ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

THE STRUCTURAL BOUNDARY BETWEEN THE KAAPVAAL AND SONAMA CRUSTAL PROVINCES

D. A. PRETORIUS

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UNIVERSITY OF THE WITWATERSRAND
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by

D. A. PRETORIUS
(Director, Economic Geology Research Unit)

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ABSTRACT

A wide variety of explanations has been offered in the past for the nature of the boundary between the high-grade metamorphic terrane of Namaqualand and Bushmanland, with its contained gneisses, migmatites, and schists, and the region covered by relatively unmetamorphosed Proterozoic sediments and volcanics in the northern portion of the Cape Province, the northern section of the Orange Free State, the whole of the Transvaal, and the northern division of Natal. In an attempt to resolve the differences in these explanations, the gravity field over the Gordonia-Carnarvon region of the northern Cape Province was re-examined by means of a polynomial trend surface analysis. The Bouguer anomaly values were treated of 491 gravity stations in an area of 220 000 sq km straddling the northeastern termination of the Sonama and the southwestern extremity of the Kaapvaal crustal provinces. Reconsideration of the geological features of the region in the light of the results obtained from the re-study of the gravity field has led to the conclusion that the structural boundary between the two provinces is a 120-km-wide tract of country trending north-northwestwards and containing a number of faults parallel to this direction, with numerous tight drag-folds developed adjacent to the fault planes. The most prominent of the dislocations in the boundary tract is the Brakbos fault zone which can be traced for at least 500 km and on which the greatest amount of vertical, and possibly also horizontal, movement has taken place. The Doornberg fault, which has been favoured by most previous investigators as the interface between the two provinces, has been shown to be a dislocation of much lesser importance within the boundary tract and 35 km to the northeast of the Brakbos fault zone. There is a progressive stepping-up of the terrane on the southwestern sides of successive faults which have their downthrows towards the Kaapvaal Province. The cumulative stepping-up in a southwesterly direction indicates that the Sonama Province has been considerably elevated relative to the Kaapvaal Province, as a result of which there has been preferential preservation of supracrustal rocks in the latter province and considerable erosion in the former province where continued vertical uplift led to deroofing of the cover and the exposure of deep tectonic levels. The boundary tract can be considered as the product of attenuation and late-stage brittle fracture on the connecting limb between the relatively upward-moving Sonama Province and the relatively downward-moving Kaapvaal Province. In the light of this interpretation, the two provinces must be regarded as parts of the same crustal domain that underwent differential vertical movement, and not as two separate plates that moved horizontally with respect to each other, during Proterozoic times, to weld together along an ancient plate juncture of the convergent type. On the northeastern flank of the boundary tract, over Kalahari-sand-covered country in the Kaapvaal Province, a major regional gravity high has been recognized for the first time. This Strondkop gravity high is thought to be due to a large mass of mantle-derived igneous material intrusive into the higher levels of the lithosphere, in a similar manner to the Bushveld Complex-type igneous intrusion causing the well-known Trompsburg regional gravity high. Between the Strondkop and Trompsburg gravity highs lies the region, centred on Kimberley, of substantial intrusion of kimberlite pipes and fissures.

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THE KAAPVAAL AND SONAMA PROVINCES

(a) The Naming of the Provinces

The name "Kaapvaal Craton" was first employed by Pretorius (1964) to describe a portion of the Earth's crust, in the northeastern section of South Africa, characterized by a well-preserved assemblage of Archean granite-greenstone formations and Proterozoic sedimentary-volcanic strata, which suffered its last period of pervasive, regional metamorphism about 3 000 m.y. ago. This fragment of old crust, as originally defined, is trapeziform in shape, with the long dimension trending east-northeast and the short dimension either north-northeast or north-south. The northerly boundary has been taken as the Zoutpansberg fault zone, beyond which is the Limpopo mobile belt; the easterly boundary as the Lebombo volcanic zone, east of which is possibly a southern extension of the Mocambique mobile belt; the southerly boundary as the Tugela fault zone, south of which is the Natal mobile belt; and the westerly boundary as the Doornberg (Doringberg) lineament, southwest of which is the Namaqualand mobile belt. On at least three sides, the Kaapvaal craton is bounded by high-grade metamorphic terranes which were subjected to their last regional metamorphisms at varying dates. Mean dates for these tectono-thermal events have been established as 2 000 m.y. for the Limpopo belt, 500 m.y. for the Mocambique belt, 1 000 m.y. for the Natal belt, and 1 000 m.y. for the Namaqualand belt.

In its classic context, the term "mobile belt" implies a long, narrow tract of country which has undergone compositional reconstitution and plastic deformation under conditions of high heat-flow. The length:breadth ratio of such belts is characteristically high. In the ratios of their dimensions, the Limpopo and the Mocambique terranes might qualify to be called mobile belts. The geometry of the Natal and Namaqualand terranes is certainly not belt-like. Because of this non-compliance with classic shape, various other terms have been employed to describe the Namaqualand "mobile belt" : Namaqua Mobile Belt, Namaqualand Metamorphic Complex, Namaqua Domain, Namaqua Tectogene, Namaqualand-Bushmanland Region, Namaqualand Metamorphic Terrane, Namaqualand Belt of Metamorphism and Granitization, Namaqualand-Bushmanland Gneissic Terrane, Western Region, and Namaqua Province. Geographically, van Eeden (1972) has indicated that the 1 000-m.y. metamorphic terrane in the northern portion of the Cape Province embraces part of the Namaqua Highlands physiographic region, the whole of the Bushmanland region, part of the Kalahari region, and part of the Griqua Fold Belt region, as well as a part of the southeastern extremity of South West Africa. By far the greater proportion of the metamorphic terrane is located in Bushmanland.

To overcome the problem of crustal fragment nomenclature in South Africa, it is proposed that the term "province" be used, as has been done in other Precambrian shield areas of the world, particularly in Canada. This would counter the genetic classification implied in the use of words such as craton and mobile belt. The Namaqualand-Bushmanland region might well have acted as a mobile belt between 2 000 and 1 000 m.y. ago, but, subsequent to the latter date, after which it attained a stable state and deformed in a brittle manner, it assumed the role of a craton. The Kaapvaal crustal fragment or craton would become the Kaapvaal Crustal Province. The word "Kaapvaal" was derived from the Kaap Plateau in the southwestern portion of the crustal fragment, the Vaal River in the central part, and the De Kaap Valley, adjacent to the Barberton Mountain Land, in the northeastern portion.

It is also put forward that the high-grade metamorphic region, presently known as the Namaqualand Mobile Belt, among other names, should be referred to, in future, as the Sonama Crustal Province. The early inhabitants of this region were, from west to east, the Namaqua, the Sonqua, and the Griqua - the Nama people, the Son people, and the Gri people. Griqualand is too well-known a part of the Kaapvaal Province for the name to be incorporated into a new designation of the metamorphic terrane southwest of the Kaapvaal Province. Bushmanland forms a greater part of the metamorphic region than does Namaqualand, and it would be appropriate if this were recognized in the renaming of the 1 000-m.y.-old province. The Bushmen were originally known as the Sonqua. From the Son people and the Nama people, the word "Sonama" has been coined to title the region of the crust previously known as the Namaqualand Mobile Belt.

In existing literature on the structural geology of the area along the Orange River between Upington and Prieska, the Doornberg lineament - frequently written as Doringberg - has been described as marking the interface between the Kaapvaal Province and the Sonama Province. Intensive exploration by mining companies since the close of the 1960's has cast doubt on the significance of the Doornberg lineament (R.C. Middleton, personal communication, 1970). Unmetamorphosed Proterozoic sediments of Kaapvaal-type were found to the west of the Doornberg fault, and age measurements on certain granites yielded dates much older than 1 000 m.y. Field mapping of the area between Upington and Prieska, in an attempt to resolve the problem of the position of the boundary between the Kaapvaal and Sonama provinces, is being undertaken by the Precambrian Research Unit of the University of Cape Town. To complement these investigations, a re-examination was carried out of the gravity field in the Gordonia-Carnarvon region of the Cape Province by the Economic Geology Research Unit of the University of the Witwatersrand. The results of this re-study form the basis of the present paper.

(b) The Extent of the Provinces

Although the Kaapvaal Province has retained essentially the same shape and dimensions as originally defined, modifications have been, or are being made, with respect to the northern, southern, and western boundaries. Only the Lebombo margin has remained unchanged, due mainly to the fact that no new, detailed geological investigations have been carried out in this region. Matthews (1959) has shown that the boundary of the Kaapvaal and Natal provinces takes the form of a thrust fault, with the Natal metamorphics overriding the older formations on the north. Mason (1973) has pointed to the fact that the metamorphic overprint of the Limpopo Province extends southwards, past the Zoutpansberg fault zone, onto the Kaapvaal Province. No sharp transition thus exists between these two provinces, and it becomes difficult to delineate the boundary. The southwards extension of the metamorphic effects indicates that the two provinces were juxtaposed before metamorphism took place, thus precluding the possibility that the Limpopo metamorphic terrane represents a suture zone along the junction of two Early Precambrian plates.

The Sonama Province still remains to be precisely defined. Its boundary, on the northeast, with the Kaapvaal Province forms the topic of this paper. Blignault (1974) has suggested that the extension of the northeastern boundary might be a zone running west-northwestwards from the Upington area, through the Keetmanshoop locality in South West Africa, to between Walvisbaai and Lüderitz, and that the southwestern margin might be a shear zone extending from Lüderitz to Pofadder. Southwest of this zone is the 1 800-m.y.-old Richtersveld terrane which shows a much lower metamorphic grade. The southern boundary against the 500-m.y.-old province containing the Cape granites lies beneath the Karroo cover, south of Beaufort West.

A feature of the Sonama Province, which has become more and more clearly established through the field mapping of the Precambrian Research Unit, is the progressive increase in metamorphic grade away from the margins and in towards the centre of the province. Joubert (1974) has depicted the grade as increasing west-southwestwards from Prieska, southwestwards from Kakamas, southwards from Pofadder, south-southeastwards from Steinkopf, eastwards from Springbok, and east-northeastwards from Garies. The focal point of the intersection of the vectors of the metamorphic gradient occurs beneath the Karroo cover between Calvinia and Brandvlei.

From the southwest to northeast across the western portion of the Sonama Province, Blignault (1974) has demarcated the following metamorphic and structural zones :

(1) Richtersveld terrane, containing the intrusive Vioolsdrif granite suite (1 800-1 900 m.y.);

(2) Marginal Zone, with thrust-belt-type structural features and a higher grade of metamorphism than is found in the Richtersveld terrane;

(3) Shear Zone, with horizontal displacement, although vertical movement is dominant, and with a core of low-grade mylonites surrounded by a wider zone of refolding which is more pronounced on the northeastern side;

(4) Central Zone, with the highest grade of metamorphism, up to granulite facies, with homogeneous megacrystic granite-gneiss in the central portion and pelitic paragneisses on both flanks, and with large-scale, late, open structures in the form of basins and domes; and

(5) Northern Marginal Zone, similar to the Marginal Zone in the southwest, with a metamorphic grade lower than that in the Central Zone.

The Central Zone is the largest, in areal extent, of the various districts making up the province. Blignault (1974) viewed the Northern Marginal Zone as the Namaqua Front separating the supracrustal rocks of the Kaapvaal Province from the highly metamorphosed infracrustal rocks of the Sonama

Province. The 1 000-m.y. Pb-U zircon ages were considered to be the product of the close of the tectonic period.

In the eastern portion of the Sonama Province, Vajner (1974) identified the following zones, from southwest to northeast :

(4) Central Zone, with coarse-grained granitoids, broad folds, and mafic bodies, and with a pegmatite sub-zone towards the middle section of the zone;

(5) Northern Marginal Zone, with coarse and fine granitoids, ultramafic bodies, and tight folds;

(6) a zone of porphyries, with occasional remnants of Kaaien quartzites;

(7) a zone of fine-grained granitoids, with frequent remnants of Kaaien quartzites;

(8) a zone with the main development of Kaaien quartzites; and

(9) a zone of late, post-Matsap refolding and shearing in the marginal parts of the Kaapvaal Province.

The zonation on the eastern side of the Sonama Province suggests that there might be no sharp demarcation line between this province and the Kaapvaal Province. The transition might thus be similar to that portrayed by Mason (1973) for the junction between the Kaapvaal and Limpopo provinces.

(c) The Kaapvaal-Sonama Boundary

In the official version of the geology of South Africa, as interpreted by the Geological Survey (van Eeden, 1972), the eastern boundary of the Namaqualand Belt of Metamorphism and Granitization (Sonama Province) and the western boundary of the Northern Cape-Transvaal Belt of Metamorphism and Granitization (Kaapvaal Province) is stated to be more-or-less along the Doornberg fault between Upington and Prieska. The Zoetlief, Transvaal, and Matsap rocks of the Kaapvaal Province are described as terminating against the Doornberg fault, as do the folds and faults in the Transvaal and Matsap formations. The Doornberg fault is shown on a structural map as having a downthrow on the northeastern side and as also having a right-lateral transcurrent movement. In the text, the Doornberg fault, one of a number of such faults in the Transvaal rocks, is stated to have a downthrow on the southwestern side. The Doornberg fault is believed to be a very old dislocation, which has continued to be active for a long time, since Dwyka strata are displaced by it. Van Eeden (1972) believed that the fault was first a right-lateral tear fault and then a normal fault with a downthrow to the southwest. A syntaxis developed along the Orange River, between Upington and Prieska, with two fold directions (Matsap and Kheis) at right-angles to each other. The part of the crust on the southwestern side of the Doornberg fault rotated clockwise relative to the part on the northeastern side, so that the syntaxis is an orocline. The fault is stated to have a right-lateral movement, but the direction of relative rotation envisaged by van Eeden (1972) would have produced a left-lateral sense of dislocation.

