Uranium

by H Roesener and CP Schreuder

1. Introduction

The upswing in the uranium market in the 1970s led to extensive uranium exploration in Namibia. Several airborne radiometric surveys were conducted by the Geological Survey during this period and several uranium deposits were located. These are grouped into three basic types: a) occurrences in and associated with plutonic rocks, b) pedogenic occurrences and c)sedimentary occurrences. An overlap exists between the pedogenic and the other main deposit types.

Uranium occurrences in and associated with plutonic rocks comprise both potentially economic deposits and source rocks for uranium deposits in pedogenic and sedimentary sequences. These deposits are confined mainly to the western portion of the Damara Orogen (Fig. 1), which contains the only currently

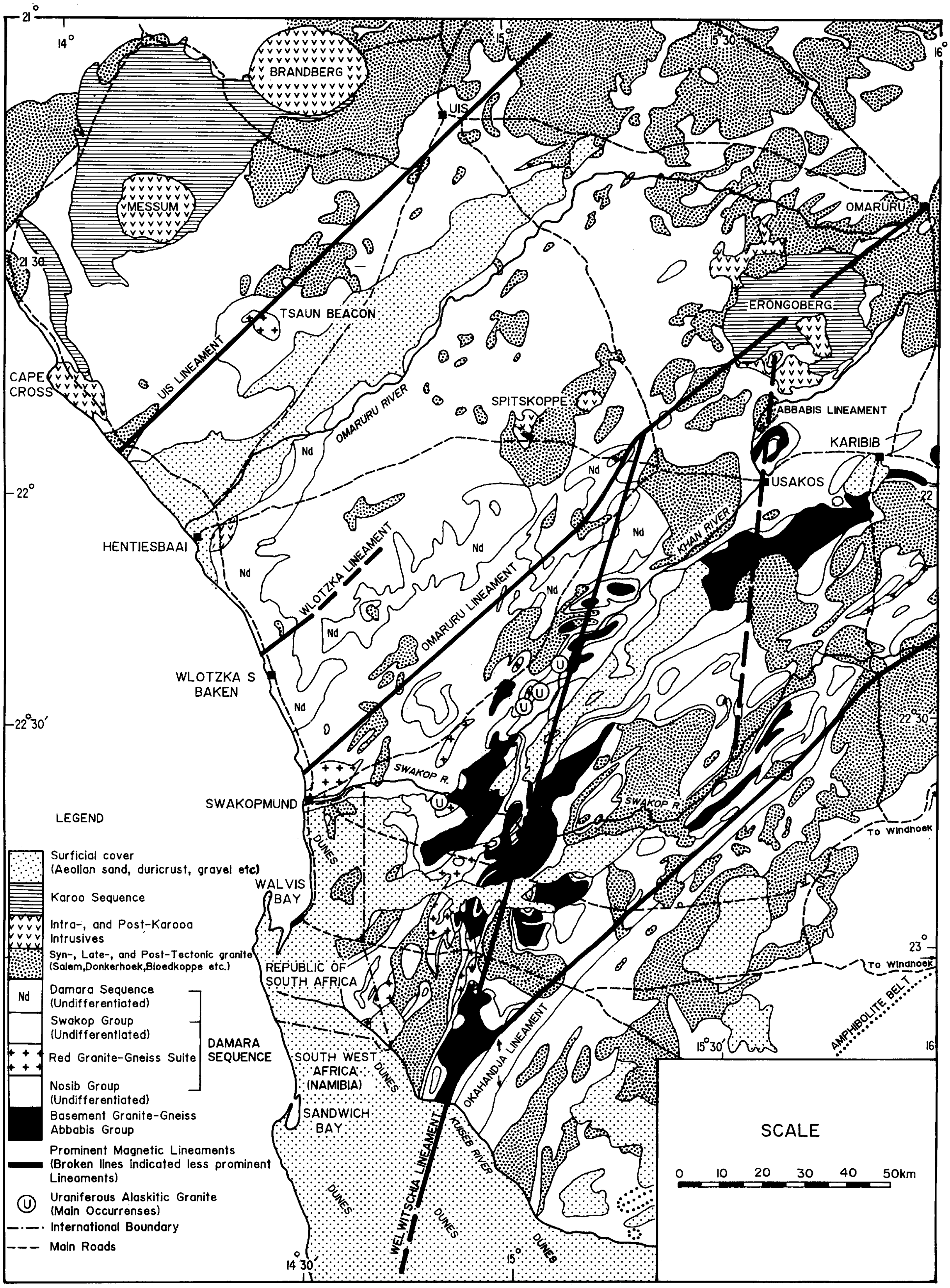

Figure 1: The Damara Orogenic Belt: Generalised geology of the western portion (after Jacob et al, 1986)

operating uranium mine at Rössing.

