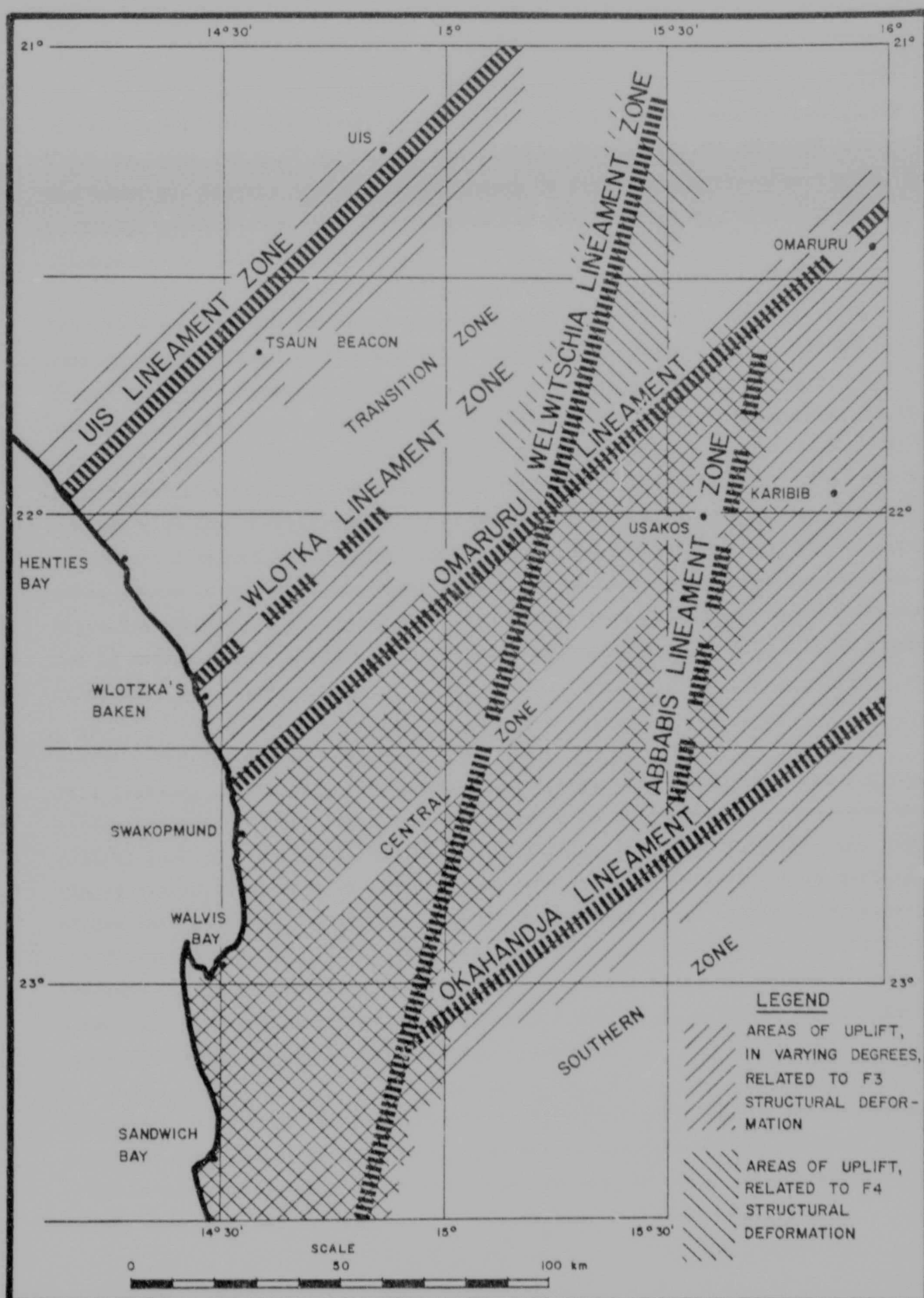

Fig 16 Schematic representation of interpreted regional structural framework north of the southern zone

downfold of the whole Damara succession that exceeds 530 km in length. It has been a fundamental line of crustal weakness throughout the history of the Damara orogen, which has constituted the northern margin of a deep early Khomas depository and has formed the locus of extensive uplift of the central zone, relative to the southern zone, of possibly 24 km. It was also the locus of late Nosib block faulting and acid volcanism, and largely delineates the northern limit of the Donkerhuk Granite. A pronounced change in structural style occurs along the Okahandja lineament in that it separates regions in which the intensity and orientation of folds differ.

The above conclusions and observations of Miller (1979) have an important bearing on the nature of the magnetic field associated with the lineament. The Khomas rocks and Donkerhuk Granite occurring in the southern zone have lost their remanent direction of magnetisation, unlike the Nosib and basement rocks in the central zone to the north which have not only retained this direction but which also have high-magnitude intensities of magnetisation (Table III). This contrast, coupled with the change in structural style across the lineament, has resulted in the observed magnetically disturbed domain of the central zone and the magnetically quiet domain of the southern zone, making the Okahandja lineament a prominent magnetic feature (Fig 3 and overlay). This change in magnetic and tectonic character is verified quantitatively in the computer-model section (Fig 17) as discussed in Section 5.2 below.

5.1.2 The Omaruru lineament

This feature, in the author's opinion, demarcates the boundary between the magnetically quiet domain of the southern portion of the transition zone from the central zone to the south. Whereas the Okahandja lineament separates the essentially linear structures of the southern zone from the dome-and-basin pattern of the central zone, this drastic change in tectonic style is not as evident over the Omaruru lineament. It is believed that this lineament demarcates the northern boundary of the central zone in the area studied and thus constitutes a line of monoclinal downfolding of the stratigraphy to the north, although not of the same magnitude as occurs along the Okahandja lineament.