Visser (1957) concluded that the Doornberg fault bounds the Transvaal Sequence and the Zoetlief Formation on the southwest, and brings the Archean granite in juxtaposition with those two groups of rocks. The statement was made before age measurements became available, and it is thought that the Archean granites referred to were, in fact, members of the Sonama gneisses, migmatites, and granites. Visser (1957) also expressed the opinion that the compression which produced the tight folding in the Transvaal and Zoetlief rocks of the Kaapvaal Province culminated in the formation of the Doornberg fault, possibly implying that the dislocation might have formed as a thrust fault.

Following upon the work of the mining companies, Vajner (1972) identified north-north-westerly-trending faults to the southwest of the Doornberg fault. The westernmost of these - the Brulpan fault - occurs just west of Marydale, and separates normal Kaaien quartzites and quartz-sericite schists on the northeast from Kaaien rocks affected by the 1 000-m.y.-old metamorphism on the southwest. Between the Brulpan and the Doornberg faults is the Vaalbult fault, and to the northeast of the Doornberg fault is the De Duinen fault, located to the east of Koegasbrug. The Draghoender granite, possibly 2 900 m.y. old, occurs between the Brulpan and Vaalbult faults, and the Skalkseput granite, 2 650 m.y. old, between the Vaalbult and Doornberg faults. Vajner (1972) established that Ventersdorp strata and Black Reef and Lower Dolomite rocks of the Transvaal Sequence are exposed west of the Doornberg fault. The fault itself was seen to diminish in importance towards the northwest, so that in the Matsap syncline, southwest of Buchuberg dam, only refolding of the strata is apparent along the trace of the north-northwesterly extension of the Doornberg fault. Another lineament - the Neuspruit structure - was reported by Vajner (1974) to occur well to the west of the Brulpan fault, and to strike northwestwards between Keimoes and Kenhardt. Low- to medium-grade metamorphism occurs to the northeast of this feature and high-grade pink gneisses to the southwest. No traces of tectonic movement were found along the lineament.

Vajner's (1972 and 1974) data for the area to the southwest of the Doornberg fault and van Eeden's (1972) for the Transvaal strata to the northeast point to the fact that a series of north-northwesterly-trending faults extend from well into the Kaapvaal Province to well into the Sonama Province. The Doornberg fault is one of this series, and apparently not a very pronounced member with regard to strike-length of conspicuous development. Whereas Visser (1957) and van Eeden (1972) believed that the Doornberg fault marked the interface between the Kaapvaal and Sonama provinces, Vajner (1972) produced convincing evidence that the Proterozoic strata of the Kaapvaal Province extend well across the Doornberg fault. It was also shown by Vajner (1972) that the 1 000-m.y.-old metamorphic event of the Sonama Province was imprinted on possible continuations of the Kaaien quartzites west of the Brulpan fault. The Kaaien quartzites, together with the Marydale and Wilgenhoutdrif volcanics, form the Kheis Sequence, believed by Vajner (1974) to be older than 2 900 m.y. This assemblage underlies the Ventersdorp Sequence in the Kaapvaal Province.

The Doornberg family of faults has been interpreted by Vajner (1974) as being composed of first-order shears with right-lateral strike-slip and oblique-slip movement. The total displacement on the group of fractures might be of the order of 50 km. By implication, the boundary of the southwestern marginal part of the Kaapvaal Province and the reconstituted and reactivated sequences of the Namaqualand metamorphic complex, if such a boundary were contained within a relatively narrow tract of country, would be between the Neuspruit lineament, well into the gneisses between Keimoes and Kenhardt, and the Brulpan fault, still in the Kheis rocks at Marydale. Vajner (1974) regarded the Doornberg fault as a major tectonic boundary along which crustal plates had slid past each other. The fault represent either a simple-shear-type of plate juncture or an ancient transform fault zone, in an arc-trench system of the Kheis belt, which was reactivated during the Namaqua tectogenesis. Vajner's (1974) subscription to plate tectonics as the dominant style of crustal development in the Sonama Province was further emphasized by his regarding the margins of this province and of the Natal metamorphic terrane as old cryptic suture zones - ancient plate junctures of the convergent type. The infrastructure was brought to the surface after a long period of almost complete deroofing of the collision mountain-belt. Despite the interpretation of two independent plates moving into collision with each other and then sliding past each other, Vajner (1974) reported that there was a direct structural link between the metamorphic terrane of the Sonama Province and the Kheis rocks of the type-area along the southwestern margin of the Kaapvaal Province.

(d) Structures Adjacent to the Boundary

The characteristic structural feature, according to Visser (1944), of the southwestern portion of the Kaapvaal Province is the parallel arrangement of arcuate belts of mountain ranges, of which the Langeberg is the westernmost belt. Strike faults and the traces of the principal fold-axes are parallel to the curving ranges. The Langeberg is composed of Upper Griquatown beds of the Transvaal Sequence and of Matsap rocks which strike N20W in the north, N-S in the centre of the belt, and N25E in the south. The beds dip to the west, and overfolding is from this same direction. The strongest folding is in the centre of the belt, with the intensity of deformation decreasing to both the north and the south. While folding is the most conspicuous structural feature of the western belt, thrusting assumes dominance in the central (Gamagara) belt. The main thrusts are the Maremane, Gamagara, Vlakfontein, Aucamprust, Matsap Hills, and Lynputs. In the eastern belt, gentle folding is the most important style of deformation.

Visser (1944) concluded that the dominant stress was from the west, and that this was shown by the decrease in intensity of deformation from the western belt through the central belt to the eastern belt, by the orientation and inclination of the thrust-planes, by the attitude of the axial planes of the overfolds, and by the westward concavity of the parallel mountain ranges. The curvature of the fold axial plane traces showed that the focal point of the tangential stresses laid to the west of the folded and faulted belts, in an area west-southwest of Sishen, west-northwest of Postmasburg, and northeast of Upington.

As the Sonama Province is approached, these curvilinear belts give way to a series of tight folds, the axial plane traces of which are oriented north-northwestwards, with the regional plunge in the same direction (Visser, 1957). East of the Doornberg fault, Transvaal and Ventersdorp rocks mainly are involved in the tight folding, whereas, to the west of the fault, the Kheis rocks, as well as these two formations, are affected, with the Kheis strata becoming progressively more dominant westwards. In the Orange River Valley, west of Upington, Visser (1957) reported that folding in the Sonama gneisses was represented essentially by synclines with east-west axial plane traces. Van Eeden (1972) also observed that the strike of the Kheis strata changed from parallel to the Transvaal and Matsap strata in the northeast, to north-northwest near the Doornberg fault, to east-west in the southwest.

Vajner (1972; 1974) recognized four major periods of folding as having affected the Kheis rocks of the Kaapvaal Province. The plunge of the first-fold axes was to the west or southwest. The axial plane traces of the third folds were oriented in an east-northeasterly direction, while the fourth folds were large and open, with their axes plunging to the northwest. The third and fourth deformations were post-Matsap in age. East of the Kaaien Hills and northwest of the Matsap syncline, in the Kaapvaal Province, the bedding and foliation of the Kheis rocks dip to the northwest, and the plunge of the fourth structures is also to the northwest. Intense, earlier folds plunge to the north-northeast in the Transvaal and Matsap formations, and the axial planes of overturned folds are inclined to the west-northwest. The intensity of the fourth folds decreases to the northeast in the Transvaal and Matsap strata. Cleavage in the Ventersdorp rocks has a strike of 040°-070° and a dip of 58°-83° to the northwest. Schistosity in the Transvaal strata strikes 040°-050° and dips northwestwards at 20°-50°. The Sonama Province is characterized by fourth-period open folding which produced basins and domes trending northwestwards or west-northwestwards (Vajner, 1974). The strike of the foliation is 310°-335° and the dip 70°-90° to the southwest. Linear structures plunge to the northwest. It is thought that the northwest-trending folds represent superimposed second- and third-period structures which were realigned parallel to the fourth-period axial trend.

Vajner (1972) observed that zones of silicification and shearing in the older, Draghoender granite, between the Brulpan and Vaalbult faults,strike west-northwest and northwest, and in the younger, Skalkseput granite, between the Vaalbult and Doornberg faults, northwest and north-northwest. Diabase dykes in the southern part of the Buchuberg-Marydale area strike at 320°-340° and in the northern part at 340°-355°.

(e) The Problem of the Boundary

The problems concerning the nature of the boundary between the Kaapvaal and Sonama crustal provinces, that have emerged from the above review, can be summarized as follows :

(1) is the boundary sharp, as advocated by Visser (1957) and van Eeden (1972), or gradational, as postulated by Vajner (1972 and 1974) and Blignault (1974)?

(2) is the boundary along the Doornberg fault, as favoured by Visser (1957) and van Eeden (1972), or along a family of faults to the west of the Doornberg fault, as suggested by Vajner (1972) and the mining companies (R.C. Middleton, personal communication, 1970)?

(3) is the boundary a thrust fault (Visser, 1957), or a right-lateral tear fault in an oroclinal syntaxis (van Eeden, 1972), or an ancient plate juncture of the convergent-type (Vajner, 1974)?

(4) did the Kaapvaal Province rotate anticlockwise relative to the Sonama Province (van Eeden, 1972), or slide past it on a simple-shear-type of plate juncture (Vajner, 1974), or slide past it on an ancient transform fault zone in an arc-trench system (Vajner, 1974), or under-ride the Sonama Province on a thrust fault (Visser, 1957), or ride up vertically on a normal fault with a downthrow to the southwest (van Eeden, 1972)?

(5) is the structural fabric of the Sonama Province distinct from that of the Kaapvaal Province (van Eeden, 1972; Vajner, 1972 and 1974), or is it in continuity (Vajner, 1974)?

(6) do the Kaapvaal Proterozoic formations of the Kheis, Ventersdorp, and Transvaal Sequences terminate against the Doornberg fault (Visser, 1957; van Eeden, 1972), or do they continue southwestwards across the fault (Vajner, 1972)?

(7) was the 1 000-m.y.-old metamorphic event restricted to the Sonama Province, or did it overlap onto the Kaapvaal Province? and

(8) is the Kheis Sequence, at the southwestern extremity of the Kaapvaal Province the equivalent in age of the Waterberg-Matsap Sequence (1 750-2 000 m.y.) (van Eeden, 1972), or is it older than the Ventersdorp Sequence (2 250-2 500 m.y.) and possibly older than 2 900 m.y. (Vajner, 1974)?

THE GRAVITY FIELD OVER THE GORDONIA-CARNARVON REGION

(a) *The Gravity Data*

In an attempt to resolve some of the problems listed above, it was decided to re-examine the gravity field over a north-northwesterly tract of country stretching from the Carnarvon district of the Cape Province, in the southeast, to the Gordonia district, in the northwest, between the Orange River and the borders with South West Africa and Botswana. The region covers approximately 220 000 sq km between Witdraai in the northwest, Kuruman in the northeast, Middelburg in the southeast, and Fraserburg in the southwest. From the Bouguer Anomaly Map (1958) of South Africa, compiled by the Geological Survey, 491 gravity observation points were selected, and the data for these obtained from Smit (1962). The resulting intensity of observation was one gravity station per 450 sq km (Figure 1).

By far the greater part of the area studied is covered by Karroo and younger strata. The Main Karroo Basin occupies the southern half of the region, south from west-northwest of Copperton to northeast of Douglas. A relatively small part of the Botswana Karroo Basin protrudes into the extreme northwestern corner of the region, between Upington and Witdraai. The exposed Precambrian terrane forms a strip of country, averaging 210 km in width, which extends north-northeastwards and west-northwestwards from the Orange River between Upington and Prieska. The Archean-Proterozoic formations of the Kaapvaal Province lie in the former direction and the metamorphic terrane of the Sonama Province in the latter direction. The Doornberg fault lies immediately southwest of the Orange River, in the vicinity of Prieska, and the Brulpan fault runs parallel to the Orange River, in the vicinity of Marydale. According to previous investigators, the boundary between the two provinces could lie along either of these two faults, or between them, or to the west of the Brulpan fault.