In the southern part of Namibia, a number of uranium- and thorium-bearing granite bodies of relatively low tenor are developed in the Namaqua Mobile Belt (Jacob, et al., 1986)

2. Occurrences in and associated with plutonic rocks

The uraniferous granite occurrences discovered so far are situated in the Central Zone of the Damara Orogen between the Omaruru and Okahandja Lineaments (see Table 1 for generalized stratigraphy of the Central Zone). The Central Zone exhibits dome-and-basin patterns where extensive granite emplacement is associated with the domes. Several phases of deformation can be recognised in the Central Zone and are indicated by fold interference patterns. The main structural grain is northeast trending and is due to an intense F3 deformation period. 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. The early fold axial planes were roughly northwesterly trending. A number of less intense phases of folding occurred after F3 and produced folds oriented in northeast and northwest directions. Uraniferous granites were emplaced post-F3 and are oriented north-northeast, which direction manifests itself in the prominent north-northeasterly trending magnetic Welwitschia lineament. Corner (1982) considered this north-northeasterly structural direction to have an important bearing on the emplacement of the uraniferous alaskitic granites since firstly, the currently known occurrences are located either in the vicinity of or to the west of the Welwitschia Lineament and, secondly, the major fold axes of the domes and structures with which these occurrences are associated, are parallel to this lineament rather than to the general northeasterly trend of the Central Zone.

The-dome-and basin structures are a feature of the Central Zone, but their origin remains controversial. Smith (1965) and Bunting (1977) ascribed them to interference folding, whereas Jacob believes that they have formed as a result of diapiric uprising at about the time of and following the F3 deformation. The domes result from an interplay of both these components. The correlation of the direction of the major axes of the domes with which the uraniferous granites are associated with the north-northeasterly F4 structural direction, supports the inference of a strong measure of structural control in the formation of these domes.

Between 660 and 460 million years ago, the Central Zone was subjected to polyphase deformation accompanied by the intrusion of pre-tectonic, syn-tectonic and post-tectonic granites. The granites where classified by Marlow (1983) into four main types; syn-to post-tectonic Salem-type granites, red granites, late-to post-tectonic leucogranites and alaskites.

In the Central Zone the peak temperature of metamorphism was estimated to increase from 555^o C at Karibib to 645 ^{o} C southwest of Swakopmund. The pressure of metamorphism was estimated to be 2.6 kbar northeast of the confluence of the Khan and Swakop Rivers and 3.4 kbar near Swakopmund.

The Salem granites constitute a suite of different generations of granodiorites, granites and adamellites with an age of 601±79 million years and are the most abundant granitic type. These granites, which are typically batholitic in form, occur well below the level of the Karibib Formation.

The red granites, with an age of 516±23 million years, also occur below the level of the Karibib Formation and were considered by Smith (1965) to be confined to anticlinal and dome structures in the area around the Khan and Swakop Rivers. They occur as domes, which can range up to 15 km across, as dykes throughout the Central Zone and as lit-par-lit intrusions southwest of Usakos.

The leucogranites, typified by the Donkerhuk and Bloedkoppie granites, have an age of 484±25 million years and occur mainly as large batholiths, but diapirs and small plugs are not uncommon.

Alaskites range in age between 458±8 million years at Rössing to 542±33 million years in the Swakop River. They are confined to the areas of highest metamorphic grade. They are fine- to coarse-grained or pegmatitic granites, characterised by their high alkali content and extremely leucocratic nature, as well as their anastomosing and vein-like style of intrusion. They commonly display sharp contacts with the rocks which they intrude. They occur preferentially in and around anticlinal dome structures and intrude into the basement, the Nosib and lower Swakop Groups.

2.1 Alaskites

2.1.1 The Rössing Deposit

The Rössing Mine is located approximately 70 km northeast of Swakopmund in the Namib Desert. Although the presence of radioactive minerals in the area has been known since 1910, it was only in 1956 that serious but limited prospecting was done on a radioactive anomaly known as SJ. In 1966 Rio Tinto South Africa commenced an intensive programme of underground bulk sampling and pilot plant test work, which was completed in March 1973. This investigation indicated the existence of a very large, low-grade deposit of uranium that could be mined by open-pit methods and also showed that the uranium could be recovered by means of conventional metallurgical processes.

The Rössing uranium deposit occurs in a migmatite zone in which uraniferous alaskitic granite/pegmatite and metamorphosed country rock show concordant, discordant and gradational relationships. The country rock comprises deformed metasedimentary rocks of the Khan and Rössing Formations (Table 1), whereas the alaskitic rocks range from small quartzo-feldspathic lenses of secretion origin, to large intrusive and replacement bodies varying widely in texture, size and emplacement habit.

A prominent band of feldspathic metaquartzite of the Etusis Formation encircles the intensely granitized core (Abbabis Complex) which forms a domal structure lying to the north of the uranium deposit (Fig. 2). Despite the high degree of recrystallisation and metamorphism, small-scale cross-bedding structures are well preserved throughout this unit. A thick unit of biotite gneiss constitutes an outer rock shell surrounding the dome. The gneiss is migmatised along the planes of gneissosity and also intruded by large amounts of late to post-kinematic uraniferous alaskite.

In the Khan Formation, clinopyroxene and hornblende are the main dark minerals present, whereas biotite is predominant in the gneisses of the Etusis Formation. The Khan Formation can be divided into four units of which the lower pyroxene-hornblende gneiss is favoured as a site for the emplacement of numerous veins and dykes of alaskite, usually parallel to the foliation though also transgressing it at various angles.

An interbedding of pyroxene-garnet gneiss between the upper and lower pyroxene-hornblende gneiss units shows metamorphic banding in the area east of the deposit, but has a massive and mottled appearance to the west. This unit carries discontinuous massive bodies and lenses of amphibolite that are exposed in the northwestern prong of the uranium deposit.

In the upper pyroxene-hornblende gneiss the amount of amphibole increases at the expense of clinopyroxene. The gneiss has a banded appearance caused by the orientation of the migmatization products parallel to the foliation. The contact with the underlying gneiss is gradational and pebble bands of limited lateral extent are present locally.