Dome-and-basin structural patterns are also evident north of the Omaruru lineament, but the mantled gneiss domes prevalent in the central zone to the south do not occur here and the rock types exposed in the domes generally belong to much higher stratigraphic levels, i.e. within the Swakop

Group. Also, the extensive granite emplacement associated with the domes in the central zone is not seen to the north of the Omaruru lineament and metamorphic grades are lower. Exposures of Nosib rocks do, however, occur in the vicinities of Wlotzka's Baken and, to a greater extent, the Tsaun trigonometric beacon (approximately 60 km due east of Cape Cross, Fig 2). At the latter locality a succession of rocks, termed the Tsaun Formation (Botha et al., 1975) and correlated with the Khan Formation (Jacob and Kröner, 1977) are exposed in and to the west of a prominent dome structure.

The Omaruru lineament is also believed to be a fundamental line of crustal weakness in the tectonic history of the area, although not to the same extent as the Okahandja lineament. The Waterberg thrust fault, striking roughly northeast of the town of Omaruru, which has forced Damara rocks southwards over those of the younger Karoo Sequence, is on the regional extension of the Omaruru lineament and suggests that this is a fundamental linear zone of structural change. The Erongo Complex was also emplaced along this lineament.

5.1.3 The Uis lineament zone

This lineament zone coincides with the northeast-trending Cape Cross-Uis belt of tin-bearing pegmatites and is demarcated by a linear regional magnetic low, roughly 150 km in length and 20 km wide in the area studied (Fig 3 and overlay, Fig 16). It was shown in Section 4 that the negative (low) magnetic anomalies constitute a magnetic signature of the Nosib Group rocks, particularly of the Khan Formation, and hence that outcrops or shallow suboutcrops of these rocks are to be expected in such anomalous zones. This is supported fully by the exposures of Nosib Group rocks in the vicinity of the Tsaun beacon which yield the highest amplitude negative anomalies along this lineament. Relatively shallow (less than 1 km) suboutcrops of these rocks may thus be expected elsewhere along the lineament.

5.1.4 The Wlotzka lineament zone

This lineament zone trends northeastwards from Wlotzka's Baken on the coast (Fig 3 and overlay, Fig 16) and is demarcated by a prominent low magnetic anomaly of limited strike (∿ 60 km). A similar origin to that of the Uis lineament zone must be called upon to explain this magnetic low and although no extensive outcrops of Nosib (or any other) rocks occur here, the author has identified exposures which may correlate with the Khan Formation.

5.1.5 The Welwitschia lineament zone

This lineament zone was identified from the abrupt change in direction of magnetic (and hence structural) fabric from the general northeasterly direction of the belt to a north-northeasterly direction transecting the central zone. Although no single regional magnetic anomaly is associated with this zone, its presence is readily evident when viewing the fabric of magnetic anomalies in Fig 3.

This magnetic/structural fabric indicates clearly (Fig 20) that the Okahandja lineament becomes either truncated or overprinted where it intersects the Welwitschia lineament. This intersection corresponds with the deviation of the Okahandja lineament to the southwest, as outlined by Sawyer (1978). The Welwitschia lineament zone continues its trend into the central zone and in turn is either truncated along the Omaruru lineament or continues north-northeastwards where it is not readily evident from the raw magnetic data. It is possible that the fabric of north-northeasterly trending magnetic anomalies, arising from dolerite dykes of Karoo age west of the Erongoberg, represents the extension of the Welwitschia lineament zone in the form of renewed intrusive activity along this line of older structural weakness. To the east of the Welwitschia lineament zone the trend of fold axial planes of structures within the belt, as seen from the aeromagnetic data, is mostly northeast (Rose diagram R1, Fig 20). To the west, however, these structural directions are both northeast and north-northeast, with the latter direction prevailing as the coast is approached (Rose diagram R2, Fig 20).

The author considers this north-northeasterly structural direction (F4, Jacob <u>et al.</u>, in press) to be of fundamental importance to the emplacement of the uraniferous alaskitic granite since, firstly, the currently known occurrences occur along the Welwitschia lineament zone and, secondly, the major fold axes of the domes and structures with which these occurrences are associated (Figs 5a, 5b and 6) are parallel to this direction rather than to the general northeasterly trend (F3) of the central zone. This latter relationship is considered by the author as being indicative of the genetic difference between the uraniferous alaskites and the numerous other non-mineralised and not necessarily late-tectonic alaskites in the area.

The Welwitschia lineament zone corresponds broadly to a greater frequency of exposure of basement in the western portion of the area (Fig 2) indicating that uplift, probably in the form of a geanticlinal ridge, has occurred along it. Haack and Hoffer (1976) have reported K/Ar ages of biotite from the Damara orogen occurring uniformly around 485 Ma but with those in the western part up to 50 Ma younger. They have suggested that the youngest ages would be found in areas of maximum uplift. This is consistent with the above proposal that uplift has occurred along the Welwitschia lineament zone resulting not only in lower stratigraphic levels, including basement, becoming exposed but also in the emplacement of the larger and better-mineralised bodies of uraniferous alaskite. This north-northeasterly structural episode is probably late-tectonic (F4) and of the same age as that of the emplacement of the uraniferous alaskites in view of their close association with it, i.e. ± 470 Ma (based on an age for the Rössing mine alaskite of 468 ± 8 Ma, Kröner and Hawkesworth, 1977, and Kröner et al., 1978).

5.1.6 The Abbabis lineament zone

This less prominent lineament zone trends roughly north-northeastwards through the town of Usakos (Figs 2, 3 and overlay). Although this lineament zone is not readily evident from the fabric of magnetic anomalies, the author has assumed its presence for a number of reasons, both geological and geophysical, i.e.

