An Interpretation of the Aeromagnetic Data Covering Portion of the Damara Orogenic Belt, with Special Reference to the Occurrence of Uraniferous Granite

Branko Corner

AN INTERPRETATION OF THE AEROMAGNETIC DATA COVERING PORTION OF THE DAMARA OROGENIC BELT, WITH SPECIAL REFERENCE TO THE OCCURRENCE OF URANIFEROUS GRANITE

Branko Corner

A Thesis submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the Degree of Doctor of Philosophy.

JOHANNESBURG 1982.

ABSTRACT

AN INTERPRETATION OF THE AEROMAGNETIC DATA COVERING PORTION OF THE DAMARA OROGENIC BELT, WITH SPECIAL REFERENCE TO THE OCCURRENCE OF URANIFEROUS GRANITE

CORNER, Branko, Ph.D. University of the Witwatersrand, 1982.

This thesis comprises primarily palaeomagnetic studies within the Damara orogenic belt of South West Africa (Namibia), as well as an interpretation of the regional structure, utilizing published aeromagnetic data. Cursory interpretation of the airborne radiometric data is also undertaken. Gravity traverses, conducted across three dome structures with which uranium mineralisation is intimately associated, are interpreted in order to determine the origin of these structures.

A number of features, having an important bearing on both the uraniferous granite occurrences and the regional structure of the area, are recognised for the first time in this study, viz.:

- all currently known uraniferous alaskitic granite occurrences of economic interest are hallmarked, on a semi-regional basis, by prominent negative magnetic anomalies. The relationship is a stratigraphic one since the palaeomagnetic studies have shown that these negative anomalies arise from a pervasive remagnetisation of the Damara rocks during the 500 Ma tectonothermal event. This remagnetisation is retained in certain rocks of the Nosib Group at stratigraphic levels with which the uraniferous granites are closely associated. The resulting unique negative magnetic signature of the Nosib Group rocks thus constitutes an important prospecting criterion in the search for uranium.

- Virtual geomagnetic poles were derived for the 500 Ma tectonothermal event and for the basement rocks in the area, the pole for the latter indicating an age of 2 150 Ma for these rocks.

- A close correlation exists between positive magnetic anomalies

and high radiometric responses over the red granites, reactivated basement and, to a lesser extent, over the Salem Granite Suite and other late- to post-tectonic granites. This could be a useful relationship, with the application of gamma spectrometry, as an aid to mapping.

- A number of structural lineaments and broader lineament zones are, apart from the Okahandja lineament, identified and named for the first time, i.e.

  - the Uis lineament zone
  - the Omaruru lineament
  - the Welwitschia lineament zone, and the less prominent
  - Wlotzka and Abbabis lineament zones.

  Interactive computer modelling indicates that these geomagnetic lineament zones are in fact fault-controlled geanticlinal ridges bounded by relatively rapid monoclinal downfolding of the stratigraphy.

- A post-F3 (northeast) structural phase, F4, oriented north-northeast is recognised as being a major structural event of particular significance to the emplacement of uraniferous granite.

- The gravity studies indicate that the investigated dome structures result from an interplay between both vertical and lateral stress components. The former component arising from gravitational instability between rocks of the Damara Sequence and basement, and the latter component arising from the lateral stress fields prevailing at the time.

DECLARATION

I declare that this thesis is entire. [illegible] own work aided only in the supervision I received from Dr. D.I. Heathorn and Dr. H.W. Bergh in use of palaeomagnetic laboratory equipment initially and in the form of discussions during the course of the study. The thesis is being submitted for the degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Branko Corner ....B Corner....................

...17.... day of ....August.........., 1982

DEDICATION

Posvećeno mojim roditeljima Oliveri i Carlu Corneru.

Page No.

TABLE OF CONTENTS

PREFACE

This study was conducted by the author during his term of office with the Geology Division of the South African Atomic Energy Board (January 1975 - April 1981). The prime objectives of the study were firstly, to aid uranium exploration programmes in the Damara orogenic belt of South West Africa (Namibia) by establishing any possible magnetic relationships associated with the uraniferous granites in the area and, secondly, to interpret regional structure from the aeromagnetic data. Palaeomagnetic studies were conducted for these purposes and not only greatly assisted in the attainment of these objectives but also provided valuable knowledge regarding the magnetic history of the area.

The author would like to express his sincere gratitude to the several persons and organisations who provided assistance during the course of this study, i.e.