Six units have been recognised in the Rössing Formation, comprising a basal, impure serpentinitic and graphitic marble overlain in turn by biotite-cordierite gneiss, conglomerate, marble, biotite-cordierite gneiss and feldspathic quartzite. The conglomerate serves as a useful marker horizon, although it grades into a gritty arkose to the east.

Metasedimentary strata of the overlying Chuos, Karibib and Kuiseb Formations occur well to the south of the Rössing deposit. The Chuos mixtite has a grey, massive to schistose matrix containing unsorted, elongated, angular erratics measuring up to one metre in diameter. It is overlain by the Karibib Formation, comprising a succession of white to bluish grey, well-bedded marble units containing thin

Table 1: Stratigraphic column of the Damara Orogen (after Jacob et al., 1986).

Group	Subgroup	Formation	Max thickness	Lithology
Swakop	Khomas	Kuiseb	>3000	Pelitic and semi-pelitic schist and gneiss, migmatite, calc-silicate rock, quartzite. Tinkas member: Pelitic and semi-pelitic schist, calc-silicate rock, marble, para-amphibolite.
		Karibib	1000	Marble, calc-silicate rock, pelitic and semi-pelitic schist and gneiss, biotite amphibolite schist, quartz schist, migmatite.
		Chuos	700	Diamictite, clac-silicate rock, pebbly schist, quartzite, ferruginous quartzite, migmatite.
	Discordance			
	Ugab	Rossing	200	Marble, pelitic schist and gneiss, biotite-horneblende schist, migmatite, calc-silicate rock, quartzite, metaconglomerate.
	Discordance			
Nosib		Khan	1100	Migmatite, banded and mottled quartzofelds-pathic clinopyroxene-amphibolite gneiss, horneblende-biotite schist, biotite schist and gneiss, migmatite, pyroxene-garnet gneiss, amphibolite, quartzite, metaconglomerate.
		Etusis	3000	Quartzite, metaconglomerate, pelitic and semi-pelitic schist and gneiss, migmatite, quartzo-feldspathic clinopyroxene-amphibolite gneiss, calc-silicate rock, metaphyolite.
Major unconformity				
Abbabis Complex				Gneissic granite, augen gneiss, quartzofelds-pathic gneiss, pelitic schist and gneiss, migmatite, quartzite, marble, calc-silicate rock, amphibolite.

interbeds of quartzose calc-silicate. The Karibib Formation is overlain by the biotite-cordierite-sillimanite schists of the Kuiseb Formation containing numerous pegmatitic dykes and veins.

Contact metamorphic effects are evident in metasedimentary rocks adjoining the alaskitic intrusives. These are insignificant in the gneisses of the Khan Formation, but in the biotite-cordierite schists and gneissses of the Rössing Formation feldspar blastesis is present along contacts that are predominantly gradational. The most marked effects are evident where the pegmatitic alaskites have invaded the marbles of the Rössing Formation. Nash (1971) reported