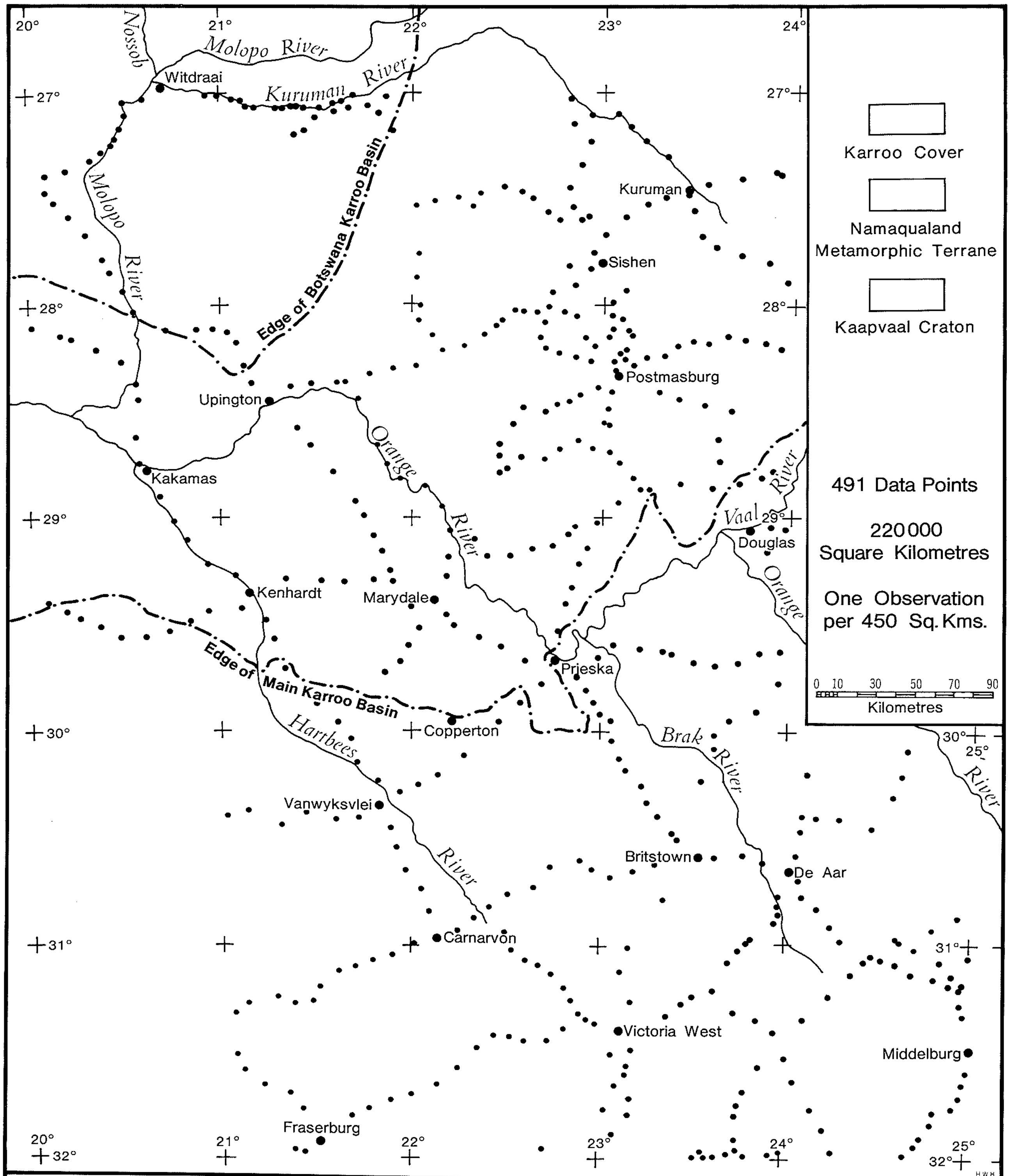
The width of exposure of Precambrian rocks between the two Karroo basins is noticeably narrower over the granites, gneisses, and migmatites of the Sonama Province. The Precambrian tracts in both provinces become wider in extent, away from the centre of the area depicted in Figure 1. The limits of exposure of Karroo strata are sub-parallel over both the Kaapvaal and the Sonama provinces, suggesting a structural control to the present contacts between Precambrian and Karroo rocks. The change in strike of these contacts along the Botswana Karroo Basin and along the Main Karroo Basin is most conspicuous on a northwesterly line between Prieska and Upington. The drainage features of the region are also indicative of structural control. The most obvious feature is the parallel north-northwesterly courses of the Hartbees River between Kakamas and Carnarvon, the Orange River between east of Upington and Prieska, the Brak River between northeast of Prieska and south of De Aar, the Orange River southeast of Douglas, and the Kuruman River northwest of Kuruman. A northeasterly or east-northeasterly trend can be seen in the drainage pattern along the Molopo River east of Witdraai, the Kuruman River east of Witdraai, the Orange River between Kakamas and Upington, the Orange River between Prieska and Douglas, and the Vaal River northeast of Douglas.

From the Bouguer anomaly values listed by Smit (1962) for the gravity stations in the region, an isogal map was prepared to illustrate the areal patterns in the gravity field (Figure 2). The more conspicuous features of this map include the following :

(1) There is a 100-milligal range in Bouguer anomaly values from -50 to -150 milligals.

(2) It is apparent that, except for an area south of Witdraai, values lower than -120 milligals are confined to the portion of the region lying to the northeast of a line from Upington to Victoria West.

(3) There is a regional flexuring of the contours along a north-northwesterly line from Middelburg to Witdraai. To the northeast of this line, the general alignment of the contours is



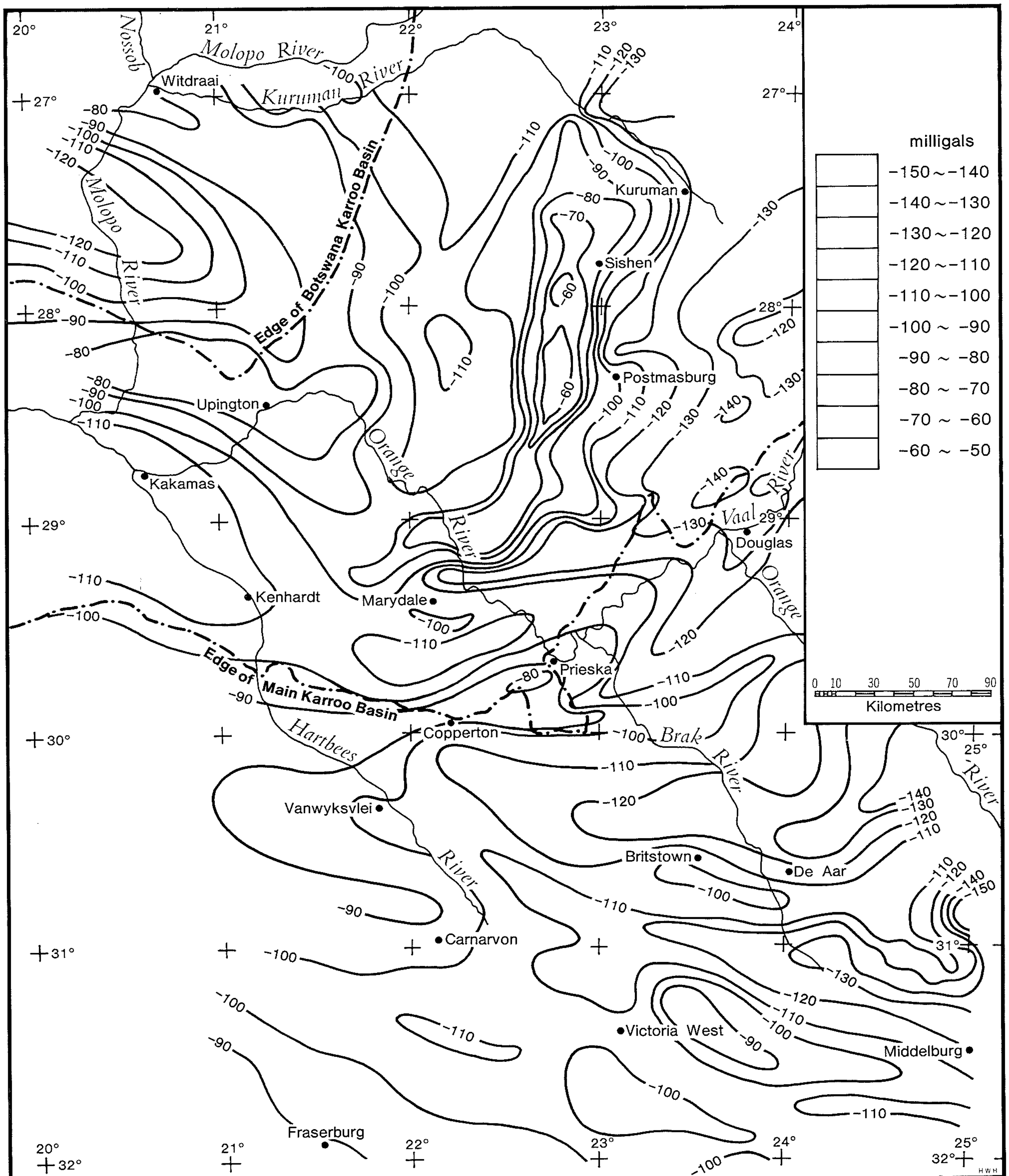
THE GRAVITY FIELD OVER THE GORDONIA-CARNARVON REGION OF THE NORTHERN CAPE PROVINCE

Based on the Bouguer Anomaly Map (1958) of South Africa compiled by the Geological Survey of South Africa

POLYNOMIAL TREND SURFACE ANALYSIS OF BOUGUER ANOMALY VALUES

LOCATION OF GRAVIMETRIC DATA POINTS

Figure 1



THE GRAVITY FIELD OVER THE GORDONIA-CARNARVON REGION OF THE NORTHERN CAPE PROVINCE

Based on the Bouguer Anomaly Map (1958) of South Africa compiled by the Geological Survey of South Africa

POLYNOMIAL TREND SURFACE ANALYSIS OF BOUGUER ANOMALY VALUES

ISOGAL MAP OF OBSERVED BOUGUER ANOMALIES

Figure 2

north-northeastwards, while to the southwest of the line, the alignment is northwestwards. This marked change in trend takes place in the tract of country which lies to the northeast of the Doornberg fault and other previously proposed boundaries between the Kaapvaal and Sonama provinces.

(4) Southwest of the Doornberg and Brulpan faults, there is an apparent discontinuity in the zones of alternating higher and lower gravity values, this break occurring along a line trending north-northwestwards between Victoria West and Kenhardt. Zones of lower Bouguer anomaly values, coming off the Kaapvaal Province, appear to abut against zones of higher values trending northwestwards off the Sonama Province.

(5) A very conspicuous zone of high gravity values strikes a little west of south, to the west of Kuruman, Sishen, and Postmasburg. At its southern extremity, this zone shows the general flexuring characteristic of the gravity contours over the whole region, so that the strike of the high values changes to southwest, before termination against the north-northwesterly discontinuity between Marydale and Kenhardt. There is a suggestion that the zone of high values might be continued in the Sonama Province, along a northwesterly direction, through Upington.

(6) The very widely-spaced gravity stations in the northwestern quadrant of the region impart a strongly subjective component to the extrapolation of contours between the stations. This is particularly true of the area east of Witdraai-Upington and west of Kuruman-Postmasburg.

(b) <u>The Regional Component of the Gravity Field</u>

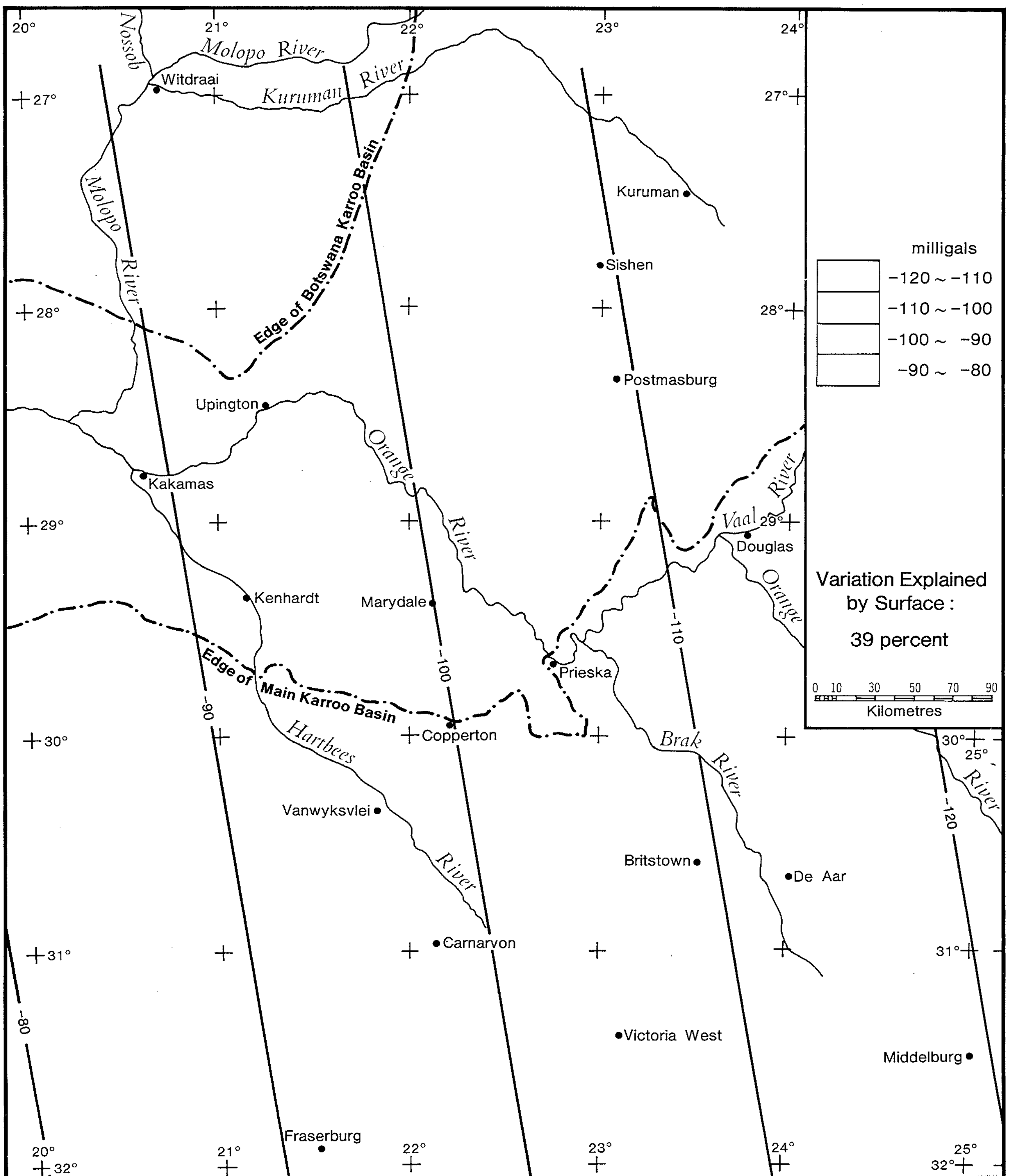
To extract more information from the gravity data, the Bouguer anomaly values were subjected to a polynomial trend surface analysis, by means of conventional computer programmes. Surfaces up to the sixth-order were constructed. The trend component of the output was regarded as reflecting the regional structures of the lithosphere, while the residual component was interpreted as being the product of shallow inhomogeneities in density in the upper part of the crust, caused by variations in the lithologies of supracrustal rocks. The goodness of fit of the computed surfaces to the observed data was determined by the reduction in the sums of squares of differences between computed and observed values.