- it corresponds to exposures of basement in the eastern portion of the area (Fig 2) and thus delineates a zone of uplift or geanticlinal ridging with a direction approximating that of the F4 structural episode;
- the Khan Formation is not developed along and to the east of this lineament zone;
- it demarcates the marked termination of negative magnetic anomalies in the east of the area. This could be due to one or more of the following possibilities, i.e. that the full sequence of Nosib rocks is not fully developed as indicated above; that the magnetic mineralogy has changed; or that the area has suffered a later period of remagnetisation possibly associated with the emplacement of the Erongo Complex.

An observational fact worthy of mention is that the Erongo Complex is located at the probable intersection of the Abbabis geanticlinal ridge, defined by the lineament zone, with the Omaruru lineament.

5.2 Computer-Modelled Magnetic Section

5.2.1 Procedure and assumptions

It is evident from the preceeding discussion that the lower stratigraphic levels, represented by basement and Nosib Group rocks, either crop out or have a shallow suboutcrop along the magnetic lineament zones. A down-folding of the stratigraphy occurs in varying degrees on the edges of these lineament zones, i.e. along defined lineaments. The author thus believes that the magnetic lineament zones are sites of geanticlinal ridges produced either by crustal warping or faulting. It was decided to test this hypothesis by quantitatively interpreting a magnetic section across the belt.

A geological section, A - B (see Figs 2 and 20 - overlay, for locality), 230 km in length, was selected for this purpose. It traverses the belt roughly from the Messum Complex in the northwest to the farm Ruimte in the southeast and incorporates all the major structural and magnetic features, viz.,

- the central (lineament) zone, bounded by the Okahandja and Omaruru lineaments,
- the Uis lineament zone and associated negative magnetic anomaly
- the northeastern extremity of the Wlotzka lineament zone
- the Rössing-Valencia anticline and associated negative magnetic anomaly, with which the uraniferous alaskites are associated.

The section was modelled according to the corresponding aeromagnetic profile, utilising the computer program of Talwani and Heirtzler (1964). The program enables the computation of magnetic anomalies caused by a two-dimensional structure of arbitrary shape by approximating a cross-section of the body with an irregular polygon. The non-iterative digital program makes use of analytical expressions to calculate the horizontal, vertical and total-field intensity magnetic anomalies caused by the body. For section A - B only the total-field intensity data were available. The program may be used irrespective of whether the magnetisation is induced, remanent or mixed (hybrid).

A geological section was first drawn along section A - B (Fig 17) based on published geological maps. With this as a basis, coupled with knowledge gained from the palaeomagnetic surveys of susceptibilities and directions and intensity of remanent magnetisation, the major formational units were approximated by polygons, each with specified magnetic characteristics.

A total of 27 separate polygons were needed to approximate the section and the total-field intensities, as calculated for each body by the program, were summed and compared with the observed aeromagnetic profile. The shape of the bodies and their magnetic characteristics were altered, within the constraints of the known or anticipated geology and measured magnetic characteristics, and the procedure repeated until a best-fit was found between the observed and theoretical profiles. Eventually 22 computer runs, incorporating all the bodies, were required to give the model section and best-fit presented in Fig 17.

In view of the large number of variables which could affect the theoretically calculated magnetic profile, e.g. structural changes and variations in magnetic characteristics for a particular formation, a number of approximations and basic assumptions had to be made in order to reduce the number of variables and hence to make the modelling at all feasible. These include:

i) Two-dimensionality of all of the structures had to be assumed for the particular computer program used. Geological mapping as well as the aeromagnetic contour map certainly indicate that the larger structural features, i.e. the major lineaments and lineament zones, are two-dimensional. Even the smaller structural features traversed by section A - B within the central zone have an elongate attitude and may be considered, as a first approximation, to be two-dimensional. This assumption is, therefore, considered to be valid.

ii) No correction was made for the regional magnetic gradient. An inspection of the colour-composite aeromagnetic map indicated this gradient to have a roughly southwesterly direction with the total-field intensity decreasing towards the southwest. Since section A - B was chosen perpendicular to this, the assumption is considered to be reasonable, particularly since no gradient was evident along section A - B itself.

iii) It was assumed that the granitic equivalents of the Damara rocks are by-and-large conformable with the stratigraphy, i.e.

that rocks of the Salem Granite Suite occur mostly in synclines above the Rossing Formation and that the red granites and reactivated basement rocks are confined to the Nosib and lower stratigraphic levels particularly in dome or anticlinal structures. This is consistent with the observations of Jacob (1974a).

iv) It was assumed that the basement underlying the section, particularly in the central zone where it abuts against the Okahandja lineament, has largely been remagnetised by the 500 Ma event. Most palaeomagnetic sites in the basement exposures within the central zone do indeed show that the basement has been affected by a later, secondary magnetisation, hybrid with the direction of the 500 Ma event. The two sites sampled in basement southeast of Rooibank on the Kuiseb River have, however, retained their original magnetisation. Even if original and secondary directions occur sporadically within the underlying basement, the calculated geometry of the basement on a regional scale is not greatly affected, particularly in view of the possible manipulations which can be made within the constraints of the ranges of observed directions and intensities of magnetisation. A secondary (hybrid) direction of magnetisation ($D = 220^\circ$, $I = -50^\circ$), derived from the palaeomagnetic sites sampled in red granite within the Trekkopje anticline, was found to give the best-fit observed in section A - B.

v) The NRM's derived from the palaeomagnetic sampling indicated that essentially two directions of remanent magnetisation and two susceptibilities (for the induced magnetisation) are sufficient to account for all the formational units although intensities of magnetisation had to be varied. These characteristic parameters are given in Table VI below. Thus the Swakop Group was considered to be a single unit magnetically, having lost its 500 Ma thermo-remanent magnetisation and now having predominantly an induced magnetisation. The Donkerhuk granite and most of the rocks of the Salem Granite Suite were included in this magnetic unit although certain members of the Salem suite as well as certain of the late- to post-tectonic granite stocks display a hybrid remanent direction. The Khan Formation and, in part, the Etusis Formation were combined as a single remanent magnetic unit, although the latter has lost its thermo-remanent direction in certain areas. The red granites and reactivated basement were considered to have a single remanent direction hybrid between the 500 Ma thermal event and a later secondary direction of magnetisation.

vi) Short wavelength anomalies due to dykes or relatively thin geological units were not modelled due to the excessive number of extra bodies that would have had to be added to the existing set. This would not only have increased the required computer time but also the number of manual iterations required for an already onerous task. The effect of these smaller features on the geodynamic significance of the model as a whole was felt to be minimal.