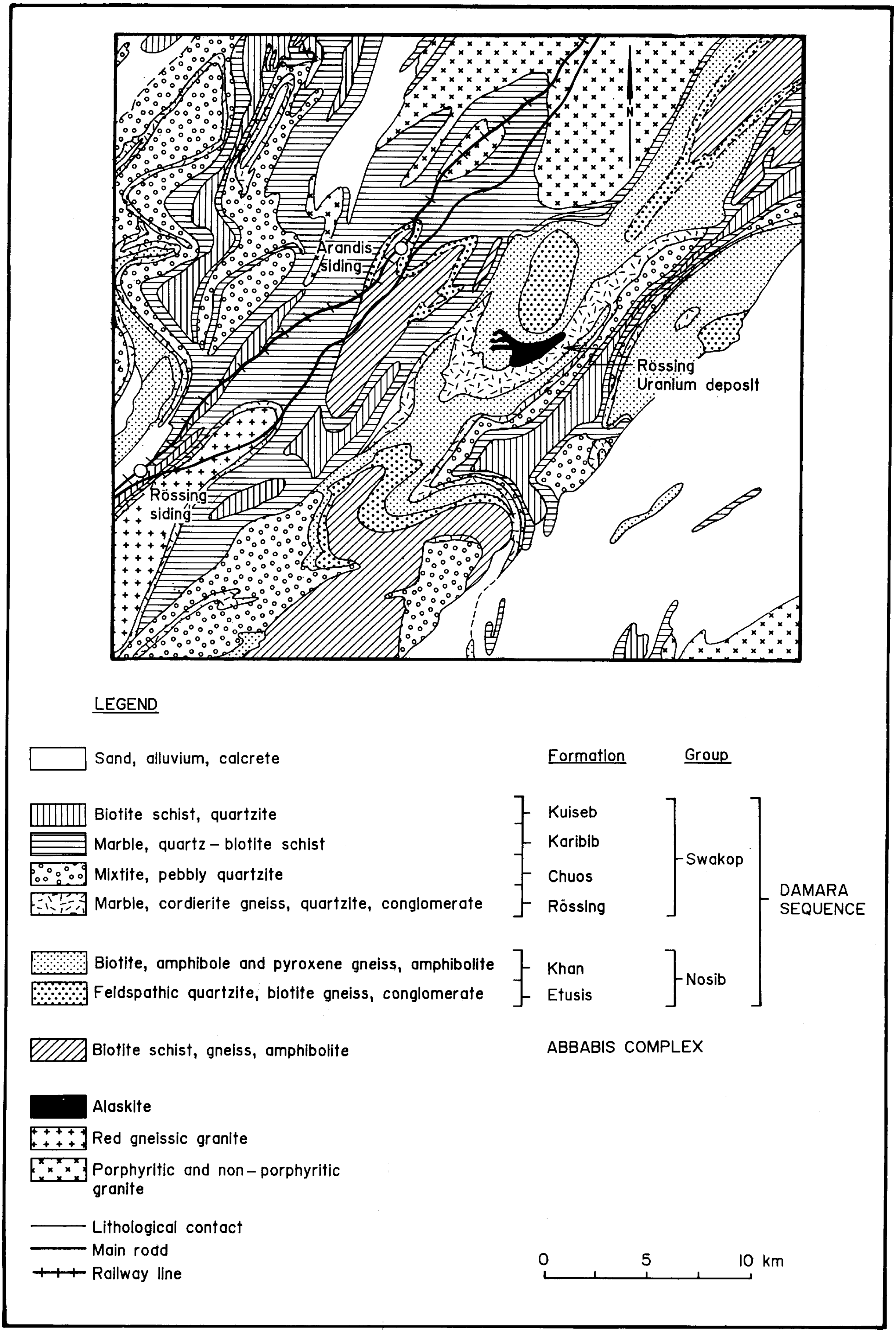

Figure 2: Geological map showing the setting of the Rossing uranium deposit (after Berning, 1986).

that: “skarn bodies, ranging in size from a few centimetres to several metres are widespread, the majority being composed of coarse aggregates of pale green clinopyroxene, brown calcic garnet and varying amounts of scapolite. Although generally hornfelsic, the rocks may contain individual growths of pyroxene and garnet up to several centimetres in size”.

The Rössing uraniferous body is situated along the northern limb of a complex synclinorium developed between the domal structure (Fig. 2) and the Khan Formation metasedimentary rocks present about 2.5 km further south. Three different structural trends are recognisable on a regional scale, but tight vertical or slightly overturned F2 folds striking northeast - southwest are the most prominent feature of the regional structure. Vertical oblique-slip faults, with horizontal displacements ranging from a few centimetres to more than 50 m, occur in the region of the domal structure and are most prolific in the core of the “mine”synclinorium. They are younger than both the F2 folds and the alaskites, but older than dolerite dykes of Karoo age.

The uranium-bearing syntectite of the Rössing deposit has been termed “pegmatite” by Smith (1965), “potash granite” by Nash (1971) and “alaskite” by the staff of the Rio Tinto Exploration Company.

The biotite gneiss of the Etusis Formation and the rocks of the Khan and Rössing Formations are the favoured host rock of the alaskite, regardless of whether it is mineralised or barren, whereas the feldspathic metaquartzites at the base of the Etusis Formation are essentially free of alaskite.

The alaskite occurs as narrow dykes concordant or discordant to large irregular bodies that transgress the foliation or banding of the country rock. In the northern sector of the ore body the alaskite is present in the lower and upper pyroxene-hornblende gneiss and forms regular dykes that have been emplaced parallel to the regional bedding and metamorphic foliation of the metasediments (Fig. 3). The alaskite present in the less-banded pyroxene-garnet gneiss and amphibolite occurring further south assumes a more massive habit. The structure of the country rock also influences the habit of the alaskite which in many localities is emplaced along the axial planes of F3 folds as dykes that transgress concentric shells of different lithologies. In the central part of the ore