- to the President of the Atomic Energy Board for his permission to publish this thesis,
- to Dr. P D Toens, a special word of thanks for his initial motivation of the project and his continued support throughout the duration thereof,
- to Dr H W Bergh, under whose supervision the study was partially conducted, for his valuable suggestions, guidance and editing of the text,
- to Dr D I Henthorn, a particular word of thanks for his invaluable assistance and guidance with the palaeomagnetic work, and for critically reviewing the text,
- to the Director of the Geological Survey for his permission to utilise the palaeomagnetic laboratory facilities and to publish the data thus obtained,
- to Rössing Uranium Ltd., Gold Fields of S A Ltd., Anglo American Corp. of S A Ltd. and Aquitaine S A Ltd., for their assistance given at all times during the course of the field work and for their permission to publish the palaeomagnetic results,
- to Dr R McG Miller for critically reviewing the text and for his valuable suggestions and guidance with structural and stratigraphic

problems,

- to the numerous Damara geologists for their comments, suggestions and criticisms during the course of the study,
- to Rainer Jakob for conducting the chemical analyses,
- to Johan Retief and Gert Harman for the accurate levelling required for the gravity traverses,
- to my sister Olga for the onerous task of assisting with the colouring-in of the colour composite maps,
- to Elsa le Grange and Sharon Roëbert for the typing of the text and, finally,
- to Benita Els, Beatrix van Niekerk and Irene Pietersen for the draughting of the figures and maps.

Certain of the results of this study, particularly relating to the palaeomagnetic work and structural interpretations, have already been published by the author or are in press (Corner, 1975; Corner and Henthorn, 1978; Jacob, Corner and Brynard, in press; and Corner, in press).

LIST OF FIGURES

Page No

1 INTRODUCTION

1.1 General

The western portion of the Damara orogenic belt in South West Africa was covered in five stages by airborne radiometric and magnetic surveys, flown during the period 1968 to 1976 (under contract to the Geological Survey of South Africa, Windhoek Branch). Although gamma spectrometry remains the most useful method in the search for new uranium deposits, and the above surveys successfully revealed a number of uranium occurrences of economic interest in the area, there are certain limitations. These include secular disequilibrium of the uranium decay series and, in particular, the absorption of gamma radiation by matter. In view of the effect of the latter, use must be made of other techniques to locate any primary occurrences which may be hidden under the cover of aeolian sand and duricrust deposits which are so widespread in the area. In particular, the magnetic and gravity methods remain relatively unaffected by surface cover. Although the uranium minerals themselves are, from an exploration point of view, non-magnetic, it is through their association with magnetic minerals or with rocks of contrasting density that invaluable information may be obtained regarding structural trends and lithologies encountered in depth.

The Geology Division of the Atomic Energy Board thus initiated a study of the aeromagnetic data covering the western portion of the Damara orogenic belt, in order to determine whether any additional information relating to the occurrence of uraniferous granite in the area could be derived from this data. The study included extensive palaeomagnetic surveys and an interpretation of the regional structure using the aeromagnetic data. A geomagnetic section traversing the orogenic belt was interpreted using two-dimensional computer modelling techniques.

A number of accurate gravity traverses were conducted across three dome structures, with which uranium mineralisation is associated.
The main object was to decide whether they were due to interference folding or to diapiric uprise at about the time of emplacement of the uraniferous granites (Jacob et al., in press; Barnes and Hambleton-Jones, 1978; Sawyer, 1978; Jacob, 1974a).

The above studies were undertaken by the author during the period 1975-1980. Two preliminary reports have been written on the early stages of the work (Corner and Henthorn, 1978; Corner, 1975). The results presented in this thesis indicate a hitherto unrecognised association of the economically interesting uraniferous alaskitic granites with a north-northeasterly structural episode and also with certain unique negative geomagnetic anomalies. These conclusions represent a major step forward both in understanding the controls of granitic uranium mineralisation in the area and in the identification of possible exploration targets.

1.2 Physiography and Location of the Area

The area studied lies in the central coastal region of South West Africa between the Atlantic coastline and 16°30'E longitude, and between latitudes 21°S and 23°30'S (Fig 1). Towns and settlements include Omaruru, Karibib, Usakos, Uis, and on the coast, Henties Bay, Swakopmund and the Walvis Bay enclave of the Republic of South Africa.