TABLE VI : MAGNETIC CHARACTERISTICS USED FOR FORMATIONAL UNITS

	Swakop Group	Nosib Group	Swakop granite (Salem - certain members of), Nosib granite (RG), Reactivated Basement	Salem and Donkerhuk granite
Type of magnetisation	Induced	Remanent	Hybrid	Induced
Susceptibility (S.I.)	110×10^{-6}	-	-	60×10^{-6}
Declination °	-	334	220	-
Inclination °	-	54	-50	-
Intensity ($A.m^{-1}$)	-	0,60 - 2,50	0,60 - 1,50	-

5.2.2 Discussion

Before entering into a discussion of the results of the modelling, the depth limitations of the magnetic method should be pointed out, i.e. although the magnetic method has a greater depth of penetration than other methods (e.g. radiometrics), potential field theory shows that it has a decreasing resolution with depth. Thus the magnetic anomalies caused by small-scale features in depth will be small when compared with near-surface anomalies. Modelling of these deeper features is made even more difficult in areas such as the Damara belt where high-amplitude magnetic anomalies of relatively shallow origin prevail. As an example, the Nosib Group has been terminated laterally in depth between the Wlotzka and Uis lineament zones more for geological than for magnetic reasons since an introduction of a 2 km slab of Nosib rocks at a depth of 5 km would only result in a small percentage change to the calculated field at surface. If this slab were, however, cut by large-throw faults the effects thereof would have a greater manifestation at surface.

The following features became evident as a result of the modelling study:

i) Certain outcrops of the Salem Granite Suite require similar directions and intensities of magnetisation as the red granites and reactivated basement rocks in order to yield the observed positive magnetic anomalies. This direction, given in Table VI, was derived from the NRM's of the red granite outcrops sampled in the Trekkopje anticline, and is considered to be hybrid between the 500 Ma direction and a later secondary direction. This later direction is possibly related either to the period of late- to post-Karoo intrusion or to the present-day direction, which in places has pervaded across the stratigraphic column.

ii) The negative magnetic anomalies are preferentially related to the development of the Khan Formation rather than of the Etusis Formation. Although the Etusis Formation in certain areas undoubtedly yields high-amplitude negative magnetic anomalies there are areas where this is not the case, e.g. in the vicinity of the Vredelus and Rooikuiseb anticlines where the field is either normal or positive (due to i. above). It would appear that the percentage of magnetic minerals or the magnetic mineralogy is such that the Khan Formation retains its thermo-remanent direction to a greater extent that the Etusis Formation. This would also explain why no negative anomalies are prevalent in the east of the area where the Khan Formation is not fully developed.

iii) The most significant geodynamic result of the modelling study is the verification of the hypothesis that the magnetic lineament zones, i.e. the central zone and the Uis and Wlotzka lineament zones, are in fact geanticlinal ridges bounded by a relatively rapid monoclinal downfolding of the stratigraphy. This could not be seen as clearly for the Welwitschia lineament zone in section A - B since it already occurs in a highly deformed area of uplift, although the frequency of basement exposures along this zone certainly support this hypothesis (Fig 2).

iv) The low magnetic field seen south of the Okahandja lineament is not due to the relative absence of magnetic minerals as initially thought (Corner and Henthorn, 1978). It is due rather to the fact that, along this lineament, reactivated basement underlying the central zone abuts against the Khomas depository. The marked change in direction and intensity of magnetisation, over a large vertical distance as one crosses from the basement rocks into the relatively inert Khomas and Donkerhuk rocks, has been shown by the modelling to cause this low magnetic field. Although Blaine (1977) has suggested that the Kuiseb Formation of the central and southern zones may have quite different ages and source areas, no change in magnetic character, which could affect the model, was evident in this study.

A vertical distance of uplift of 20 km was used in the model in order to get the best-fit between observed and theoretical profiles. This distance could obviously be affected by changes in the direction and intensity of magnetisation used for the reactivated basement, particularly since this is a hybrid direction and is not that well-defined by the current palaeomagnetic work. Whatever the changes, however, the amount of uplift along the Okahandja lineament will still be extremely large, supporting the conclusions of Miller (1979) who postulated an uplift of possibly 24 km. Further palaeomagnetic surveys, aimed specifically at sampling Khomas and Donkerhuk rocks south of the Okahandja lineament and reactivated basement rocks to the north, would be necessary to better quantify the uplift.

Qualitative interpretation of the aeromagnetic data, as given in the interpretative overlay, initially indicated the Okahandja lineament to be a relatively narrow vertical feature (i.e. less than ± 10 km) feature when viewed on surface. The modelling results indicate however that the Okahandja lineament is a much broader non-vertical zone of structural change when viewed in geomagnetic section. This supports the findings of Sawyer (1978) that the lineament extends southwards and is up to 40 km wide in places.

5.3 Geodynamic Considerations

Since the Damara orogenic belt contains many features also found in Phanerozoic fold belts, which are generally attributed to continental margin deposition, ocean closure and subsequent plate collision (Kröner, 1977), it was a natural consequence that plate-tectonic models were envisaged to explain the evolution of the belt (Burke and Dewey, 1972 and 1973; Burke et al., 1977; Barnes and Sawyer, 1980). Martin and Porada (1977) and Kröner (1977) have, however, enumerated many features of the belt which are incompatible with plate-collision processes making it apparent that other tectonic models have to be called upon to fully explain the formation of the belt.