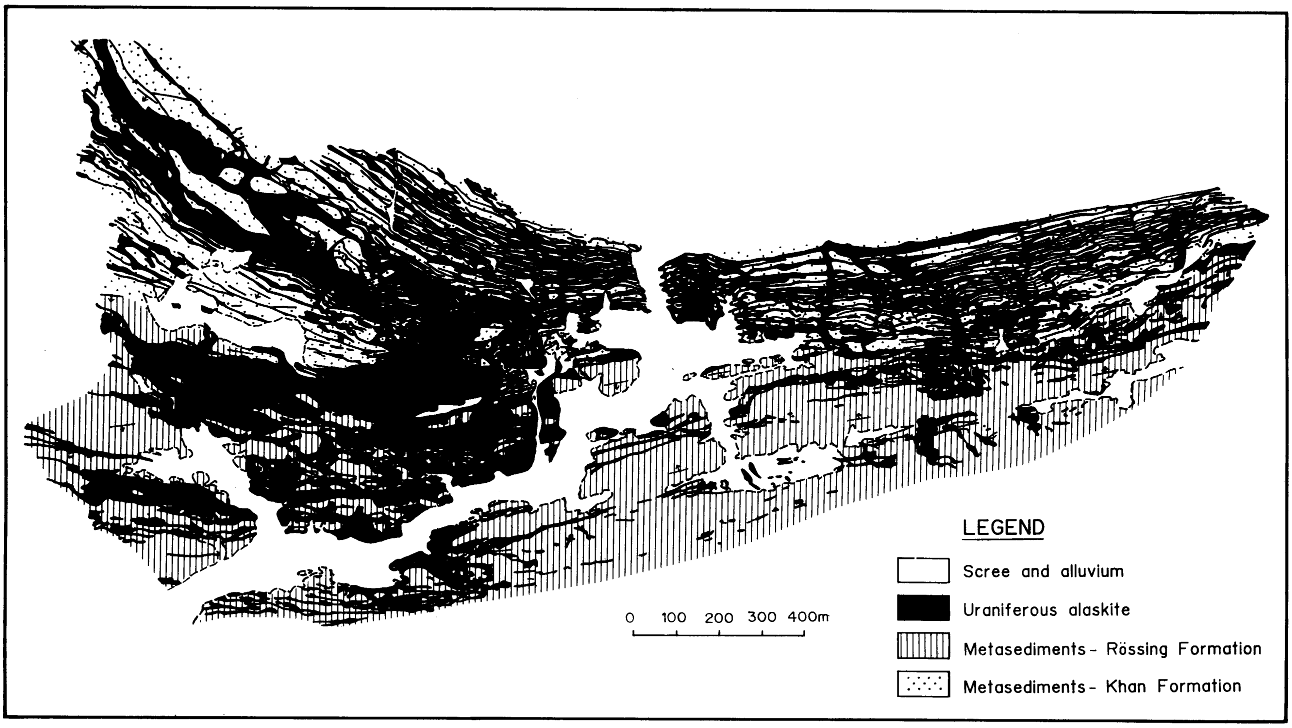

Figure 3: Generalised geological map of the Rossing alaskite body (after Berning, 1986).

body, massive alaskite has completely engulfed large undisturbed country rock xenoliths more than 100 m in size.

Textural variations ranging from aplitic, granitic to pegmatitic are displayed by the alaskite, with the latter predominating. Graphic texture is also evident in certain localities.

The bulk of the economic mineralisation in the Rössing deposit (Figs. 3 and 4) is contained in alaskite on the northern limb of the “mine” synclinorium. The alaskite is preferentially emplaced into the pyroxene-hornblende gneiss and biotite-amphibole schist units of the Khan Formation in the northern ore zone, and into biotite-amphibole schist/lower marble/lower biotite-cordierite gneiss of the Rössing Formation in the central ore zone. On the western edge of the deposit the two ore zones are separated by a considerable width of largely barren upper pyroxene-hornblende gneiss, whereas further east, thinning of the strata coupled with steeping of dip, narrows the surface exposures of ore zones and also the gap between them to a point where they merge. Towards the western end of the deposit, rich ore in both zones is exposed on surface, but drilling has established that it is of limited vertical extent. Further east the better grade ore extends to progressively deeper levels, and towards the far eastern limit of the pit blind bodies of uraniferous alaskite are encountered at depth.

The alaskite is widely distributed beyond the limits of the open pit but is not uniformly uraniferous. Portions are entirely barren or only slightly mineralized while only a few restricted sections are sufficiently rich to support exploitation. The reason for the localisation of the rich ore is still unclear.

Alaskite hosts all the primary and most of the secondary uranium minerals. In certain localities secondary mineralization spreads into the country rock and /or into a sporadically developed layer of surficial limestone. Within the uraniferous zone, enrichment is present along biotite-rich selvages in the alaskite, at places where robust alaskite bodies display sharp upward-narrowing to form dykes or veins, in alaskite emplacement along the axial planes of folds and in localities where amphibolite has been replaced by alaskite in the ore zones.

Uraninite [UO_2], the dominant primary mineral, occurs as grains ranging in size from a few microns to 0.3 mm, with the majority in the 0.05 to 0.1 mm fraction. It is included in quartz,