Climatically, the area includes part of the Namib Desert which stretches up to 100 km inland at its widest point. The prevailing winds are westerly in the summer months and easterly during the winter, resulting in dry and at times extremely dusty conditions, with rather large variations in temperature and humidity. Precipitation is infrequent, averaging about 28 mm per annum, and decreases towards the coast to roughly 20 mm per annum. Rainfall of short duration and light intensity may, however, occur. The desert is, for a large part of the year, fog bound which provides about 130 mm of equivalent rainfall per annum and results in a wide variation in humidity of between 5 and 80 percent. Temperatures range between 4,5°C and 40°C on average.

Communications are good and all the towns are served by good tar, gravel or salt roads. Walvis Bay is the main industrial centre and harbour and is also served by a railway line from the interior.

Major rivers draining the area and hinterland include the Omaruru, Khan, Swakop and Kuiseb Rivers which are dry although subsurface flow does occur.

The above studies were undertaken by the author during the period 1975-1980. Two preliminary reports have been written on the early stages of the work (Corner and Henthorn, 1978; Corner, 1975). The results presented in this thesis indicate a hitherto unrecognised association of the economically interesting uraniferous alaskitic granites with a north-northeasterly structural episode and also with certain unique negative geomagnetic anomalies. These conclusions represent a major step forward both in understanding the controls of granitic uranium mineralisation in the area and in the identification of possible exploration targets.

1.2 Physiography and Location of the Area

The area studied lies in the central coastal region of South West Africa between the Atlantic coastline and 16°30'E longitude, and between latitudes 21°S and 23°30'S (Fig 1). Towns and settlements include Omaruru, Karibib, Usakos, Uis, and on the coast, Henties Bay, Swakopmund and the Walvis Bay enclave of the Republic of South Africa.

Climatically, the area includes part of the Namib Desert which stretches up to 100 km inland at its widest point. The prevailing winds are westerly in the summer months and easterly during the winter, resulting in dry and at times extremely dusty conditions, with rather large variations in temperature and humidity. Precipitation is infrequent, averaging about 28 mm per annum, and decreases towards the coast to roughly 20 mm per annum. Rainfall of short duration and light intensity may, however, occur. The desert is, for a large part of the year, fog bound which provides about 130 mm of equivalent rainfall per annum and results in a wide variation in humidity of between 5 and 80 percent. Temperatures range between 4,5°C and 40°C on average.

Communications are good and all the towns are served by good tar, gravel or salt roads. Walvis Bay is the main industrial centre and harbour and is also served by a railway line from the interior.

Major rivers draining the area and hinterland include the Omaruru, Khan, Swakop and Kuiseb Rivers which are dry although subsurface flow does occur.