The linear surface of the Bouguer anomaly values over the Gordonia-Carnarvon region is shown in Figure 3. The contours have a north-northwesterly strike which conforms to the direction of the Brulpan, Vaalbult, Doornberg, and De Duinen faults, of the axial plane traces of the tight, north-northwesterly plunging synclines in the Kaaien quartzites between Upington and Prieska, of the major drainage features of the region, of the discontinuity between Kenhardt and Victoria West, and of the various boundaries that have been postulated between the Kaapvaal and Sonama terranes. It is readily apparent that the lithospheric fabric, as it is now constituted, has a dominant north-northwesterly element.

The linear regional component of gravity shows an increase from east to west, which can be interpreted as a thinning of the sialic constituents of the lithosphere in this direction. The higher values over the Sonama Province possibly point to the crust being of a lower order of thickness than under the Kaapvaal Province, and to the mantle being at a shallower depth. This could be taken as indicating that the Sonama Province has undergone relative uplift and deroofing, so that the gneisses and migmatites of Bushmanland and Namaqualand represent deeper tectonic levels than do the granites and gneisses of the older Kaapvaal Province.

The third- and higher-order surfaces show variations of the configuration of contours in Figure 4, which represents the sextic surface of Bouguer anomaly values. The most striking feature of all the surfaces in the circular Strondkop gravity high which is centred on the featureless country between Upington and Kuruman. The high is named after a small hill shown on the 1970 edition of the Geological Map of the Republic of South Africa and the Kingdoms of Lesotho and Swaziland, compiled by the Geological Survey of South Africa. The hill is the only elevated ground in the pan country between Laaistokpan, Tellery Pan, Rogela Pan, and Klein-Milanipan. The maximum computed values in the gravity high are between -75 and -80 milligals. The lowest values, between -130 and -135 milligals, are located northeast of Middelburg. There is a subsidiary gravity low (between -103 and -105 milligals) between Vanwyksvlei and Kenhardt.

Figure 5 shows the main components of the higher-order trend surfaces. The Strondkop gravity high lies on the intersection of the Keimoes and Tellery axes of high gravity values. A displaced continuation of the Tellery axis possibly occurs between Marydale and Copperton. The



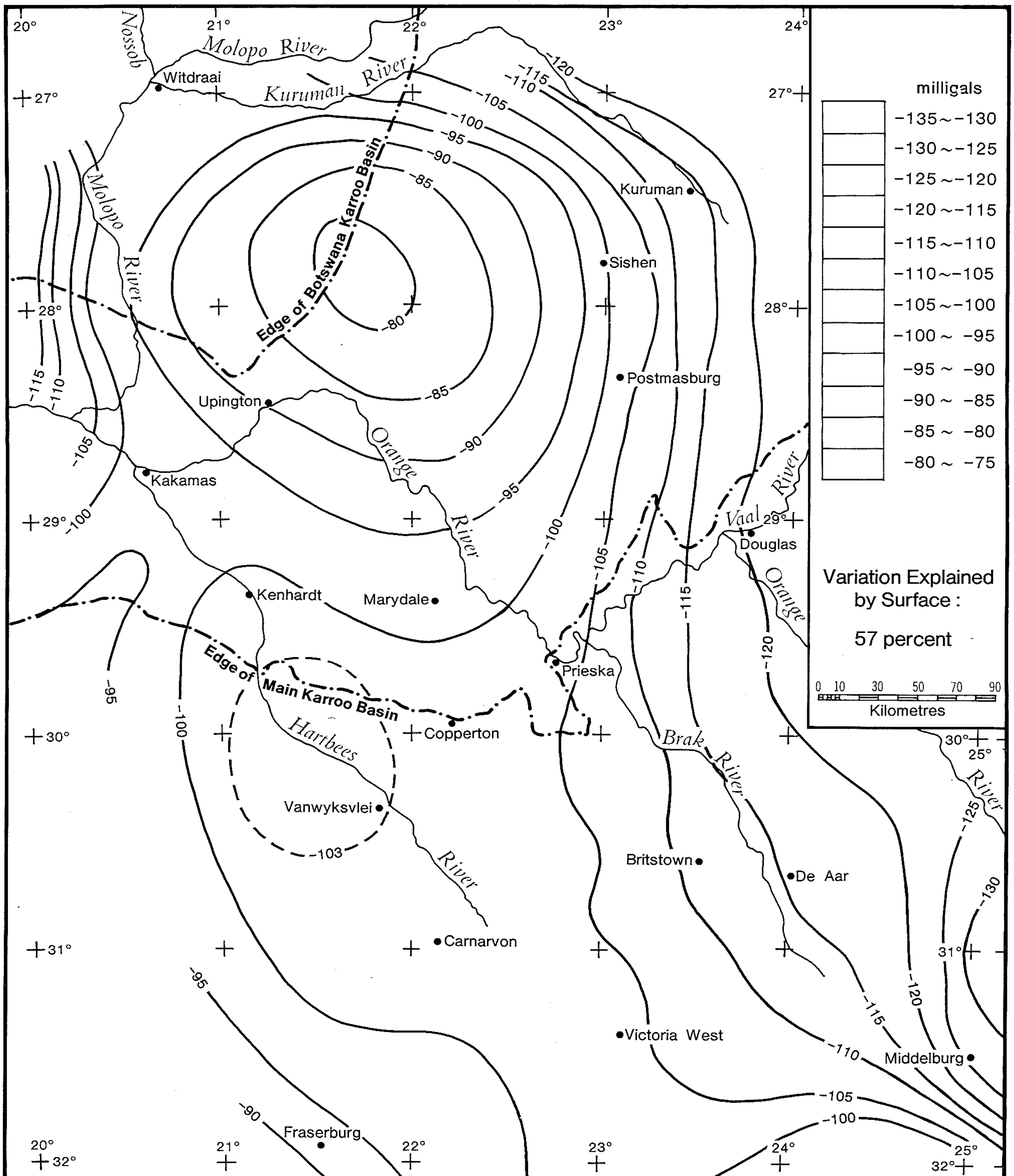
THE GRAVITY FIELD OVER THE GORDONIA-CARNARVON REGION OF THE NORTHERN CAPE PROVINCE

Based on the Bouguer Anomaly Map (1958) of South Africa compiled by the Geological Survey of South Africa

POLYNOMIAL TREND SURFACE ANALYSIS OF BOUGUER ANOMALY VALUES

ISOGAL MAP OF COMPUTED LINEAR SURFACE

Figure 3



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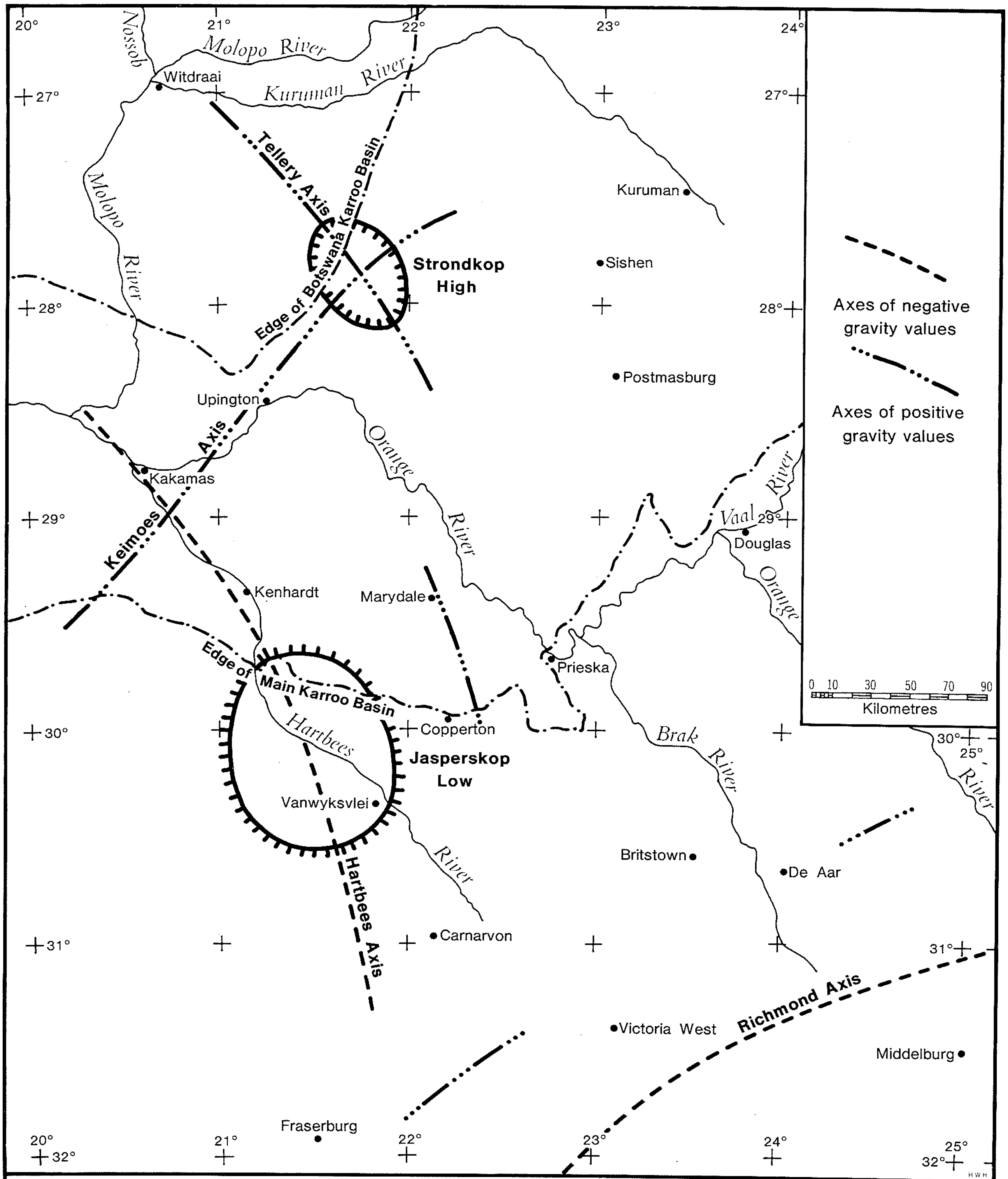
POLYNOMIAL TREND SURFACE ANALYSIS OF BOUGUER ANOMALY VALUES

ISOGAL MAP OF COMPUTED SEXTIC SURFACE

Figure 4



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POLYNOMIAL TREND SURFACE ANALYSIS OF BOUGUER ANOMALY VALUES

INTERPRETIVE MAP OF COMPUTED TREND SURFACES

Figure 5

Jasperskop gravity low is located on the Hartbees axis of low values. The Richmond axis delineates another zone of low values. The axes of zones of lower and higher regional gravity values conform to two trends : a north-northwesterly trend (Hartbees and Tellery axes) a northeasterly trend (Keimoes and Richmond axes). These two trends characterize the structural fabric of the whole of South Africa, and together they form the Vosfi Pattern - the Vaal-Orange superimposed fold interference pattern. The Vaal trend lies between east-northeast and northeast, and the Orange trend between north-northwest and northwest. These trends in the regional component of gravity over the Gordonia-Carnarvon region show that the broad tectonic style across the interface between the Sonama and Kaapvaal provinces is the same as it is in the rest of South Africa. There are apparently no structural anomalies in the lithospheric infrastructure across the junction of the two provinces.