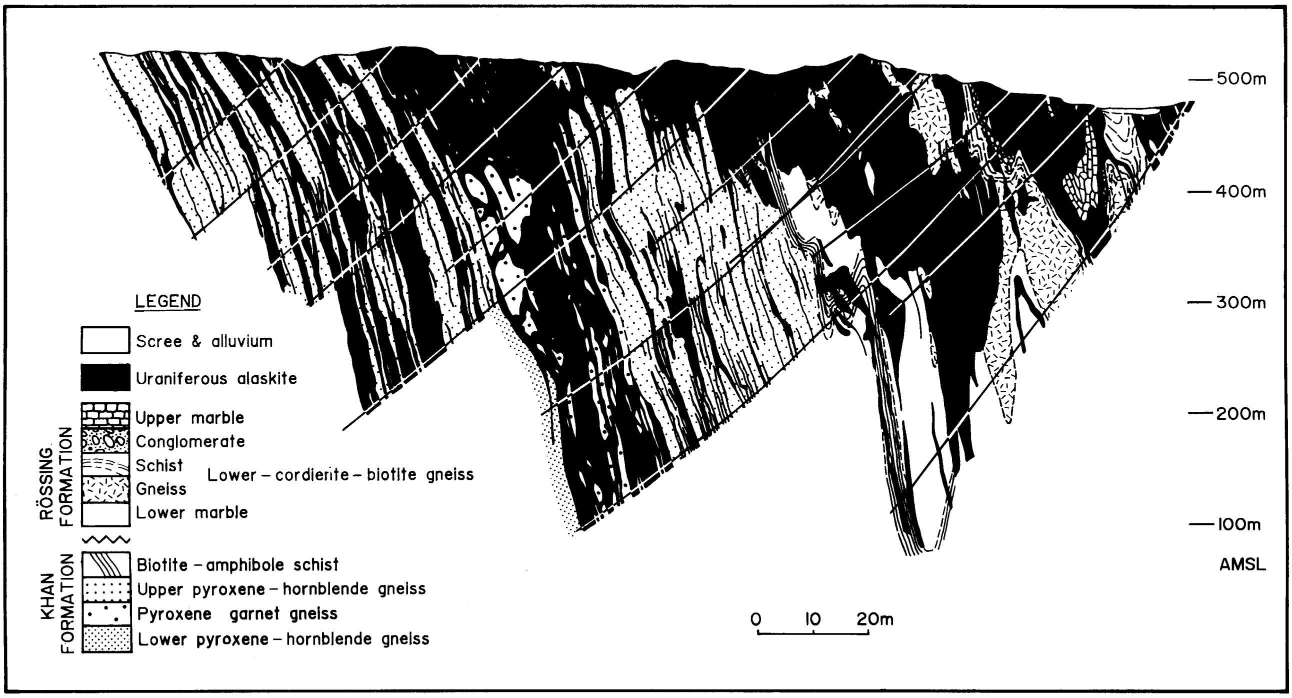

Figure 4: Cross-section of the Rossing alaskite body showing geology and boreholes (drill section zero) (after Berning, 1986).

feldspar and biotite, and also appears interstitially to these minerals or along cracks within them. The uraninite displays a preferential association with biotite and zircon, the latter appearing as inclusions within uraninite grains or as clusters of grains attached to them. Alteration haloes around the uraninite grains are common.

Monazite is widespread in some samples of ore and commonly closely associated with uraninite. Single monazite crystals seldom measure more than 0.04 mm in diameter.

Betafite $[(U,Ca,Ce)(Ti,Fe)_2O_6]$ is subordinate to uraninite and contains a minor proportion of the uranium in the ore. It shows a striking range of colours, from the usual dark brown variety with typical conchoidal fracture, to a bright yellow variety resembling carnotite and uranophane, but is distinguished from them by its greasy lustre. Betafite, commonly present as inclusions in quartz and feldspar, has been found to contain high concentrations of niobium and titanium, a fair amount of uranium and small amounts of tantalum and tungsten.

Brannerite $[(U,Ca,Ce)(Ti,Fe)_2O_6OH]$ is rare, but may contain a significant proportion of uranium.

Zircon, apatite and sphene are commonly associated with the radioactive minerals. Pyrite, chalcopyrite, bornite, molybdenite, arsenopyrite and the oxides magnetite, hematite and ilmenite are encountered in places, whereas fluorite is frequently present.

The alteration of uraninite and betafite gives rise to secondary uranium minerals that are usually bright yellow in colour. These occur in situ, replacing the original minerals from which they were formed, or they commonly form in cracks as thin coatings or occasionally as discrete crystals.

Of the secondary uranium minerals, beta-uranophane $[Ca(UO_2)Si_2O_7.6H_2O]$ is by far the most abundant. It is not always confined to alaskite but may spread into the enveloping country rocks. Uraninite; contains about 55% of the uranium present, betafite less than 5%, and secondary minerals about 40%.

Ore reserves of the Rössing deposit were calculated from the data obtained from the surface diamond-drilling programme undertaken by the Rio Tinto Exploration Company between 1967 and 1971. Using computer techniques, a series of long-term mining plans was developed from the ore reserve data until an optimum 20-year plan was obtained. This called for an opencast mining operation with 15 m-high benches resulting in a pit, which at the end of the 20 year period will be 3 km long, 1 km wide and 0.3 km deep.

Data obtained from detailed drilling are used to develop medium- and short-term plans of mining sequences designed to optimise mining of the ore body. The controlling factor in formulating the mining plans is that sufficient ore of the required grade should be available for mining at any time, in order to meet the plant’s requirements.

The mineability of the Rössing ore body is complicated by the following factors:

i) it consists of a mixture of uranium-bearing alaskite and barren metamorphic rock;

ii) the uranium content of the alaskite is extremely variable;

iii) in some areas the alaskite is present as large masses, whereas in others it consists of narrow bodies intercalated with barren metasedimentary rock;

iv) the acid consumption of the rocks (in the metallurgical process sulphuric acid is used to leach the uranium from the ore) varies greatly from low consumption for alaskite to very high consumption for marble.

Control of the uranium grade coupled with the acid consumption characteristics of the rocks is therefore of major importance. Special care needs to be taken with the blasting techniques used. Maximum fragmentation of the rocks is desired, but this often results in excessive movement of the rock resulting in a mixing of high-grade, low-grade and waste material, as well as of low- and high-acid-consuming ore.

In a further attempt to control grade, radiometric truck scanners are used to determine the level of radioactivity of each truck load of ore removed from the pit. Depending on the level of radioactivity recorded, a truck is dispatched either to the ore crushers, or to the low-grade stockpile, or to the waste dumps (Berning, 1986).

The plant was commisioned in June 1976 and commercial production started in January 1978. Table 2 gives annual production for the years 1976 to 1994.

Table 2. Uranium Production of Rössing Mine

Year	Metric tons U	Year	Metric tons U
1976	670	1986	3471
1977	2340	1987	3599
1978	2766	1988	3491
1979	3766	1989	3080
1980	4098	1990	3127
1981	3981	1991	2435
1982	3803	1992	1660
1983	3737	1993	1679
1984	3695	1994	1895
1985	3324		

2.1.2 The "SH"-uranium deposit

The "SH"-uranium deposit is situated 1.5 km southwest of the Rössing ore body and measures some 500 by 250 m. The long axis of this body trends in a northwestly direction and transgresses the strike of the surrounding metasedimentary formations. The body is emplaced in marble, quartzite and schist of the Rössing Formation, and consists of coarsely-crystalline to pegmatitic alaskite with numerous amphibolite- and biotite-schist inclusions (Fig. 5).