Of particular relevance to this study is the proposal of Martin and Porada (1977) that the intracontinental branch of the Damara belt comprised three major graben systems which passed through an aulacogen stage and, with continued subsidence, led to the formation of a broad ensialic geosynclinal basin. Damara tectonics are interpreted as having been controlled by gravitational instability according to the proposals of Ramberg (1967). They have made three observations on the Nosib sediments in the central zone which have an important bearing on the early history of the fold belt and on the magnetic responses observed today, viz.,

i) The Nosib sediments within the central zone, with the exception of a local basal conglomerate, were not derived from the inlier but from the south and south-southwest.

ii) Changes in sedimentary thicknesses are so rapid that it is concluded that the depository was fault bounded.

iii) The Nosib age faults had an east-northeast orientation similar to the current structural trend. These early faults do not in general have a surface manifestation today since they have been obscured by later overstepping sedimentation and by deformation and intrusive plutonism.

The model thus proposed by Martin and Porada for the Damara belt is briefly that fault-bounded rifts were initially filled with clastic sediments of the Nosib Group deposited onto a sialic floor. The Nosib depositories were thus separated from each other and lateral increases in the thickness of the sedementary piles were rapid. Continued subsidence led to the deposition of the denser pelitic and carbonate sediments of the Swakop Group over a much wider area and to voluminous granitic (particularly) and mafic plutonism. Vertical movements predominated throughout the history of the belt, and the Nosib depositories later became buoyed up in large antiforms, such as the central zone, by gravitational instability.

The results of the structural interpretation of the magnetic data, and of the computer modelling study, are strongly compatible with the above tectonic model in the following respects:

i) Steep magnetic gradients and large negative magnetic anomaly amplitudes support the proposal that the increases in the apparent thickness of the Nosib rocks are rapid and either controlled by faulting during sedimentation or by subsequent folding. In view of the discontinuity of the Nosib rocks in the central zone, as seen from exposures in anticlines and dome structures, it is concluded that the apparent thicknesses are fault controlled.

In section A - B (Fig 17) numerous vertical faults have been postulated to conform to this conclusion. It is possible that some of these are hypothetical (e.g. in the Wlotzka lineament zone) although many were found to be necessary within the central zone and Uis lineament zone in order to obtain the indicated best fit. These may be obscured today by the overstepping sedimentation and deformation described by Martin and Porada.

ii) The magnetically quiet domain north of the Omaruru lineament indicates that, apart from the Uis and Wlotzka lineament zones, Nosib rocks are either not present or are buried at depth under a thick pile of younger Damara rocks. The proposals of paragraph (i) above indicate that Nosib sedimentation in the transition zone north of the Omaruru lineament is discontinuous and where present occurs in fault bounded depositories. It is for this reason that a block of Nosib sediments is proposed to occur, in depth, along the northeastern extension of the Wlotzka lineament zone in Fig 17 and this certainly is compatible with the geomagnetic profile.

In the light of the above and in view of the good fit between theoretical and observed magnetic profiles in the model section, it is concluded that the magnetic lineament zones represent initial fault bounded Nosib depositories which have subsequently been buoyed up, in varying degrees, as a result of gravitational instability to form the geanticlinal ridges which they represent today.

5.4 The Erongo Anomaly

A highlight of the aeromagnetic colour composite (Fig 3) is the conspicuous anomaly caused by the Erongo Complex. The shorter wavelength anomalies situated south of latitude 21°30'S, roughly between the 15°30'E and 16°E longitudes, are due to basalts of Karoo age overlying the outcropping Erongo granites and obscure, in part, the Erongo anomaly. Inspection of the deep-seated large (positive) anomaly indicates, however, that the centre of the complex occurs at depth roughly on the intersection of 15°45'E and 21°30'S (see overlay to Fig 3 for locality), which is offset from the outcrops of Erongo granite.

It was initially thought that this offset could have resulted from over-thrusting of portions of the top of the Complex southwards along the extension of the Waterberg thrust fault and thus causing Damara granites to overly the centre of the Complex. Aldrich (personal communication), however, of the Geological Survey (Windhoek Branch) who is currently investigating the Complex magnetically and gravimetrically, considers this to be unlikely. It is thus possible that the exposures of Erongo granite reflect emplacement away from the main complex, along zones of structural weakness or tension.

No further interpretation was conducted on the Erongo anomaly in view of the present studies of Aldrich.

5.5 Radiometric Coverage and Magnetic Relationships

5.5.1 General

The radiometric data, recorded simultaneously with the magnetic data during the course of the five airborne surveys of the area, are presented in the form of a colour composite in Fig 4. As mentioned previously, only the total-count-gamma contour maps are available on Open File and it was not possible to convert these to more meaningful equivalent-uranium contours due to the lack of adequate calibration facilities at the time the surveys were flown. The varying sensitivities resulting from the different detector-crystal volumes and the different flight altitudes used for the various surveys have resulted in the generally poor quality of the total-count composite. This has made the colour (and hence amplitude) matching between the respective surveys impossible in a regional sense as is obvious in Fig 4. The quality of the composite is also adversely affected by the prevalent northwest/southeast herringbone effect which has resulted from poor flight-altitude corrections with the earlier surveys. This is also prevalent to a lesser extent with the more recent surveys, D and E, although they are of a much better quality in terms of sensitivity.

A number of features are evident from the airborne radiometric colour composite when comparing it to the interpretative aeromagnetic overlay and to the geological map of the area (Fig 2). These are discussed separately below. A detailed discussion of the radiometric data in relation to each formational unit is, however, beyond the scope of this text. Attention is given here only to the salient features and to the correspondence with the aeromagnetic responses.