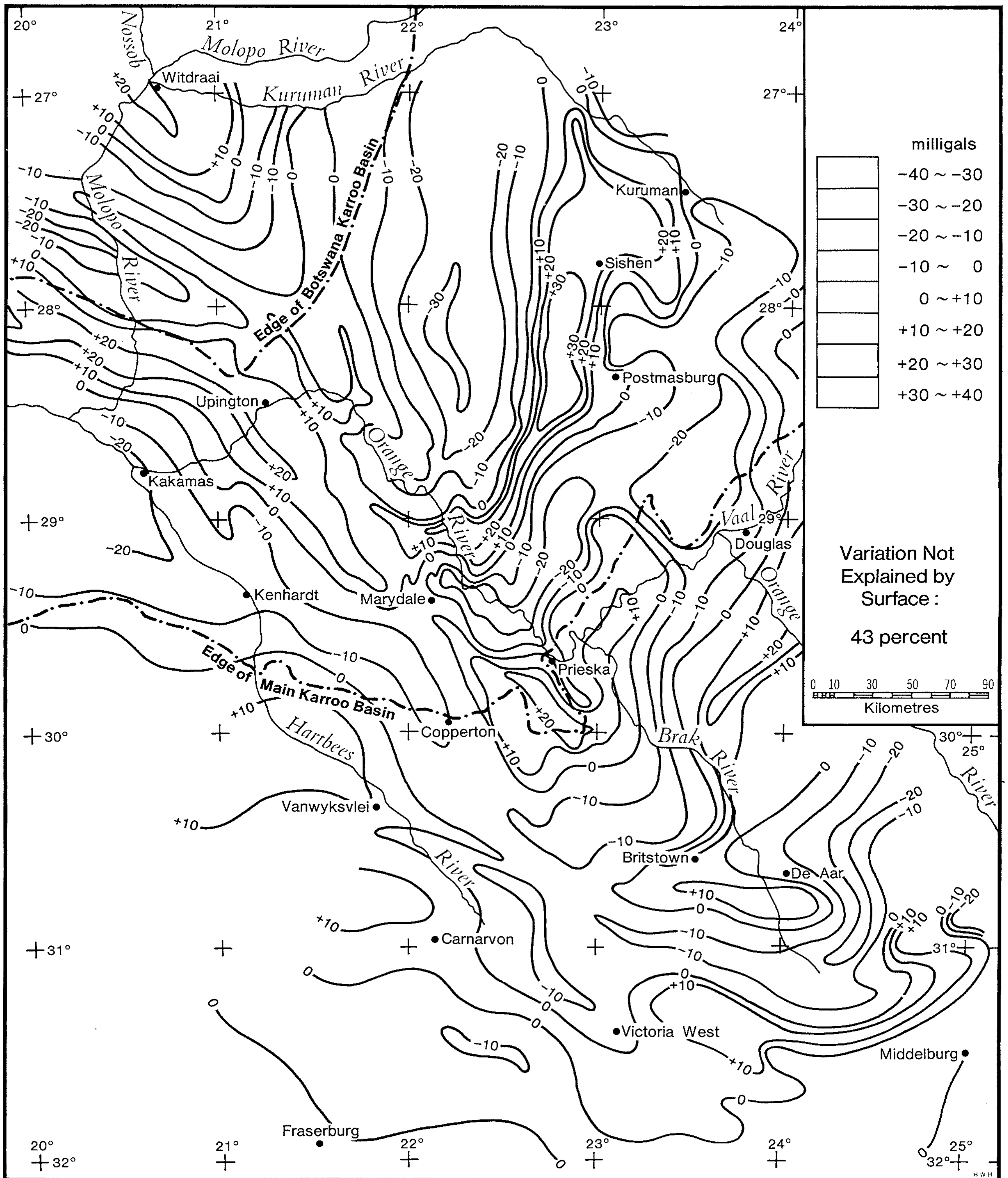
The Strondkop gravity high is a regional feature of the first magnitude, comparable with the positive gravity pattern over the Trompsburg igneous intrusion. Whereas the latter has been recognized and tested by drilling, the Strondkop feature has emerged only now as a result of the trend surface analysis of the gravity field over the Gordonia-Carnarvon region. It must be borne in mind that the gravity high northeast of Upington is a phenomenon in the regional component of gravity, and is therefore likely to have its origin at depth in the lithosphere. There need not be any expression of the cause of the high in the crustal suprastructure. The Strondkop feature can best be interpreted as a reflection of the presence at depth of a large mass of material of higher density, probably derived from either the lithospheric or asthenospheric region of the upper mantle. The Trompsburg gravity high, with which it has been compared, lies approximately 500 km to the southeast, and has been shown to be the product of the intrusion of a large, circular mass of Bushveld Complex-type material. In between the two positive features is the extensive Kimberley province of kimberlite intrusion.

The discovery of the Strondkop gravity high takes on added structural significance in the light of Visser's (1944) observations on the arcuation of the mountain ranges in the Kuruman-Postmasburg area, and his conclusions that the focal point of the eastward-directed stress responsible for the curvature of the geological formations was situated in an area west-southwest of Sishen, west-northwest of Postmasburg, and northeast of Upington. The postulated focal point of the tangential stresses falls within the central portion of the Strondkop feature. The curvature of the regional gravity contours on the eastern side of the Strondkop high coincides precisely, in regard to alignments of strike arcuation and direction of concavity, with the curvature of the Langeberg, Gamagara, and other fold belts. This coincidence is particularly evident in the case of the computed quartic surface, the -95 milligal contour lying along the central part of the Langeberg for the whole of its strike length. The absence of outcrops in the Kakamas-Witdraai area, where the cover of Kalahari sand is persistently thick, does not permit observations being made as to whether or not the underlying Precambrian rocks are disposed in a similar curvilinear pattern on the western side of the Strondkop high, with the arcuation being concave eastwards, instead of westwards, as in the fold belts of the Transvaal and Matsap strata.

It would appear that the folding of the Precambrian formations, which decreases in intensity from west to east in the Kuruman-Postmasburg area, the large-scale overthrusting from the west, the overturning of the folds so that their axial planes dip westwards, and the arcuation of the generally north-northeasterly-trending longitudinal folds in the Transvaal and Matsap rocks - all of which features characterize the structural style of the southwestern extremity of the Kaapvaal Province - might have resulted from the stress field associated with the inhomogeneity in the lithosphere, which is indicated by the Strondkop gravity high. If this gravity feature is a reflection of the movement of denser mantle material upwards into higher levels of the lithosphere, then the space problem created by the intrusion of a large mass of igneous material might well have been resolved in a manner which could have given rise to the structures described above. The regional structural style northeast of the Orange River between Upington and Prieska, in the Griqua fold belt, points clearly to compression being the dominant component of the stress field. Such compression could have been directed radially outwards and upwards from the rising mantle-derived material underlying the Strondkop gravity high.

(c) *The Residual Component of the Gravity Field*

To obtain a clearer picture of the effects of supracrustal lithologies and structures on the total gravity field, the residual Bouguer anomaly values were computed by subtracting the regional component of gravity from the observed gravity field. By this means, the patterns in the isogal map of the observed Bouguer anomaly values have been more sharply delineated, as can be seen in Figure 6 which is a contour map of the residuals from a sextic surface.



THE GRAVITY FIELD OVER THE GORDONIA-CARNARVON REGION OF THE NORTHERN CAPE PROVINCE

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POLYNOMIAL TREND SURFACE ANALYSIS OF BOUGUER ANOMALY VALUES

ISOGAL MAP OF RESIDUALS FROM A SEXTIC SURFACE

Figure 6

The alternating zones of positive and negative residuals are clearly defined. When compared with existing structural maps of the region, it is apparent that the positive residuals, for the most part, coincide with synclinal features in the supracrustal Precambrian rocks of the Kaapvaal Province, and the negative residuals with anticlines. In the Sonama Province, the absence of a readily discernible stratigraphic succession makes it difficult to tie in gravity features with structures. However, it is obvious that the major zone of negative residuals between Kakamas and Kenhardt occurs over one of the large domes produced by the late, open folding of the gneissic terrane. This association suggests that, in the Sonama Province, negative gravity values might also point to the presence of anticlines and positive residuals to the development of synclines.

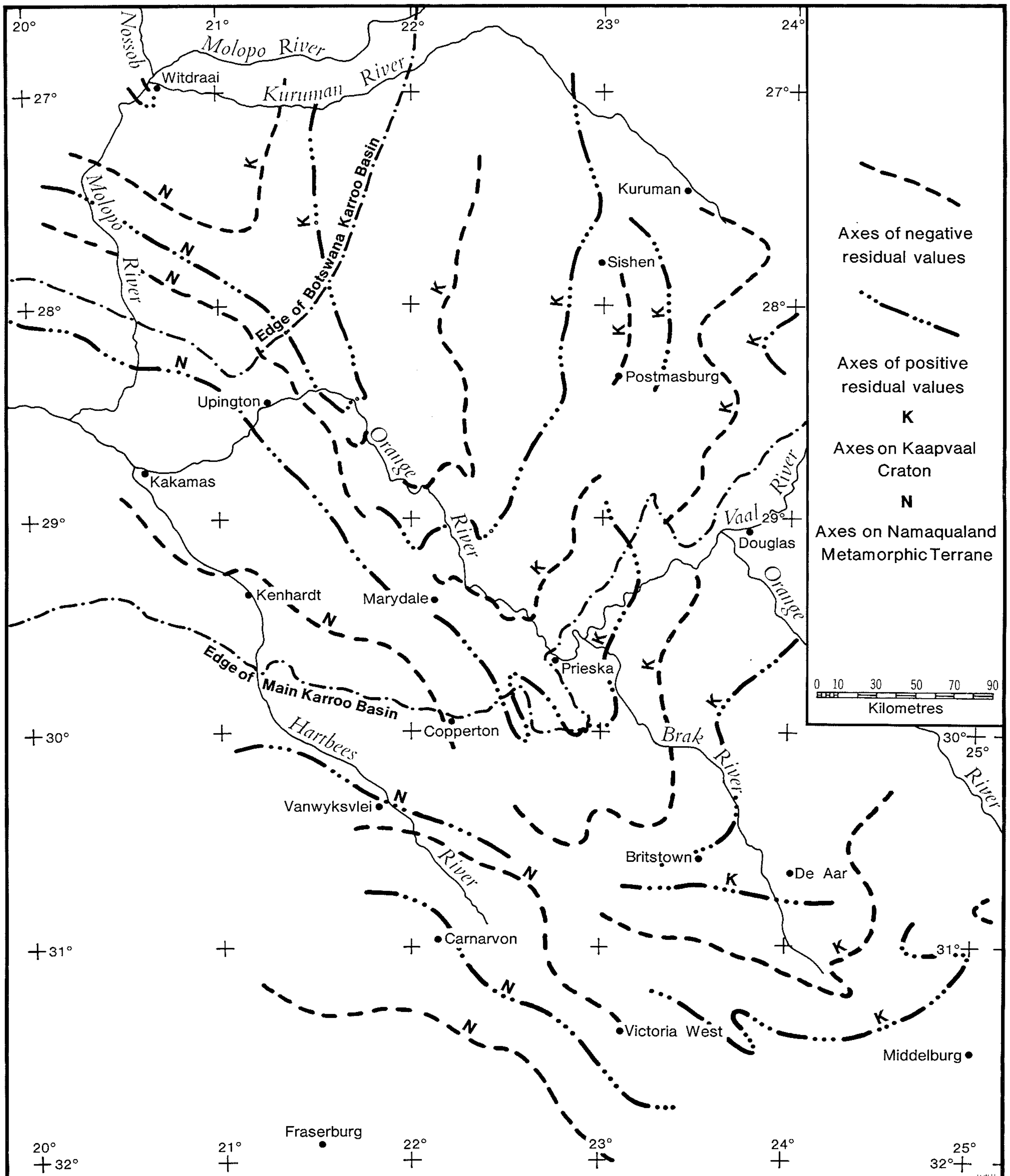
The one exception to the correlation of residuals with different types of folds is the area of very pronounced positive residuals, up to in excess of 30 milligals, lying west of Kuruman-Sishen-Postmasburg. This anomaly is the same as that indicated by high Bouguer anomaly values on the isogal map of observed gravity. Although the positive residuals lie within a synclinal structure, the anomaly is considered to be too large to be the product of simple infolding of supracrustal strata. The anomaly occurs in the vicinity of the major iron deposits of the Sishen area, where there is abundant evidence that a very appreciable volume of denser ferruginous material is interstratified in the Transvaal sediments. Hales and Gough (1962), from their study of the isostatic anomaly map of South Africa, concluded that a feature other than the ironstones is responsible for the isostatice anomaly which they called the Northwest Cape Anomaly. They calculated that the mass anomaly giving rise to the gravity anomaly is largely uncompensated, and probably consists of a body of density greater than that of the crust, at a depth of less than 20 km. If the density difference is assumed to be 0.3 gm/cm^3 between the material producing the anomaly and the surrounding rock-types, then the possibilities range from a small depth with a maximum thickness of 5 km of dense rock to 15 km depth with a maximum thickness of 8.5 km.

The Groenwater positive anomaly, as it has now been named, lies in a Vaal-trend synclinal downwarp which extends northwards into Botswana and then eastwards into the Transvaal where it is continued as one of the main downwarps in which the Bushveld Complex is located. The presence of the regional gravity anomaly around Strondkop, suggesting the intrusion into upper crustal levels of an appreciable mass of mantle-derived material, lends support to the interpretation of Hales and Gough (1962) that, in the area between the regional positive gravity feature and Kuruman-Sishen-Postmasburg, there might be a large body of denser material beneath the cover of Transvaal strata. Such a body might be an offshoot derived from the larger mass beneath the Strondkop gravity high. The fact that the Groenwater positive anomaly has a structural position within the Transvaal Basin of the northern Cape Province similar to that of the positive anomalies associated with the Bushveld Complex in the Transvaal Basin of the central Transvaal leads to speculation that the denser material under the Groenwater anomaly might have a similar character to that of the Bushveld Complex.

The contours of the residuals of the sextic surface show the same flexuring from northeast to northwest that is evident in the isogal map of observed gravity values. The trace of the axis of flexuring is more clearly defined by the sextic residuals, and can be seen to be located more-or-less along the Brak River and along the course of the Orange River between Prieska and Upington. It coincides with the positions, and extensions, of the De Duinen and Doornberg faults of Vajner (1972). The residual contours are not smooth through the zone of flexuring, but show a crumpled appearance. This crumpling occurs over a width of at least 60 km, between a north-northwesterly line midway between the Brak River and the Orange River, southeast of Douglas, and a parallel, north-northwesterly line through Marydale, which would coincide with the Brulpan fault of Vajner (1972).

To emphasize the trends of the zones of positive and negative residuals, Figure 7 has been prepared, in which the axes only of the alternating zones of Figure 6 are depicted. The three most obvious features of Figure 7 are the following :

(1) The discontinuity of all the trends is most marked along a north-northwesterly line from east of Victoria West, through Copperton and a point west of Marydale, to a point east of Upington. Although the trends are shown as continuous between the Orange and Kuruman rivers, this pattern can be questioned because of the paucity of gravity stations in the Gordonia district. It is more likely that a discontinuity will also be present, instead of the very sharp flexuring depicted between the Orange River east of Upington and the confluence of the Nossob, Molopo, and Kuruman rivers at Witdraai. The most satisfactory interpretation of this major, regional discontinuity is that it represents a fault or fault zone, to which the name Brakbos fault zone has been given.



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INTERPRETIVE MAP OF RESIDUALS FROM COMPUTED SURFACES

Figure 7

(2) The shorter, but equally conspicuous, discontinuities which occur in the trends east of Douglas and southeast of Postmasburg, are also orientated in a north-northwesterly direction. Bending of the contours east of Postmasburg and southeast of Kuruman takes place along a line striking in the same direction.