The main uranium-bearing mineral is betafite, which is not soluble in the acid solutions normally used in uranium leaching.

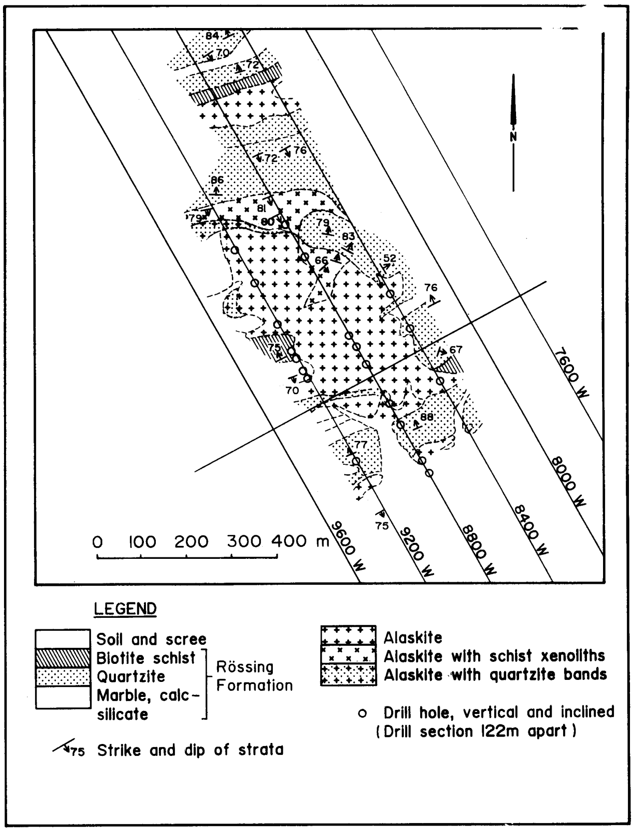

Figure 5: Geological map showing the setting and crosscutting nature of the SH alaskite body (after Rio Tinto Exploration Company).

The betafite grains, up to 3 mm in diameter, are characteristically surrounded by a narrow brownish grey alteration rim. The grains are commonly associated with inclusions or veinlets of sphene, rutile, leucoxene, anatase, brannerite and davidite.

Uraninite is present in minor amounts, the approximate ratio of betafite to uraninite being 8:1. The mineral forms small euhedral to subhedral equidimensional crystals some 0.3 mm across. Minor amounts of galena, presumably originating from radiogenic lead, are generally present as small round inclusions within the uraninite, or as narrow, irregularly shaped veinlets.

A small proportion of grains are a darker brown than the betafite and are thought to be davidite $[(Fe,U,Ca,Zr,Th)(Ti,Fe,V,Cr)_{15}(O,OH)_{36}]$, a mineral that has a similar composition to betafite, but contains more rare-earths and titanium. Beta-uranophane and other secondary minerals are abundant (Berning, pers.comm. Schreuder).

The deposit was investigated by detailed mapping, ground radiometric surveys and percussion and diamond drilling.

2.1.3 The G.P. Louw Deposits

The G.P. Louw prospecting grant area surrounds the Rössing mining grant and was first examined after an airborne geophysical survey in 1968 indicated a number of radiometric anomalies (Fig. 6). Reconnaissance ground radiometric surveying, geological mapping and limited test diamond drilling (3 boreholes) of the SK-area (Fig. 7) were completed in 1970.

The G.P. Louw area is underlain by the same rock types as the Rössing uranium deposit and the stratigraphy, structure and metamorphism are broadly similar.

Uranium mineralisation is closely associated with alaskitic granites and pegmatites emplaced in highly metamorphosed and migmatized country rocks. The alaskite bodies range from small quartzo-feldspathic lenses of secretionary origin to large bodies of intrusive and replacement habit. Alaskite hosts all the primary and most of the secondary uranium minerals.

Mineralised alaskites tend to be more deeply coloured (reddish) on weathered surfaces than unmineralised bodies. However, there are exceptions, as almost white mineralized alaskites have been found. Smoky quartz is usually associated with uranium mineralisation.

Uraninite is the dominant hypogene radioactive mineral. It occurs as grains ranging in size from a few microns to 0.3 mm with the majority falling in the 0.05 to 0.1 mm fraction. It is included in quartz, feldspar and biotite, but also occurs interstitially to these minerals or along cracks and fractures within them. Uraninite displays a preferential association with biotite and zircon, with the latter mineral occurring as inclusions within uraninite grains or as clusters of grains attached to them. Alteration haloes around the uraninite grains are common.

Minor amounts of monazite and betafite are usually present. Zircon, apatite and sphene are commonly associated with the radioactive minerals. Trace amounts of pyrite, chalcopyrite, bornite, molybdenite, arsenopyrite and the oxides magnetite, hematite and ilmenite are encountered occasionally, whilst flourite is abundant.