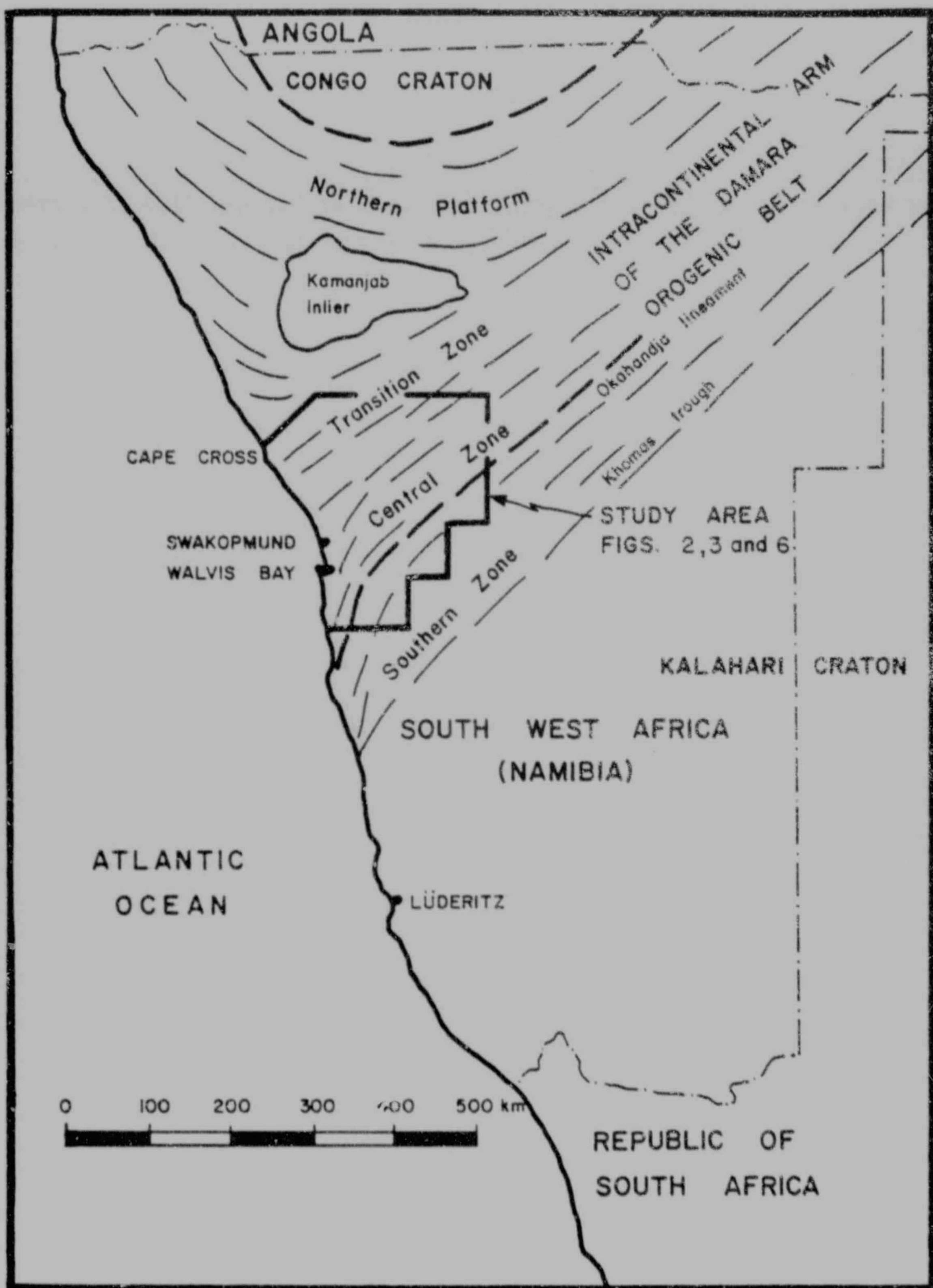

Fig 1 Locality map of the study area

Flash floods are not uncommon during periods of heavy rainfall inland. The southern portion of the area falls within the Namib Desert Park which contains some game, such as oryx, springbuck, zebra and ostrich, towards the fringe of the desert. A desert plant, the Welwitschia Mirabilis, is unique to the area.

Bedrock is well exposed in the river valleys but is largely covered by aeolian sand, scree and duricrust deposits in the intervening plains. South of the Kuiseb River, and between Walvis Bay and Swakopmund along the coast, the region is almost entirely blanketed by aeolian sand, giving rise to spectacular north-trending longitudinal dunes which attain heights of up to 400 m.

2 GEOLOGICAL SETTING

It is necessary to review the geological setting of the area with regard to those aspects pertinent to the present study, viz.: tectonism, stratigraphy, structure, metamorphism and nature of the uranium mineralisation. Since a full discussion is beyond the scope of this text, this review, after Jacob, Corner and Brynard (in press), is intentionally brief.

2.1 Regional Tectonic Setting

The Damara metamorphic belt of South West Africa belongs to a late-Precambrian, early-Palaeozoic Pan-African mobile belt system that surrounds and transects the African continent (Kröner, 1977; Martin and Porada, 1977). It consists of two branches, viz.: a coastal branch extending in a northerly direction along the Atlantic coast, and an intracontinental branch, roughly 400 km in width, trending northeast between the Congo and Kalahari cratons (Fig 1). The coastal branch extends as far north as the Congo and has not been extensively studied.

Martin (1965) subdivided the intracontinental branch into a northern miogeosyncline and a southern eugeosyncline, partly separated by a geanticlinal basement inlier, termed the Kamanjab Inlier. In view, however, of the paucity of volcanic rocks and the existence over large areas of shallow-water sediments, Blaine (1977) regards only the Khomas trough in the extreme south as an eugeosyncline, the remaining area to the north being the miogeosyncline.

Martin and Porada (1977) recognised four main structural domains in the intracontinental branch, viz.:

- a northern platform consisting of weakly folded mainly carbonate rocks;
- a transition zone to the south of the northern platform, where the intensity of folding and metamorphism increase southwards;
- a central zone, characterised by medium to high grades of metamorphism and voluminous granitic intrusions;
- a southern zone containing the Khomas trough which consists of a flysch-like sequence of mica schists, quartzites and minor mafic metavolcanic rocks (e.g. the Matchless belt).