(3) The trends change their strike from north-northeast in the Kaapvaal Province to northwest in the Sonama Province within a north-northwesterly-striking tract along the Brak and Orange rivers, in which the axes of the positive and negative residuals are markedly crumpled. The Doornberg fault occurs within this tract, and there is no discontinuity in the trends across this fault. The Strondkop gravity high lies just beyond the northeastern margin of the crumpled zone.

STRUCTURAL INTERPRETATION OF THE GRAVITY FIELD

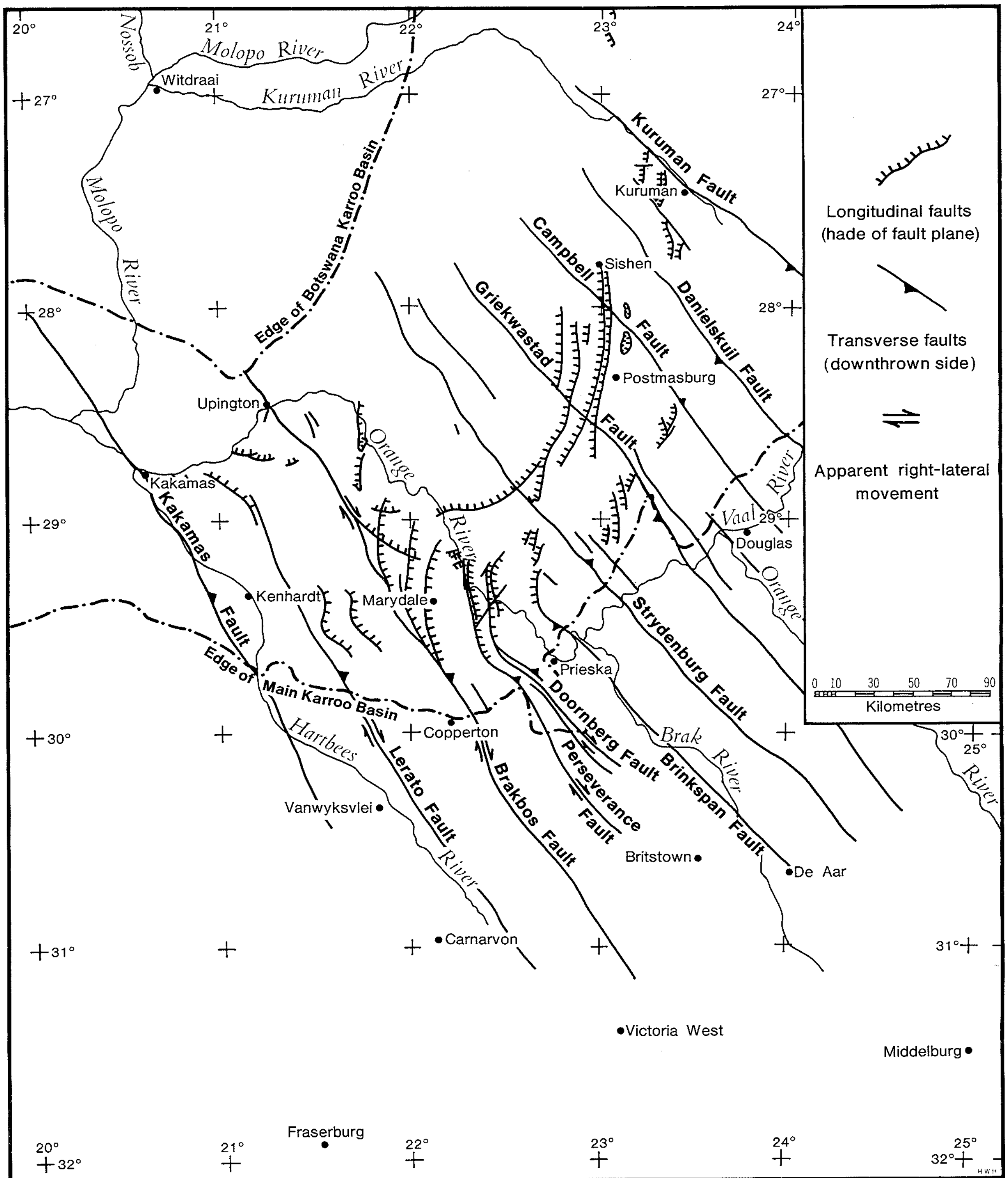
(a) The Major Faults of the Region

The discontinuities in the trends of observed Bouguer anomaly values and in the positive and negative residuals resulting from a trend surface analysis of the observational data are considered to reflect the presence of faults or fault zones. The discontinuities are marked by either sharp terminations in the axes of trends or right-angled bending of such axes. In a number of instances, these discontinuities can be correlated with mapped faults, particularly in the Kaapvaal Province where the more varied stratigraphy permits easier recognition of displacements than is possible in gneisses and other metamorphic rocks of the Sonama Province.

The discontinuities which have been recognized in the trends of the Bouguer anomaly values are shown in Figure 8. The longitudinal faults, which parallel the Vaal-trend of the fold axes in the Transvaal and Matsap formations, have been taken from the mapping of Visser (1944). They are not detectable from the gravity trends. Although the presence of north-northwesterly-trending faults has long been known, Vajner (1972) produced the first evidence that they might be more frequent than had been reported previously. The interpretation of the gravity data supports this contention, and Figure 8 reveals that these linear features dominate the fracture pattern of the interface between the Kaapvaal and Sonama provinces. The country is cut up into long, narrow slivers, trending north-northwestwards, between the faults, and it is this sliver-controlled fabric that determines the orientation of the contours of the linear surface of the regional component of the gravity field. The length of the country, in a northeasterly direction, which has been covered by the gravity study is 350 km, and over this distance 13 major north-northwesterly-trending discontinuities have been identified in the gravity data, so that the average distance between such features is of the order of 25-30 km.

There is a sense of right-lateral movement on some of the faults - Lerato, Brakbos, Perserverance, and Doornberg - as determined from the relative displacements, on plan, of stratigraphic and lithologic features. Vertical movement is also apparent on some of the fault planes. From the observations of Visser (1957) and of mining companies, the regional plunge of the folds in the region is to the north-northwest. From this, it follows that, where vertical movement has taken place on the fault plane, the outcrop of a feature crossing the fault will be displaced to the southeast on the downthrown side of the fault, and to the northwest on the upthrown side. Such a displacement of plunging strata along a normal fault will, on plan, produce a sense of right-lateral dislocation. Although there is little doubt that some transcurrent movement in a right-lateral sense has taken place along some of the major transverse faults, it is possible that the displacement pattern of outcrops owes more to vertical movement on the fault planes than to horizontal dislocation.

The interpretation that was placed on the linear component of the regional gravity favoured the possibility that the gneissic terrane of the Sonama Province represents a deeper tectonic level that has been elevated through vertical movement. With the Sonama Province having moved up relative to the Kaapvaal Province, there is a high likelihood that this relative movement was effected, for the most part, along the extensive transverse faults indicated in Figure 8. It would seem that the two fragments of the crust moved vertically past one another in the boundary tract between the Sonama and Kaapvaal provinces, and did not slide past each other horizontally or rotate past each other, as has been favoured by previous investigators of the region.



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POLYNOMIAL TREND SURFACE ANALYSIS OF BOUGUER ANOMALY VALUES

POSTULATED REGIONAL STRUCTURAL GEOLOGY : I. Major Faults

Figure 8

The coincidence between some of the transverse faults and the courses of the Orange, Hartbees, Brak, and Kuruman rivers is well illustrated in Figure 8. The distinct linear trends in the regional drainage regime are clearly reflecting the frequency and extent of the north-northwesterly faults.

The region acts as host to a large number of kimberlite pipes and fissures, and when the distribution pattern of these is superimposed on the fault pattern revealed by the re-processing of the gravity data, there is a significant degree of coincidence between elongated clusters of kimberlite intrusions and the positions of the north-northwesterly faults. These dislocations, which have facilitated differential vertical movement of large portions of the Earth's crust, were apparently sufficiently penetrative, at certain times and under certain conditions, to permit the lithosphere to be breached and the asthenosphere to be tapped.

(b) The Boundary Between the Sonama and Kaapvaal Provinces

If there is to be a discrete boundary between the two crustal provinces, then it is most likely to be represented by the Brakbos fault zone, and not the Doornberg fault. It has already been stated that the supracrustal rocks of the Ventersdorp, Transvaal, and Matsap sequences, which are typically developed in the Kaapvaal Province, have been found by Vajner (1972) to extend over the Doornberg fault. The Kaaien quartzites, which underlie the above formations, occur eastwards from Marydale, whereas the gneisses typical of the Sonama Province make their first appearance west of Marydale. The present study has shown that the gravity trends continue across the Doornberg fault, without any apparent discontinuity. The boundary between the two provinces, therefore, must be west of the Doornberg fault.

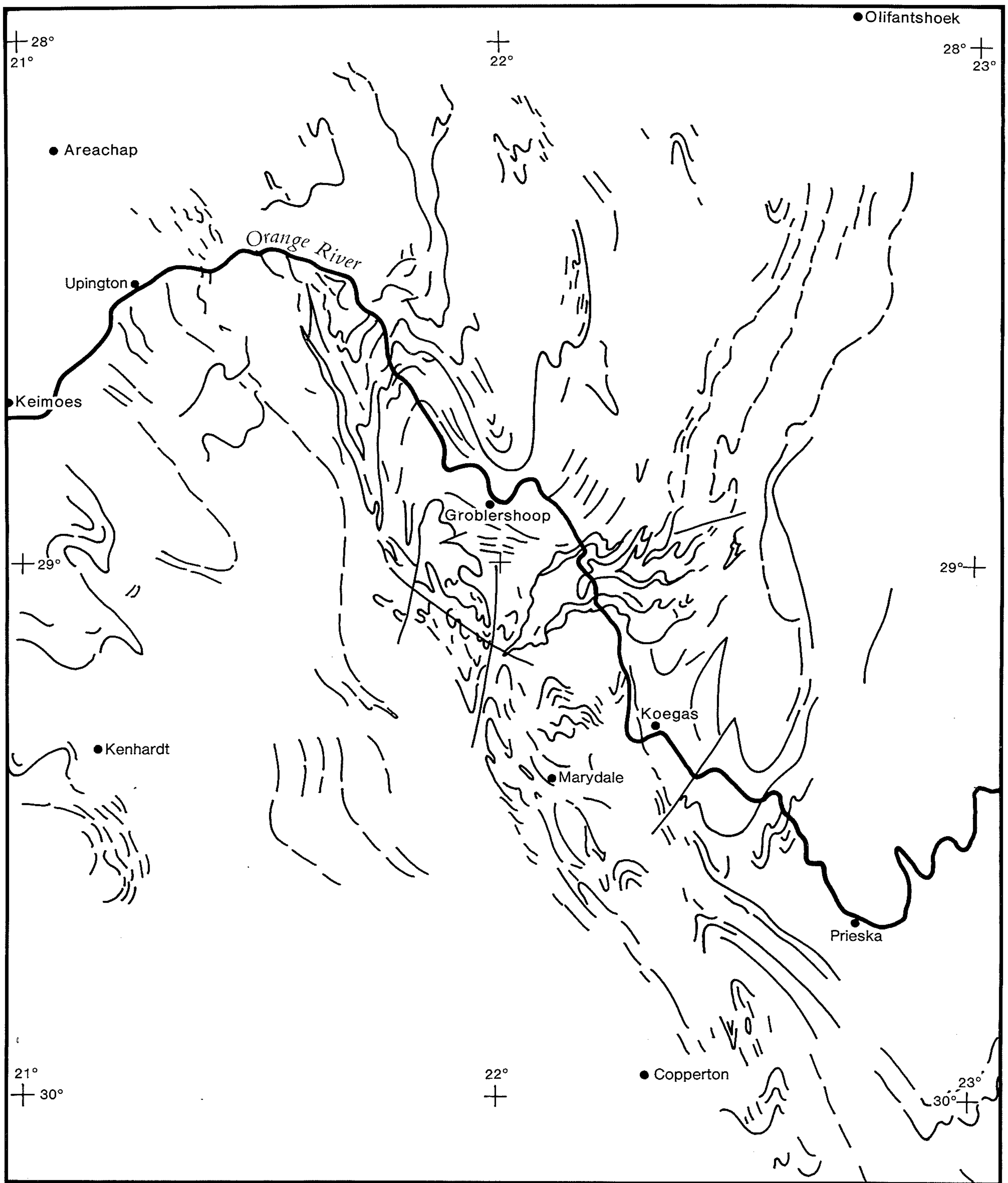
The discontinuity in the gravity trends is most marked along the Brakbos fault zone, and the most significant displacement, in either a vertical or horizontal sense, between the two provinces is apparent along this discontinuity. The type-area of development of the Kaaien quartzites, on its southwestern side, terminates abruptly against the Brakbos fault zone. West of this discontinuity, only problematic remnants of quartzites have been found in the gneissic terrane of the Sonama Province, and there is doubt attached to their being the equivalents of the Kaaien quartzites of the Kaapvaal Province. The eastern limit of the gneisses and migmatites of Namaqualand and Bushmanland is against the Brakbos fault zone, Vajner (1974) having shown that the granitic material east of the Brakbos is older than 2 500 m.y., whereas the age of the metamorphism of the Sonama Province is 1 000 m.y.

The Brakbos fault zone coincides with the limit, which the mining companies have come to recognize, of the high-grade metamorphic gneissic terrane (R.C. Middleton, personal communication, 1973). West of the Brakbos discontinuity lies the country in which exploration targets, such as the Prieska copper-zinc mineralization at Copperton, are being sought. Indications of this type of ore deposit have not been found east of the Brakbos fault zone.