5.5.2 Radiometric lows

Prominent radiometric lows occur in the area south of the Kuiseb River, due to the thick cover of aeolian sand, and in the areas of outcrop of Karoo rocks which are relatively inert radiometrically, e.g. over the Etendeka basalts north of Usakos and over the Karoo sediments in the extreme northeast corner of the area.

It should be borne in mind that it takes only one metre of unconsolidated sand cover to entirely mask the gamma radiation arising from the rocks beneath. In view of the extensive cover of aeolian sand, scree and duricrust deposits in the area, this attenuation has greatly affected the appearance of the colour composite and the detection of buried uranium occurrences.

5.5.3 Radiometric highs

Prominent radiometric highs occur throughout the belt and are related to a number of formational units and lithologies, chiefly to the various granite and granite-gneiss phases in the area, i.e.:

i) Outcrops of red granite and reactivated basement invariably result in high radiometric anomalies, due mostly to varying concentrations of thorium (in particular) and also subeconomic quantities of uranium. Potassium obviously also makes a contribution, however this is considered to be small in a regional sense due to its relatively low gamma activity. The alaskitic granites with which uranium deposits are associated do have a relatively high concentration of potassium and this can readily be detected spectrometrically on the ground (Corner, 1975) or from the air with a high sensitivity survey. Quantitative gamma spectrometry could thus be successfully employed in mapping various granitic phases, and the total-count data of Fig 4 are not considered to be a beneficial aid to regional mapping in view of the lack of spectrometric discrimination.

Examples of radiometric highs due to outcrops of red granite and basement in the central zone may be seen;

- to the north and northeast of Goanikontes,
- east, southeast and northeast of the Ida dome,
- southeast of Karibib
- along the southern Welwitschia lineament zone, although these anomalies are less prevalent due to the paucity of outcrop.

These radiometric highs are invariably related to positive magnetic anomalies, as mentioned in Section 3.2, arising from a direction of magnetisation hybrid between the 500 Ma and a later or present-day direction, or from a reversed 500 Ma direction.

ii) Regional radiometric highs of a similar amplitude to those specified in paragraph (i) occur over most phases of the syn-, late- and post-tectonic granite. These are mostly associated with increased thorium concentrations and are not always associated with magnetic highs. Examples of these regional anomalies may be seen;

- in the area north of Langer Heinrich which is not related to a magnetic high
- associated with the Donkerhuk granites south of the Okahandja lineament which are magnetically relatively inert. A secondary uranium occurrence is situated northeast of Gobabeb in this environment
- from the mass of anomalies east of the 16°E meridian; in the vicinity of Omaruru; in the north of the area; and also north of the Omaruru lineament. Certain of the phases of the Salem Granite Suite also have positive magnetic anomalies associated with them, e.g. in the northeast and north of the area.

Radiometrically inert outcrops of post-tectonic granite and granite gneiss occur along the northern flank of the Uis lineament zone. These outcrops, however, display marked magnetic (positive) anomalies suggesting a different genesis from both the magnetically and radiometrically inert Donkerhuk granite and from the radiometrically active phases of the Salem Granite Suite.

iii) The Erongo granite north of Usakos also has a raised radiation level but is magnetically inert.

iv) High radiometric anomalies obviously also result from the presence of uranium occurrences in the area. These may be related to magnetic anomalies (e.g. the primary granitic uranium occurrences as discussed in this thesis) or with secondary calcareous/gypsiferous occurrences, which have no associated magnetic effects. Radiometric anomalies of the latter occurrences appear as low order and uninteresting features on the total-count map, e.g. at Mile 72 immediately southeast of Cape Cross, at the Tsaun beacon or, to a lesser extent at Langer Heinrich, but are immediately evident spectrometrically.

5.6 Data Processing

A study of the aeromagnetic data would ideally have been complete with the inclusion of sophisticated filtering techniques such as upward continuation, downward continuation and selected bandpass filtering. This may have facilitated the recognition of the lineament zones and perhaps brought to light certain structural features which are not readily evident in the raw data.

Such an interpretation would have to cover the area in its entirety if it were to be of value in interpreting the structural framework of the area. This was unfortunately not possible in view of the fact that the area was covered in a patchwork manner, with the earlier surveys being flown over key areas such as the central zone and Welwitschia lineament zone. The data accumulated during these surveys were recorded in analogue form often on poor quality chart paper. Digitising the data into a form suitable for filtering procedures would not only have been a task well beyond the scope of this text but also virtually impossible in view of the poor quality of the two initial key surve, .

zone. These outcrops, however, display marked magnetic (positive) anomalies suggesting a different genesis from both the magnetically and radiometrically inert Donkerhuk granite and from the radiometrically active phases of the Salem Granite Suite.

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iv) High radiometric anomalies obviously also result from the presence of uranium occurrences in the area. These may be related to magnetic anomalies (e.g. the primary granitic uranium occurrences as discussed in this thesis) or with secondary calcareous/gypsiferous occurrences, which have no associated magnetic effects. Radiometric anomalies of the latter occurrences appear as low order and uninteresting features on the total-count map, e.g. at Mile 72 immediately southeast of Cape Cross, at the Tsaun beacon or, to a lesser extent at Langer Heinrich, but are immediately evident spectrometrically.

5.6 Data Processing

A study of the aeromagnetic data would ideally have been complete with the inclusion of sophisticated filtering techniques such as upward continuation, downward continuation and selected bandpass filtering. This may have facilitated the recognition of the lineament zones and perhaps brought to light certain structural features which are not readily evident in the raw data.

Such an interpretation would have to cover the area in its entirety if it were to be of value in interpreting the structural framework of the area. This was unfortunately not possible in view of the fact that the area was covered in a patchwork manner, with the earlier surveys being flown over key areas such as the central zone and Welwitschia lineament zone. The data accumulated during these surveys were recorded in analogue form often on poor quality chart paper. Digitising the data into a form suitable for filtering procedures would not only have been a task well beyond the scope of this text but also virtually impossible in view of the poor quality of the two initial key surveys.