The southern zone is separated from the central zone by a pronounced change in structural style, first described as major shear zone by Gevers (1963). The term 'Okahandja lineament' is now being widely used for this feature (Miller, 1979; Blaine, 1977; Martin and Porada, 1977; Sawyer, 1978). According to Miller, the Okahandja lineament, which also has a marked aeromagnetic expression (see Fig 3 with overlay, and Fig 17), represents the locus of considerable uplift of the central zone relative to the Khomas trough, possibly by 24 km.

The Damara belt is asymmetric with respect to the distribution of sediment types, metamorphism and structure. Although a flysch-like sequence of sediments similar to that of the Khomas trough does occur north of the central zone it is not as thickly developed. In addition, the Okahandja lineament separates the essentially linear structural features of the southern zone from the dome-and-basin structural pattern to the north. Explanations of the asymmetry differ according to the geodynamic model proposed for the formation of the belt. Martin and Porada (1977) suggest an ensialic, multiple aulacogen model, whereas Blaine (1977) and Sawyer (1978) propose a plate-tectonic, continental-collision origin. The results of the computer-model study (described in detail in Section 5.2), are consistent with the former proposal.

The area included in the present study lies in the southwestern portion of the intracontinental branch and covers the southern portion of the transition zone, the central zone, and portion of the southern zone (Fig 1).

2.2 Stratigraphy

Stratigraphic classification and nomenclature have undergone a number of changes in recent years. The latest proposals of the South African Committee for Stratigraphy (1980), are used throughout this text and are given in Table 1. A generalised geological map of the area showing the main formational units is given in Fig 2.

The oldest rocks in the central zone belong to the Proterozoic Abbabis Metamorphic Complex, and crop out in numerous anticlinal structures as mantled gneiss domes along a broad northeast-trending zone, termed the

TABLE 1 : LITHOSTRATIGRAPHY OF THE DAMARA SEQUENCE AND ABBABIS METAMORPHIC COMPLEX IN THE KARIBIB AND SWAKOPMUND DISTRICTS

Group	Subgroup	Formation	Lithology	Maximum thick-ness (m)	Age (Ma)
		Kuiseb	Biotite-rich quartzo-felaspathic schist, biotite-garnet-cordierite schist, minor amphibole-schist, quartzite, calc-silicate rock and marble; basal graphitic schist with cal-silicate lenses (Tinkas Member).	3 000	429-517 (K-Ar, biotite)
SWAKOP	Khomas	Karibib	Marble, biotite schist, quartz schist, calc-silicate rock.	700	
		Chuos	Mixtite, pebble- and boulder-bearing schist, minor quartzite.	700	
	DISCORDANCE				
	Ugab	Rössing	Very variable: marble, quartzite, conglomerate, biotite schist, biotite-cordierite schist and gneiss, aluminous gneiss biotite-hornblende schist, calc-silicate rock.	200	
UNCONFORMITY OR CONFORMABLE TRANSITION					
		Khan	Pyroxene-amphibole feld-spathic quartzite, amphi-bole-pyroxene gneiss, amphibole and biotite schist.	1 100	665±34 (Rb-Sr whole rock)
NOSIB		Etusis	Pinkish well-bedded feld-spathic quartzite, arkose, conglomerate, quartzo-feldspathic gneiss; minor biotite schist, marble, amphibolite, metarhyolite and calc-silicate rock.	3 500	
MAJOR UNCONFORMITY					
ABBABIS METAMORPHIC COMPLEX			Gneissic granite, augen gneiss, quartzofeldspathic gneiss, pelitic schist and gneiss, migmatite, quartzite, marble, calc-silicate rock, amphibolite		1 925 ± 300 (U-Pb, zircon from granite)

Abbabis swell by Gevers (1963) and corresponding to southern portion of the central zone of Martin and Porada (1977). It has been dated at 1 925 ± 300 Ma (Jacob et al., 1978). The complex comprises mainly gneissic granites, granitic gneisses, paragneisses, and includes minor amounts of metasediment.

The Abbabis Metamorphic Complex is overlain unconformably by rocks of the Damara Sequence whose sedimentation began about 900 to 1000 Ma ago (Martin and Porada, 1977). The sequence consists of a lower, psammitic Nosib Group overlain by a calcareous-pelitic Swakop Group.