In Figure 8 can be seen another feature which tends to favour the Brakbos discontinuity as being the most important structural dislocation in the region. The Griekwastad, Doornberg, and Perserverance faults have an effect on the position of the northern outcrop of the Main Karroo Basin, and have obviously been reactivated in post-Karroo times. However, the Brakbos fault produces the most conspicuous change in strike of the contact between the Karroo and Precambrian rocks. On the edges of both the Botswana and Main Karroo basins, there is a marked swing in the direction of the contact on either side of the Brakbos fault. A north-northeasterly trend, northeast of the fault, becomes a west-northwesterly trend, southwest of the Brakbos discontinuity.

The pattern of lineaments on ERTS-imagery gives very strong support to the conclusions drawn from the trend surface analysis of the gravity data. Two images of the ERTS-A series cover the central part of the region studied, and visual examination of these permitted the preparation of Figure 9 in which is indicated all the observed lineaments between Areachap and Copperton, and between Kenhardt and Olifantshoek. The Brakbos discontinuity between Copperton and Areachap is strongly expressed in the conspicuous change in the intensity of lineaments to the northeast and southwest of it. The structural fabric of the Kaapvaal Province has its obvious termination, not along the Orange River, where the Doornberg fault is developed, but 35 km to the southwest, along the most important line of discontinuities in the gravity trends.

The effects of movement between the two crustal provinces are apparent over a north-northwesterly zone approximately 120 km wide, extending from east of Kenhardt to east of the Orange



LINEAMENTS: UPINGTON - PRIESKA AREA

ERTS A IMAGERY: 13 - 14 SEPTEMBER 1972
ALTITUDE 900 KMS. - CENTRE IMAGE 1053 - 07542

0 20 40 60 80
Kilometres

Figure 9

River, with the Brakbos fault in the centre of this zone. For 60 km southwest of the Brakbos discontinuity, the lineaments in the Sonama gneissic terrane reflect a north-northwesterly trend. West of the Keimos-Kenhardt area, the lineaments assume the typical northwesterly trend of the eastern section of the Sonama Province. For 60 km northeast of the Brakbos fault, the Precambrian strata of the Kaapvaal Province are delineated by sinuous lineaments with rapid changes in strike, beyond which distance the lineaments follow the normal north-northeasterly trend of the Griqua Fold Belt.

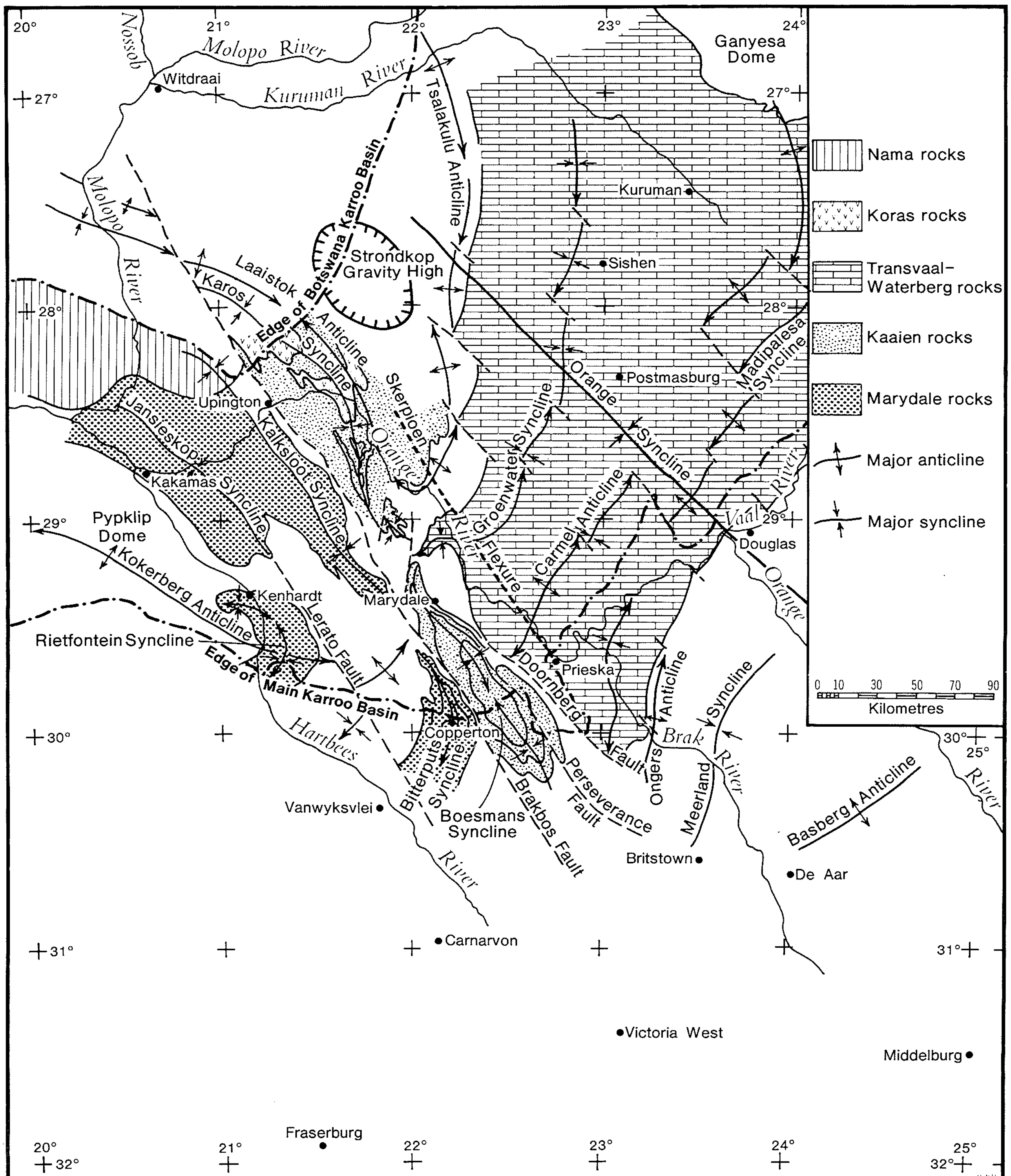
The sinuous lineaments straddling the Orange River between Prieska and Upington, coupled with the tight folds, plunging north-northwestwards, observed by Visser (1957), and the crumpled contours exhibited by the residual gravity values, clearly point to the 60-km-wide tract of country immediately northeast of the Brakbos fault zone as being the host to intense folding. The closures of a number of synclines and anticlines stand out sharply among the lineaments in Figure 9. The axial plane traces of the folds strike north-northwestwards, parallel to the direction of the transverse faults shown in Figure 8, and the general direction of plunge has the same orientation. Within the intensely deformed zone, there are local changes in the direction of plunge. Immediately southwest of the Brakbos fault, the north-northwesterly folding in the gneissic environment is much less intense than in the supracrustal sediments and volcanics. Bearing in mind the vertical movements on the transverse faults and the regional tilting of the country to the north-northwest, the intense folding between the faults can be interpreted as drag structures produced mainly by vertical movement on the fault planes. The tightness of the folds was subsequently increased by the later right-lateral horizontal movement that took place on the same fault planes.

It would appear, then, that the structural boundary between the Kaapvaal and Sonama provinces is a 120-km-wide tract of country trending north-northwestwards and containing a number of faults, parallel to this direction, with numerous, tight drag-folds developed adjacent to the fault planes. The axes of the drag-folds plunge to the north-northwest, on a regional scale, with reversals of plunge on a local scale. The most prominent of the dislocations is the Brakbos fault zone on which the largest amount of vertical, and possibly also horizontal, movement has taken place. There is a progressive stepping-up of the terrane on the southwest side of successive faults which have their downthrows towards the Kaapvaal Province. The fault pattern continues beyond both the southwestern and the northeastern limits of the boundary tract, but the intense drag-folds do not. This folding is considered to be restricted to the region in which most of the differential vertical movement was resolved between the two crustal provinces. The progressive stepping-up in a southwesterly direction indicates that the Sonama Province has moved upwards relative to the Kaapvaal Province. The main consequence of this has been the preferential preservation of the supracrustal Precambrian rocks in the Kaapvaal Province and the erosion of such material over the Sonama Province, where continued vertical uplift led to deroofing of the cover and the exposure of deep tectonic levels.

The boundary tract can be viewed as a product of attenuation and late-stage brittle fracture on the connecting limb between the relatively upward-moving Sonama Province and the relatively downward-moving Kaapvaal Province. In the light of this interpretation, the two provinces must be considered as parts of the same crustal domain that underwent differential vertical movement, and not as two separate plates that moved horizontally with respect to each other, to weld together along an ancient plate juncture of the convergent type.

(c) The Main Components of the Regional Structure

In an attempt to synthesize the information provided by geological mapping, both old and new, of the Gordonia-Carnarvon region of the northern Cape Province, by the reprocessing and re-interpretation of the gravity data, and by geochronological measurements of the ages of the metamorphic overprints in the two crustal provinces, Figure 10 has been prepared. The boundary zone can be taken as occurring between the Lerato Fault, which might coincide with Vajner's (1974) Neuspruit lineament, on the southwest, and the Skerpioen Flexure, on the northeast, this flexure marking the northeastern limit of the tight folds trending north-northwestwards, as well as the trace of the axis about which the gravity trends start changing from north-northeast on the Kaapvaal side, through east-west, to northwest on the Sonama side. Because of the intense deformation of planar features in this boundary tract, it is not possible to conclude, with any degree of certainty, whether the axial plane traces of folds on the Kaapvaal segment can be tied in to traces on the Sonama side of the boundary tract. The orientation of the axial plane traces of the Karos, Kalksloot, Jansieskop, Boesmans, and Bitterputs synclines and of the Laaistok anticline is



THE GRAVITY FIELD OVER THE GORDONIA-CARNARVON REGION OF THE NORTHERN CAPE PROVINCE

Based on the Bouguer Anomaly Map (1958) of South Africa compiled by the Geological Survey of South Africa

POLYNOMIAL TREND SURFACE ANALYSIS OF BOUGUER ANOMALY VALUES

POSTULATED REGIONAL STRUCTURAL GEOLOGY: II. Major Folds

Figure 10

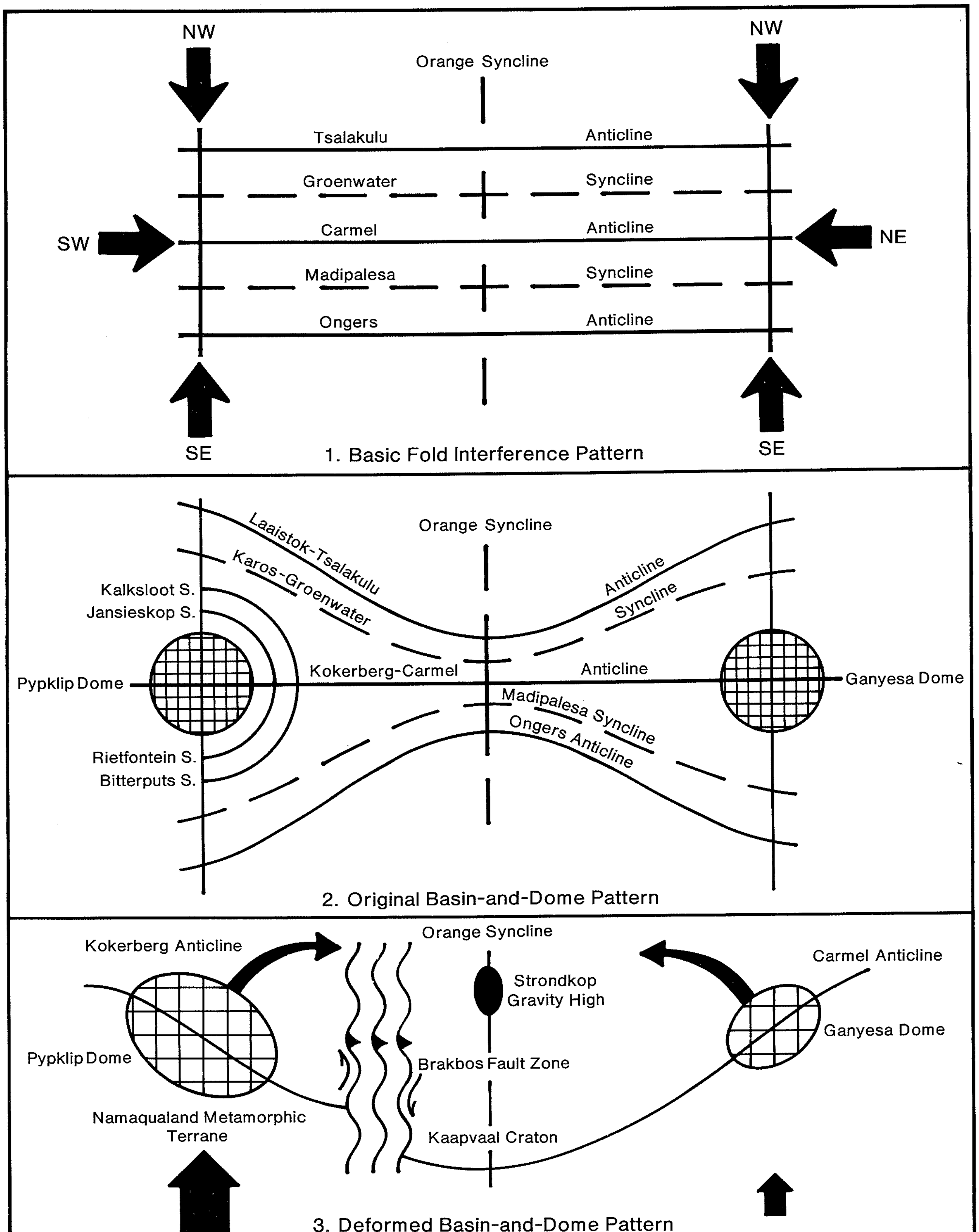
in accord with the north-northwesterly trends characteristic of the terrane contained within the 120-km-wide boundary tract. It is possible that the Laaistok anticline and the Karos syncline might be continuations into the boundary tract of the Tsalakulu anticline and the Groenwater syncline, respectively, of the Kaapvaal Province, and that the Laaistok and Karos folds might be continued across the Molopo River west of the Brakbos fault zone.