6 GRAVITY MODELLED SECTIONS ACROSS THE DOME STRUCTURES

6.1 Introduction

Mantled-gneiss dome structures are a feature of the central zone but their origin remains controversial. Smith (1965), and Bunting (1977) ascribe them to interference folding whereas Jacob (1974a), Sawyer (1978), and Barnes and Hambleton-Jones (1978) believe that they have formed as a result of diapiric uprise at about the time of, and following, F3 deformation. Those favouring formation by diapiric uprise propose, according to Ramberg's theory (Ramberg, 1967), that inverted density stratification of viscous strata (resulting from the metapelites and carbonates of the Swakop Group overlying the less dense Etusis Formation, basement rocks and certain Damaran granites) causes the spontaneous uprise of the lighter material at specific centres. These centres may be determined by lateral lithological inhomogeneities or (ibid.) by the spontaneous uprise of viscous strata in the form of waves (resulting in ridge diapirs), whose wavelength is controlled by a complex interaction of the thickness, rheological properties and densities of the layers. Sawyer (1978) has in fact calculated the dome spacing derived from a simple two-layer model representative of the Damara cover on the granitic basement, and found it to be in general agreement with field observations.

While gravitational instability arising from an inverted density stratification (Table VII) is not questioned by the author as a cause of diapirism, the close correlation between the major axes of many of the domes with the north-northeasterly F4 structural direction indicates a measure of structural control as well. Since the uraniferous alaskitic granite occurrences are mostly associated with dome structures affected by the F4 direction, it was decided to conduct accurate gravity traverses across three such structures to determine the extent of the gravitational contribution to their formation. Computer modelling techniques were used to interpret the results.

The domes chosen for this study include the Rössing dome, the Ida dome and the dome occurring at the Tsaun beacon (see Figs 2, 5a, 5b and 6 for localities). The latter structure has no preferred orientation and although secondary uranium does occur in weathered bedrock and gypcrete, no uraniferous alaskites have been identified at the locality as yet. The three traverses varied in length from 12,5 km to 18 km and were conducted perpendicular to the local strike direction.

6.2 Field Procedure and Reduction of the Data

A Scintrex CG-2, Worden-type, gravimeter (of the Geological Survey, Windhoek Branch) was used for the surveys. Heights and distances were determined by theodolite and staff, with intervals between stations averaging 300 m.

Gravimeter drift was determined by the 'leap frog' method, i.e. an arbitrary base station was established for each traverse and after about three-quarters of an hour of surveying the gravimeter was re-read at one of the preceeding stations, usually about 1 km back along the traverse. This procedure was repeated along each traverse and the differences in the readings at each of the check points were summed progressively along the traverse and plotted against time to yield a gravimeter drift curve. Typically the drift was negligible or slightly negative during the cool hours of the morning and thereafter was positive during the day, averaging 0,05 - 0,08 mgal/hour.

The heights between stations were considered to be accurate to within 5 cm, making the corresponding gravity error less than 0,01 mgal per station.

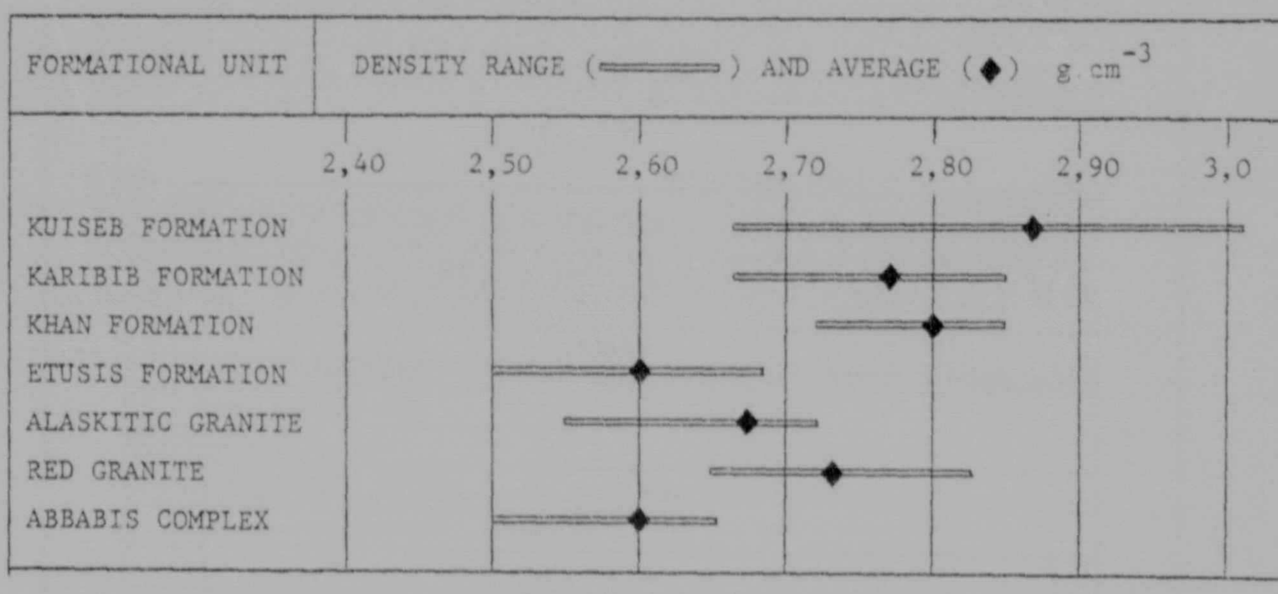
Standard gravimeter drift, free-air, Bouguer and latitude corrections were applied to the readings using a Bouguer density of 1,9 $g.cm^{-3}$ for the areas of thick alluvium and 2,67 $g.cm^{-3}$ for the hard-rock areas. The Ida and Rössing dome traverses were conducted in river gorges (Swakop river and Dome gorge respectively) which often had high cliff-like sides. In order to reduce the topographic effects to a minimum the stations were always sited as far away from the gorge sides as possible, mostly in the middle of the river beds. Topographic corrections were nevertheless applied in the rugged areas using the Hammer graticule technique (Dobrin, 1960) and published 1:50 000 topographic maps. These corrections proved to be small, however, never exceeding 0,2 mgal and mostly less than 0,1 mgal.