The Etusis Formation of the Nosib Group has a wide-spread distribution north of the Okahandja lineament. It was deposited in local basins on a topographically uneven Abbabis surface and its thickness varies considerably over short distances. The Etusis rocks are mainly metamorphosed fluviatile quartzites, conglomerates and other psammitic sediments. Felsic metavolcanic rocks are present in places near the Okahandja lineament.

The Etusis rocks grade upwards and laterally into the Khan Formation, whose outcrop occupies a much smaller area. It consists of banded and locally migmatitic quartzofeldspathic amphibole-clinopyroxene gneisses and represents a change in sedimentation to more calcareous sediments and reduced clastic input. Towards the top, amphibole-biotite schists are developed locally. In many places this formation appears to be a preferred locus of emplacement of the uraniferous alaskitic granites.

The Rössing Formation forms the lowest unit of the Swakop Group and this overlies older rocks paraconformably and disconformably. Its distribution is more restricted than that of the Khan Formation. It is characterised by great lithological hereogeneity both vertically and laterally, and consists of marbles, calc-silicate gneisses, pelitic schists and gneisses, quartzites and conglomerates. Sulphides are commonly present and weathered outcrops frequently exhibit a deep red-brown colour.

The Rössing Formation is discordantly overlain by the Chuos Formation, the lowest member of the Khomas Subgroup. It is regarded as being of either glacial-marine or mass-flow origin. The formation consists of boulders in a semi-pelitic to pelitic matrix, schists and ferruginous quartzites, and it constitutes a most important marker horizon. Where present, it allows the separation and recognition of the Rössing and Karibib Formations.

The overlying and partially conformable Karibib Formation consists of local basal schists followed by variable thicknesses of marble and calc-silicate rock. The formation is widespread in the central zone and it constitutes a good marker horizon since thickness variations are not as abrupt as in underlying formations. The formation represents a period of carbonate sedimentation on a more or less planar surface of wide extent. Over most of the central zone the marbles of the Karibib Formation are conformably overlain by pelites of the Kuiseb Formation. The top of the formation is nowhere exposed but it is at least several thousand metres thick. Its thickest development is possibly in the Khomas trough of the southern zone. In the central zone it comprises pelitic schists (locally migmatitic) and gneisses. Its position is taken up in many places by members of the Salem Granite Suite.

Sediments and basalts of the Karoo Sequence crop out north of 22^{o}S latitude and are intruded by intra- and post-Karoo acid, alkaline and basic rocks which form the Spitzkoppe, Cape Cross, Messum, Brandberg and Erongo Complexes. Karoo dolerites are common throughout the belt.

Large portions of the area are covered by Tertiary to Recent superficial sand, scree and duricrust deposits such as calcrete and gypcrete.

2.3 Granitic Rocks

Extensive granite intrusion has taken place and numerous phases of syntectonic, late-tectonic and post-tectonic gneissic granite and granite have been recognised.

Foliated or homogeneous red granites, leucogranites and pegmatitic granites varying in age from syn- to post-tectonic are found either below or at the level of the Etusis Formation but some intrude to higher levels. Preliminary dating of the suite yields ages between 950 and 550 Ma (unpublished data, Dr A J Burger), the oldest of which may represent partial resetting of basement ages as a result of Damaran metamorphism. These granites constitute, in part, the Red Granite Gneiss Suite of Jacob (1974a). However, most of the members of this Suite are currently considered to be products of basement reactivation through anatectic processes (Jacob, 1978), and geochemical evidence supports this (Bunting, 1977). Assimilation of Nosib Group rocks has in places contributed to the heterogeneity of the Suite. The distinction between these rocks and the basement granite-gneiss is not always clear and many outcrops previously mapped as red granite-gneiss in fact belong to the basement. For this reason the term Red Granite Gneiss Suite has been disbanded (Miller, personal communication). Fractionation during crystallisation of the red granites and leucogranites of the Damaran episode yielded K-rich melts, enriched in volatiles and uranium-ore constituents, which finally crystallised as alaskitic pegmatitic granite and pegmatite.

