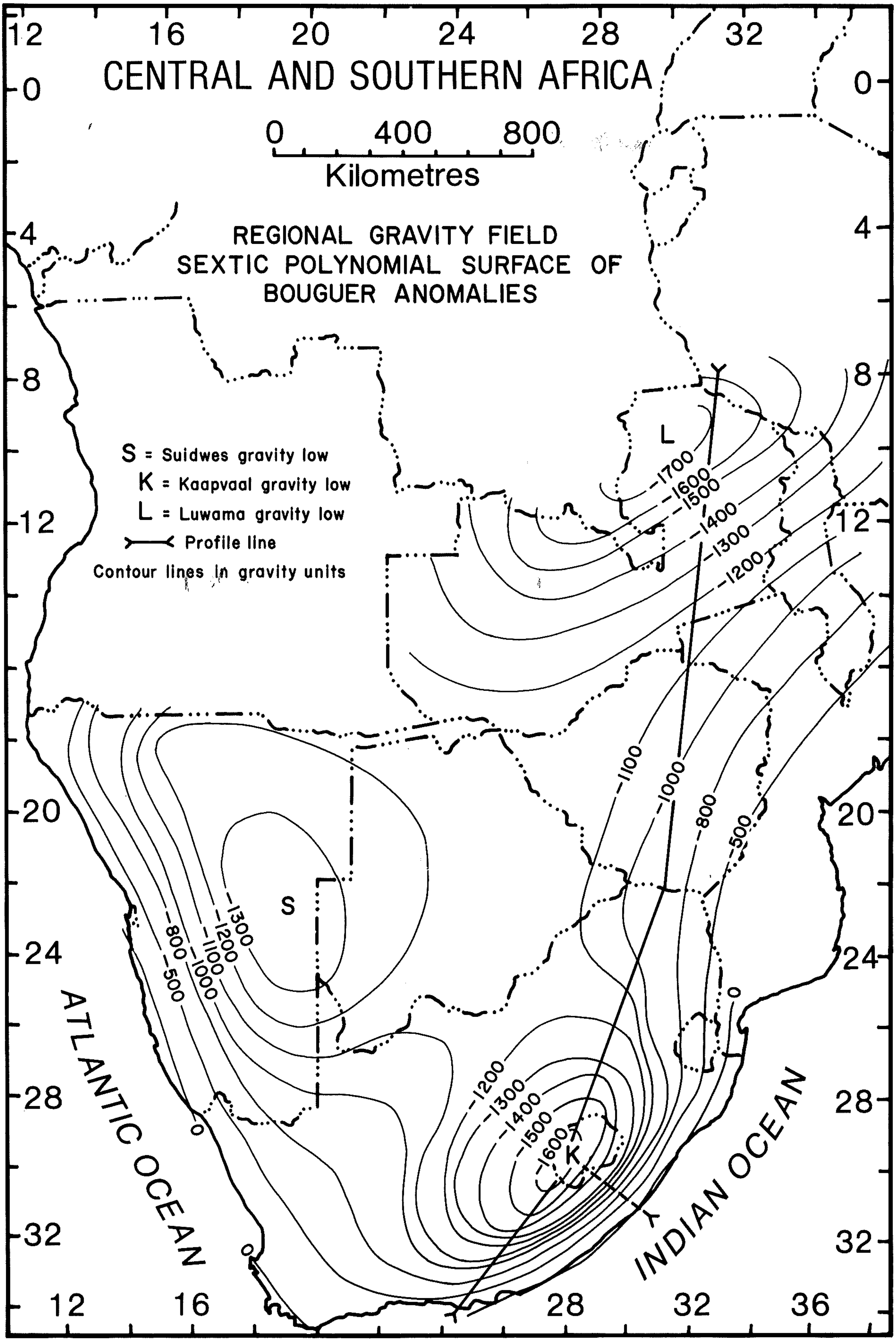
CENTRAL AND SOUTHERN AFRICA
0 400 800
Kilometres
REGIONAL GRAVITY FIELD
SEXTIC POLYNOMIAL SURFACE OF
BOUGUER ANOMALIES
S = Suidwes gravity low
K = Kaapvaal gravity low
L = Luwama gravity low
Profile line
Contour lines in gravity units
ATLANTIC OCEAN
INDIAN OCEAN
S
K
L
-1700
-1600
-1500
-1400
-1300
-1200
-1100
-1000
-800
-500
0