The most prominent anticline in the Kaapvaal portion of the region is the Carmel structure which can be traced, both geologically and geophysically, through a series of fault dislocations, from the Ganyesa dome in the north to the Orange River north of Prieska. The residual gravity values are lower over the Tsalakulu anticline, but the absence of outcrops in the area of this gravity feature makes it impossible to determine at present whether or not the Tsalakulu anticline is of greater structural importance than the Carmel anticline. It cannot be deciphered what happens to the projection of this anticlinal axis into the boundary tract. West of the Lerato fault, the most important anticlinal structure is the Kokerberg upwarp which runs from south of Kenhardt northwestwards to the Pypklip dome. The Ganyesa and Pypklip domes are pronounced structural culminations, and it is suggested that they lie along the same regional anticlinal structure. The Carmel anticline, then, would change direction from south-southwest, as it encounters the boundary tract between the Skerpioen flexure and the Lerato fault, to northwest, to be continued as the Kokerberg anticline. The culminations on the Ganyesa and Pypklip domes are the product of the superimposition of two northwest-striking anticlines of the Orange trend on the Kokerberg-Carmel anticline of the Vaal trend. The Orange-trend anticlines are not shown on Figure 10.

The residual gravity values, as well as the pattern of outcrops in the Kaapvaal Province, reveal that the Vaal-trend folds change their direction of plunge in the general vicinity of the Postmasburg-Douglas locality. On Figure 10 it can be seen that the width of exposure of the Transvaal Sequence is at its narrowest in this same locality. Northeast of Postmasburg, the area of outcrop of the Transvaal strata becomes progressively wider north-northeastwards. Southwestwards of Douglas, in the relatively short strike-length of exposure before the Transvaal rocks terminate within the boundary tract, the width of outcrop becomes progressively greater towards the south-southwest. This pinching-in is the result of the presence of the Orange syncline, of the Orange trend, which runs southeastwards, from west of Sishen, down the valley of the Orange River southeast of Douglas. Downwarping along this transverse fold axis has brought about the change in plunge of the longitudinal Vaal-trend folds such as the Tsalakulu anticline, the Groenwater syncline, the Carmel anticline, and the Madipalesa syncline. The Orange downwarp is the syncline between the two anticlines of the Orange-trend, which run northwestwards through the Pypklip and Ganyesa domes. The Strondkop gravity high lies close to the northwestwards extension of the axial plane trace of the Orange syncline.

(d) The Tectonics of the Northern Cape Province

Figure 11 is a schematic representation of the deformational processes which are thought to have resulted in the structures that have now been deciphered geologically and geophysically in the Gordonia-Carnarvon region of the northern Cape Province. A single fragment of the Earth's crust, which now includes the Kaapvaal and Sonama provinces, among other segments, was subjected to superimposed folding along the Vaal and Orange directions to produce the basic interference pattern illustrated at the top of Figure 11. The formation of structural culminations where anticline intersected anticline was related to the generation of the Pypklip and Ganyesa domes beneath which the granitic basement moved upwards. The space problem produced by the ever-increasing dimensions of successive stages in the history of dome-development caused the bending of the Vaal-trend folds around the flanks of the domes and the pinching-in of the axial plane traces along the Orange syncline of the Orange-trend. During this period, portrayed in the middle of Figure 11, the main axis of upwarp, along the Kokerberg-Carmel anticline, remained relatively straight. Upward movement on the Pypklip dome assumed greater importance than it did on the Ganyesa dome, with the passage of time, so that flexuring of planar features around the Pypklip dome became more pronounced, and attentuation of the strata between this dome and the Orange syncline reached more critical proportions than it did between the Orange syncline and the Ganyesa dome. Ultimately, the crust failed by brittle fracture along the boundary tract between what were then to become the Sonama and Kaapvaal provinces. The Brakbos fault zone was formed in the centre of this boundary environment, and the maximum vertical movement occurred along the Brakbos dislocation. The bottom portion of Figure 11 indicates that vertical uplift of the Pypklip dome was possibly accelerated after the rupture of the crust in the boundary tract, so that the space problem was accommodated by a certain amount of differential horizontal movement between the two crustal provinces, to give the right-



SCHEMATIC MODEL OF THE TECTONICS OF THE NORTHERN CAPE PROVINCE

Figure 11

lateral displacements seen in the boundary tract along the Lerato, Brakbos, Perserverance, and Doornberg faults. Such transcurrent movement also aided in the flexuring of the Kokerberg-Carmel anticlinal axial trace, but it is thought that the most important contributor to this arcuation process was the rising of denser igneous material into the upper part of the lithosphere beneath the Strondkop gravity high. The emplacement of this mantle-derived material created another space problem which was again accommodated by the bending of planar features around the flanks of the intruded body.

A schematic section, from southwest to northeast, through the bottom portion of Figure 11 has been prepared in Figure 12. The interface between the gneissic and migmatitic terrane of Namaqualand and Bushmanland and the sedimentary-volcanic supracrustal terrane of the Kaapvaal Province is shown as the zone of normal faulting and intensive drag-folding between the Lerato fault and the Skerpioen flexure. The more gentle warping of the Precambrian strata north-northwestwards from the Skerpioen flexure, through the Orange syncline, to the Ganyesa dome is also portrayed, as well as the relatively greater amount of upward vertical movement on the Pypklip dome than on the Ganyesa dome.

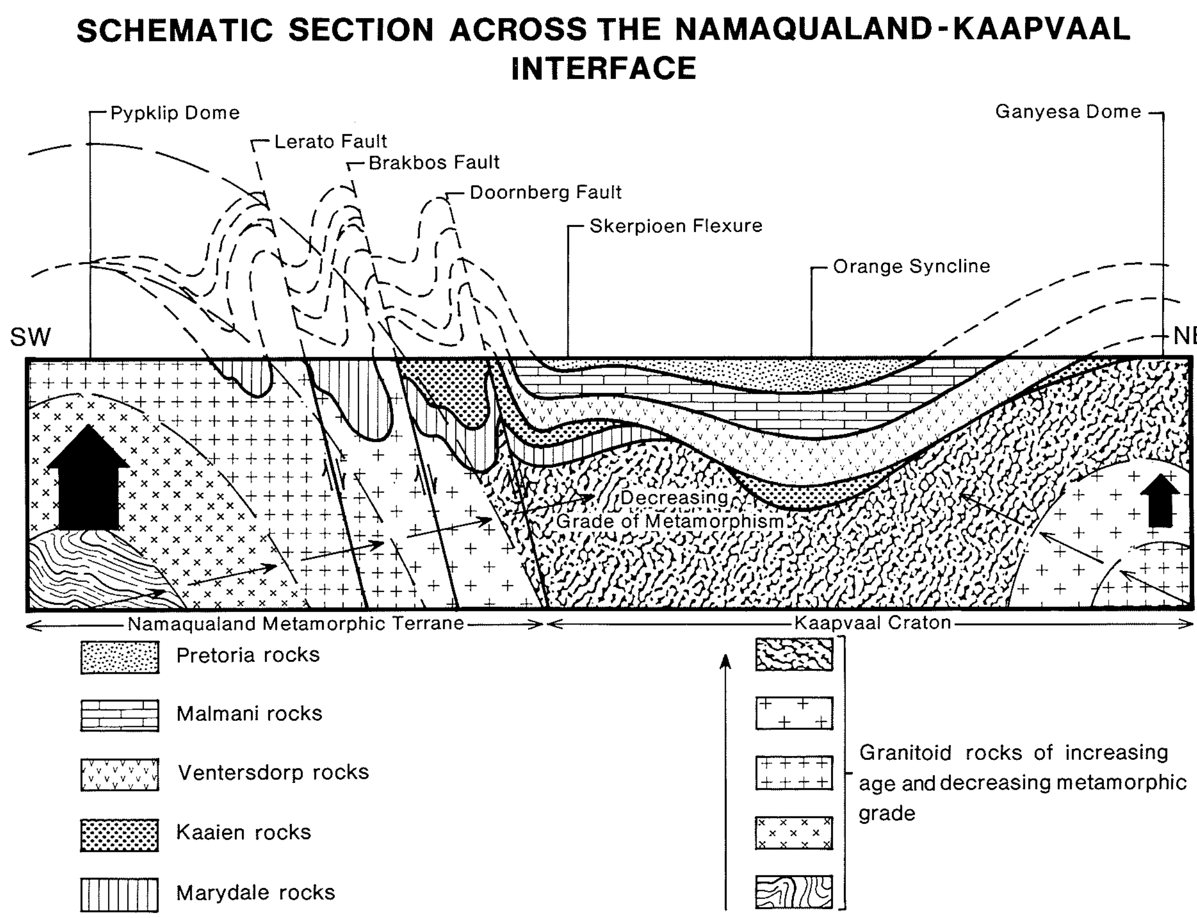


Figure 12

It is thought that the lithosphere under rising domes undergoes partial melting and differentiation, with a diapiric rising of the more granitic components. A thermal aureole develops around diapiric material, which imposes a progressively higher grade of metamorphism on the rocks flanking the diapir, as the core of the rising granitic material is approached. The intensity of metamorphism increase radially with greater depths towards the centres of the domes. As the domes rise and are deroofed by erosion, so deeper tectonic levels, with associated higher grades of metamorphism are exposed. The observations of Blignault (1974), Joubert (1974), and Vajner (1974) support the schematic zonation of metamorphism in the gneisses shown in Figure 12, since all three investigators have reported that more intense degrees of metamorphism are successively encountered, the greater the distance into the Sonama Province away from the boundary tract between the two crustal provinces. The changes in metamorphic grade are often sharp, and take place over short distances, which feature can be accounted for by moving southwestwards from one block of lower-grade metamorphism, across an Orange-trend fault, into a block where a higher-grade metamorphism has been exposed as a result of relative uplift on the southwestern side of the fault.

The greater the uplift associated with the domes, the younger the ages of the metamorphic rocks exposed over the centre of the dome. In addition to a downward increase in intensity of metamorphism, there is a downward decrease in apparent age of the granitic rocks. As these rise from depth under the domes, the temperature drops, and, at a critical level, the geological clocks are set, and the time at which such equilibrium is attained is imprinted on the particular layer in the concentric shell around the diapir. Further upward movement will push this layer towards the surface, while the underlying layer reaches its critical temperature-level and a younger date is imprinted on it. If vertical movement still continues, the older layer will be elevated to an erosional level, the younger layer will be exposed, and a still younger date will be set on the third layer which has moved into its critical temperature-level. The greater the tectonic elevation on any dome, the more of the supracrustal strata will be stripped off, the higher will be the grade of metamorphism in the exposed basement, and the younger will be the age of the metamorphic overprint.

Over the Pypklip dome, no remnants occur of the Proterozoic strata which Figure 12 postulates as having extended well to the southwest of the present erosional limit of Ventersdorp, Transvaal, and Matsap rocks, the metamorphism reaches the granulite facies, and the age of the metamorphism is, at most, 1 000 m.y. In the boundary tract straddling the Brakbos fault, only the Kheis rocks, underlying the Ventersdorp, Transvaal, and Matsap strata, are present on a granitic basement which has been dated at between 2 500 and 2 900 m.y. On the flanks of the Ganyesa dome, much greater proportions of the full succession of the Kheis, Ventersdorp, and Transvaal formations are preserved, and the age of the granitic basement is in excess of 3 000 m.y. The geological and the geophysical data indicate that the crust has been elevated to its relative maximum over the Pypklip dome, to its relative minimum over the Ganyesa dome, and to an intermediate level in the boundary tract between the Sonama and Kaapvaal provinces.

The conclusion has been drawn from the present study that the Sonama and Kaapvaal provinces were parts of the same crustal fragment during Archean and Early and Middle Proterozoic times, and that the Proterozoic sedimentary-volcanic basins, which are so well preserved in the Kaapvaal Province, extended over onto the Sonama Province. It is not now possible to say how far to the west and southwest they did extend. As a result of processes in the lithosphere and asthenosphere, which are not understood, the crust started rising, in post-Waterberg (Matsap) time, about 1 750 m.y. ago, to a much greater extent over the present Sonama Province than over the Kaapvaal terrane, so that the former region underwent uparching and the latter region relative downwarping. The pronounced elevation of the Sonama Province continued to at least 1 000 m.y., and resulted in the complete stripping-off of the supracrustal cover; the exposure of deep tectonic levels, high-grade metamorphic zones, and younger age-layers in the lithosphere; the attentuation and failure by brittle fracture of the crust between the locus of maximum uplift and the locus of maximum downwarp; and the intrusion of a substantial mass of denser mantle-derived igneous material into the upper levels of the lithosphere close to the boundary tract between the two provinces. This boundary tract is believed to be of the order of 120 km wide, and to be characterized by the development of a number of north-northwesterly-striking faults which have both vertical and, to a lesser extent, horizontal movement on them, and of numerous, tight drag-folds which plunge in the same direction. The faults have their downthrown sides on the northeast. Horizontal displacement is right-lateral. The folds have been produced mainly by vertical movement on the fault planes. The most conspicuous of the dislocations is the Brakbos fault zone which occurs in the centre of the 120-km-wide boundary tract. This fault zone extends for at least 500 km. If a line has to be selected as marking the boundary between the Sonama and Kaapvaal crustal provinces, then the choice could only be the Brakbos fault zone, and not the Doornberg fault which has been favoured by most of the previous investigators.

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