Rocks of the Salem Granite Suite crop out over a wide area in the transition and central zones and comprise a number of granitic rocks that have intruded over an extended period. The suite in most places is concordantly emplaced into synclinal structures and normally occupies volume previously taken up by the Kuiseb Formation. The majority of the suite comprises porphyritic biotite granodiorite/adamellite. Early members are strongly foliated and are pre-tectonic and syntectonic (Jacob, 1974a; Sawyer, 1978) whereas later members appear undeformed and are post-tectonic. The origin of the Salem Suite has been ascribed to granitisation *in situ* (Smith, 1965), anatectic melting of the Kuiseb Formation (Miller, 1973) and intrusion from considerable depth (Miller, *et al.*, in prep.).

Other late- to post-tectonic intrusive granites, which occur as irregular stocks or anastomosing veins, include the Bloedkoppie, Achas, Gawib and Donkerhuk Granites, the latter being emplaced along and immediately south of the Okahandja lineament.

2.4 Structure

Several phases of deformation can be recognised in the central zone and are indicated by fold interference patterns such as that of the Rössing mountain structure (Smith, 1965). The main structural grain is north-east and is due to a strong (F3) deformation. This was preceded by one or possibly two periods of folding. The early phases of folding produced overturned and recumbent structures and were accompanied by thrusting and shearing. Several investigators agree that the trend of early fold axial planes was roughly northwesterly (Smith, 1965; Roering, 1961; Bunting, 1977; Blaine, 1977; Sawyer, 1978). The later northeasterly F3 folds are upright but become overturned to the southeast as the Okahandja lineament is approached.

The basement (Abbabis Metamorphic Complex) has been deformed by ductile shearing in lower metamorphic grade areas and has been folded in higher grade zones.

A number of later, less intense fold phases occurred after F3 and produced folds oriented between northeast and northwest. The significance of a post-F3 phase, F4, oriented north-northeast, with respect to the emplacement of the uraniferous granites is recognised for the first time in this study and is discussed more fully in Section 5. (This F4 direction supercedes the F4 nomenclature utilized by Jacob, 1974a (Jacob et al., in press)).

The Okahandja lineament separates the essentially linear structures of the southern zone from the dome-and-basin structures which are a feature of the central zone. The origin of the domes is controversial with some authors (Smith, 1965, and Bunting, 1977) ascribing them to interference folding while others (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. Gravity traverses were conducted as part of this study across three of the dome structures in order to obtain a better understanding of their origin, particularly since the relatively less dense uraniferous alaskitic granites are mostly associated with such structures. The results are discussed fully in Section 6.

Interpretation of the aeromagnetic data has revealed a number of hitherto unrecognised structural lineaments which have an important bearing both on the emplacement of the uraniferous alaskitic granites and on the geodynamic processes involved in the formation of the belt. (See Section 5 for discussion).

2.5 Metamorphism

University of Göttingen workers have delineated isograds over a large area of the intracontinental branch (Hoffer, 1977), which indicate that the metamorphic grade is highest in the central zone and increases along the axis of the belt in the direction of the Atlantic coast. Higher pressures and lower temperatures distinguish the metamorphism of the southern zone from that of the central zone, where high temperatures (750°C) and lower pressures (about 4×10^5 kPa) prevailed (Sawyer, 1978). Medium- and high-grade metamorphism characterise the central zone and migmatitic phenomena are present (Jacob, 1974a; Bunting, 1977; Sawyer, 1978).

Recent results indicate that more than one pulse of metamorphism occurred (Kröner et al., 1978; Sawyer, 1978). An early metamorphism, with a possible age of 665 ± 34 Ma (Kröner et al., 1978) predated widespread granite intrusion, produced migmatites, and accompanied the early periods of deformation. According to Sawyer (1978), this was followed by another period of metamorphism accompanying the F3 deformation, and was in turn followed by intrusion of various granitic rocks whose ages are in the order of 550 Ma.

A late- to post-tectonic thermal event, around 470 Ma, is indicated by Rb/Sr dating of gneisses of the Khan Formation and the Rössing Mine alaskite (Kröner et al., 1978), and it is possible that K/Ar biotite ages of 520-450 Ma (Haack and Hoffer, 1976) also reflect this event. Since the 470 Ma uraniferous alaskites are intimately related to F4 structural deformation it may be concluded that the F4 episode is of this age (520-470 Ma)i.e. it was the last clearly recognisable episode of regional structural deformation associated with the Damara Orogeny.

2.6 Uranium Mineralisation

The radioactive mineralisation in the area has been discussed by numerous workers including Jacob et al. (in press), Jacob (1974b), von Backström (1970) and Smith (1965). The uranium occurs chiefly within two lithological regimes, viz., in granitic rocks and in calcareous and gypsiferous duricrustal deposits.