The resultant three Bouguer-anomaly profiles are presented, using an arbitrary local datum for each profile, together with the relevant geological sections in Fig 18 (sections CD - Rössing dome, and EF - Tsaun dome) and in Fig 19 (section GH - Ida dome).

Considering an inherent gravimeter accuracy of ± 0,02 mgal and the abovementioned sources of error due to station height, gravimeter drift, station location and topography, a maximum error of ± 0,1 mgal may be associated with the plotted values.

In order to make the theoretical modelling possible it was necessary to accurately know the range of densities of the various formational units. Barnes and Hambleton-Jones (1978) have tabled some densities and these are incorporated in Table VII with the 60 density measurements made on samples collected along the three traverses. An inverted density stratification is clearly evident from the results.

TABLE VII : DENSITIES OF THE FORMATIONAL UNITS IN THE DAMARA OROGEN



6.3 Modelling Procedure

The expression derived for the vertical component of the gravitational attraction due to a two-dimensional body of arbitrary shape is based on approximating the body by an irregular polygon in the same way as was done for the magnetic model. Only the coordinates of the polygon's vertices and its density contrast need be specified for the rapid com-

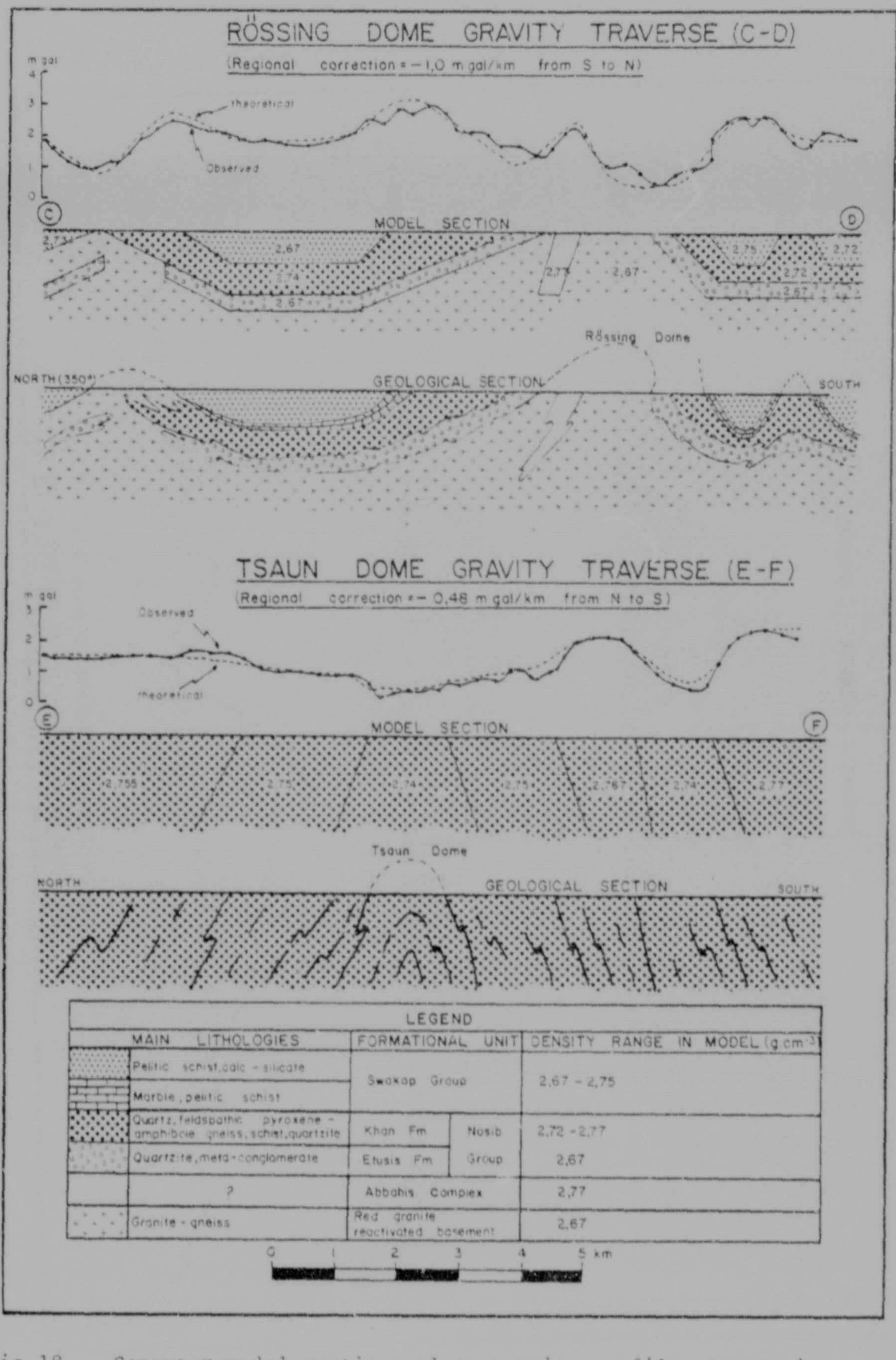


Fig 18 Computer-model sections along gravity profiles traversing the Rössing and Tsaun domes