Figure 4

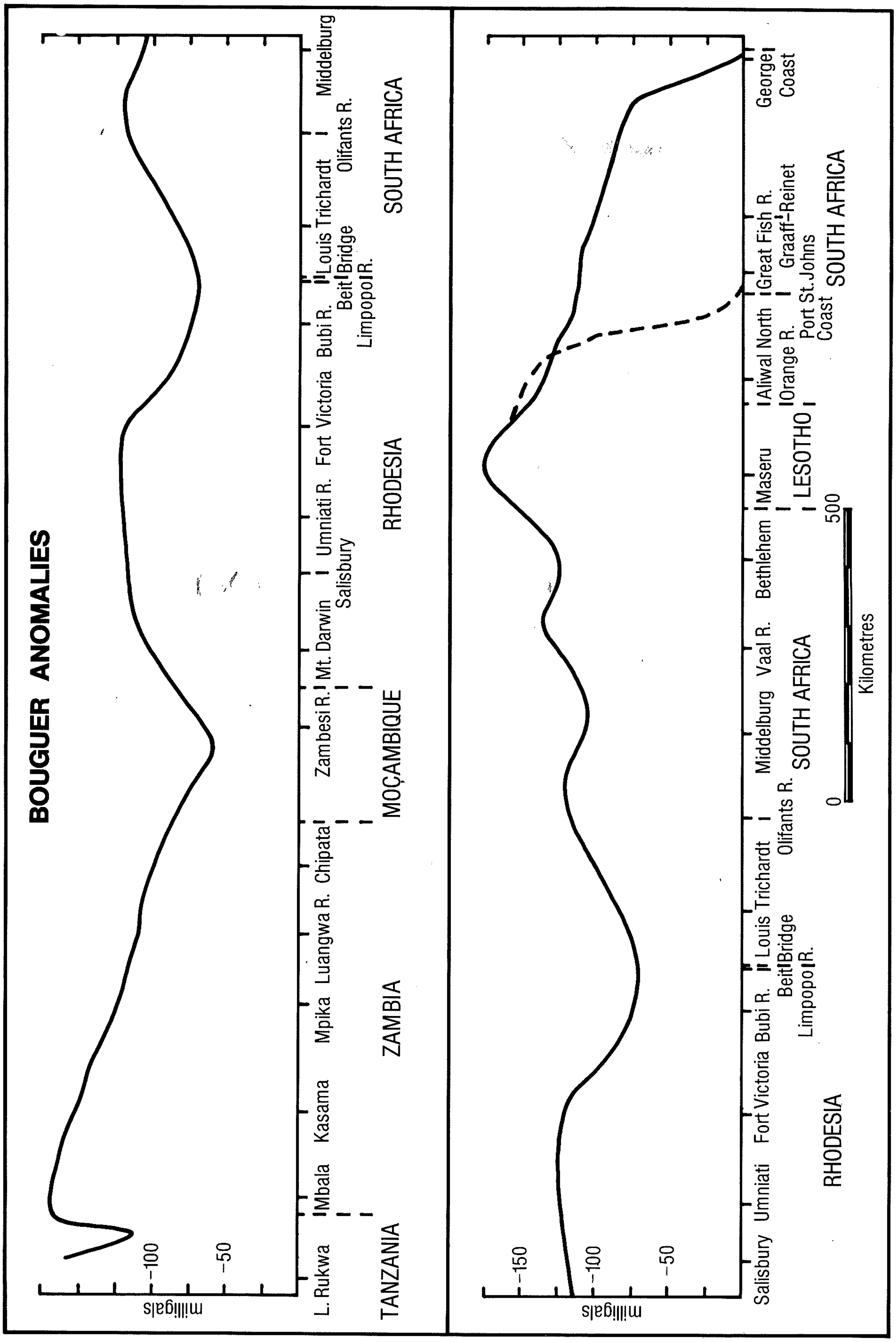
BOUGUER ANOMALIES
milligals
-100
-50
L. Rukwa
Mbala
Kasama
Mpika
Luangwa R.
Chipata
Zambesi R.
Mt. Darwin
Umniati R.
Salisbury
Fort Victoria
Bubi R.
Beit Bridge
Limpopo R.
Louis Trichardt
Olifants R.
Middelburg
TANZANIA
ZAMBIA
MOÇAMBIQUE
RHODESIA
SOUTH AFRICA
milligals
-150
-100
-50
Salisbury
Umniati
Fort Victoria
Bubi R.
Beit Bridge
Limpopo R.
Louis Trichardt
Olifants R.
Middelburg
Vaal R.
Bethlehem
Maseru
Aliwal North
Orange R.
Great Fish R.
Graaff-Reinet
Port St. Johns Coast
George Coast
RHODESIA
SOUTH AFRICA
LESOTHO
SOUTH AFRICA
0
500
Kilometres

Figure 5.

greatest amount of uplift and erosion, while the Kaapvaal craton would be intermediate between the Luwama and Suidwes fragments. The second-rank cratons - Rhodesia, Ondasha, and Sanama - would all have undergone greater vertical elevation and erosion of higher-level crustal material, to account for the possible thinner sialic crust under their central portions, as suggested by the higher average regional gravity values than are present over the Kaapvaal, Suidwes, and Luwama crustal fragments.

The analysis of the gravity data over Southern Africa leads to a conclusion - tentative until such time as the newly-available data from Botswana, Zambia, and Malawi have been processed - that the structural framework of the sub-continent might be compared to an inverted egg-tray. The receptacles for the eggs would become the quasi-circular, updomed, crustal fragments, or cratons, underlain by thicker sialic crust, while the divisions between the receptacles would become the narrow, concentric, mobile belts, underlain by attenuated sialic crust. Such a regional pattern to the framework would be analogous to that seen, on an areal scale, in classic Archean granite-greenstone terranes, with diapiric granitic plutons encircled and separated by greenstone belts. Sub-continental, regional, areal, and local structural fabrics all seem to reflect the same pattern.

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ISBN 0 85494 496 6