The Salem Granite Suite and (especially) the red granites contain anomalous, but essentially non-economic, quantities of uranium, mostly in association with thorium. Economically interesting uranium mineralisation occurs, however, in the late-phase alaskitic granite differentiates of the red granites.

Numerous uraniferous occurrences have been found in this environment, the localities of which are indicated in Fig 2. In particular, the Rössing deposit is of this type (von Backström, 1970; Berning et al., 1976). The uraniferous alaskitic granite occurs preferentially in and around anticlinal and dome structures and intrudes into the basement and into the Nosib and lower Swakop Groups, mainly below the prominent marbles of the Karibib Formation. Certain of these stratigraphic units, such as the Khan and Rössing Formations appear to be favoured hosts. The concentration of the mineralised bodies below the Karibib Formation is due partly to the structural trapping effect of the marble bands, partly to water saturation at this level and partly to chemical effects such as assimilation, the precipitating effect of iron-sulphide-bearing schists and reductants such as graphite (Jacob, 1974b). Jacob et al., (in press), believe that the alaskitic melts were derived through partial melting of the Abbabis basement and, to a certain extent, also of the Etusis Formation, during high-grade Damaran metamorphism. During anatexis the incompatible elements, particularly uranium, were incorporated into the melts which then rose, in an attempt to attain gravitational equilibrium. The various levels to which these melts rose were determined by the depth of origin of the melts, on their water content and on the availability of tensional environments. Fractional crystallisation during ascent and increased water content concentrated the uranium into residual melts which finally crystallised as alaskitic pegmatitic granite.

Numerous sporadic occurrences of secondary uranium mineralisation (chiefly carnotite) occur in Tertiary to Recent calcareous and gypsiferous palaeodrainage sediments as a result of supergene groundwater activity. The Langer Heinrich deposit is the best example of such mineralisation.

The Damara belt is thus a uranium province providing a good example of multi-cyclic processes of ore formation. Initial concentrations in basement and Nosib rocks have led, through ultrametamorphism and fractionation to uraniferous granites, followed by partial secondary enrichment. These uraniferous granites in turn have acted as sources of carnotite mineralisation in overlying superficial calcareous and gypsiferous sediments of Cainozoic age (von Backström & Jacob, 1979; Hambleton-Jones et al., in press).

Numerous uraniferous occurrences have been found in this environment, the localities of which are indicated in Fig 2. In particular, the Rössing deposit is of this type (von Backström, 1970; Berning et al., 1976). The uraniferous alaskitic granite occurs preferentially in and around anticlinal and dome structures and intrudes into the basement and into the Nosib and lower Swakop Groups, mainly below the prominent marbles of the Karibib Formation. Certain of these stratigraphic units, such as the Khan and Rössing Formations appear to be favoured hosts. The concentration of the mineralised bodies below the Karibib Formation is due partly to the structural trapping effect of the marble bands, partly to water saturation at this level and partly to chemical effects such as assimilation, the precipitating effect of iron-sulphide-bearing schists and reductants such as graphite (Jacob, 1974b). Jacob et al., (in press), believe that the alaskitic melts were derived through partial melting of the Abbabis basement and, to a certain extent, also of the Etusis Formation, during high-grade Damaran metamorphism. During anatexis the incompatible elements, particularly uranium, were incorporated into the melts which then rose, in an attempt to attain gravitational equilibrium. The various levels to which these melts rose were determined by the depth of origin of the melts, on their water content and on the availability of tensional environments. Fractional crystallisation during ascent and increased water content concentrated the uranium into residual melts which finally crystallised as alaskitic pegmatitic granite.

Numerous sporadic occurrences of secondary uranium mineralisation (chiefly carnotite) occur in Tertiary to Recent calcareous and gypsiferous palaeodrainage sediments as a result of supergene groundwater activity. The Langer Heinrich deposit is the best example of such mineralisation.

The Damara belt is thus a uranium province providing a good example of multi-cyclic processes of ore formation. Initial concentrations in basement and Nosib rocks have led, through ultrametamorphism and fractionation to uraniferous granites, followed by partial secondary enrichment. These uraniferous granites in turn have acted as sources of carnotite mineralisation in overlying superficial calcareous and gypsiferous sediments of Cainozoic age (von Backström & Jacob, 1979; Hambleton-Jones et al., in press).