Of the secondary uranium minerals, beta-uranophane is by far the most abundant. Other secondary minerals include gummite (generic term for amorphous hydrous oxides of uranium formed as alteration products of uraninite and pitchblende), uranophane [$Ca(UO_2)_2Si_2O_7.6H_2O$], torbernite [$Cu(UO_2)_2(PO4)_2.8\text{-}12H_2O$], carnotite [$K_2,(UO_2)_2(VO_4)_2.3H_2O$], metahaiweeite [$Ca(UO_2)_2Si_6O_{15}.5H_2O$] and thorogummite. These occur in situ, replacing the original uraninite grains from which they were formed, along cracks as thin films, or occasionally as discrete crystals.

The individual occurrences of the G.P.Louw area are described briefly below and their localities are indicated in Figure 6.

RA. Low-grade uranium mineralization is associated with numerous closely-spaced alaskite dykes in the nose region of a complex anticlinal fold structure. The metasedimentary host rock consists predominantly of banded amphibole- and pyroxene-rich gneiss of the Khan Formation.

Uranium mineralisation is accompanied by concentrations of smoky quartz and biotite. A programme of shallow percussion drilling has revealed the presence of low-grade uranium values over an area measuring approximately 200 by 200 m.

SK4. This deposit is located some 2 km east of the Rössing open pit, on the southern contact of a large, irregular body of alaskite (Fig. 7). The alaskite body is associated with a zone of faulting and fracturing along a synclinal structure. The metasedimentary rocks include

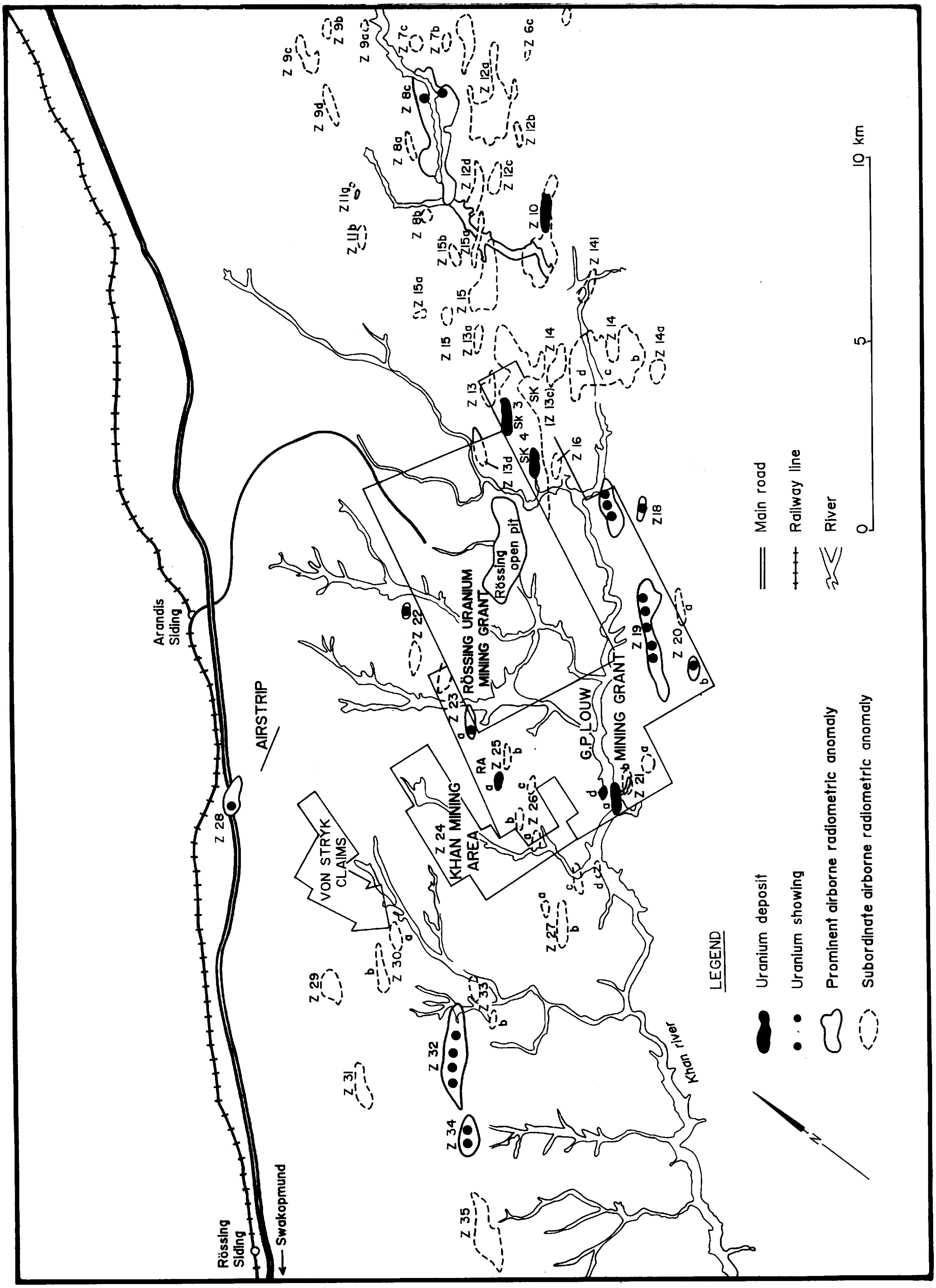

Figure 6: Locality map showing the radiometric anomalies in the viscinity of Rossing Mine (after Rio Tinto Exploration Company).

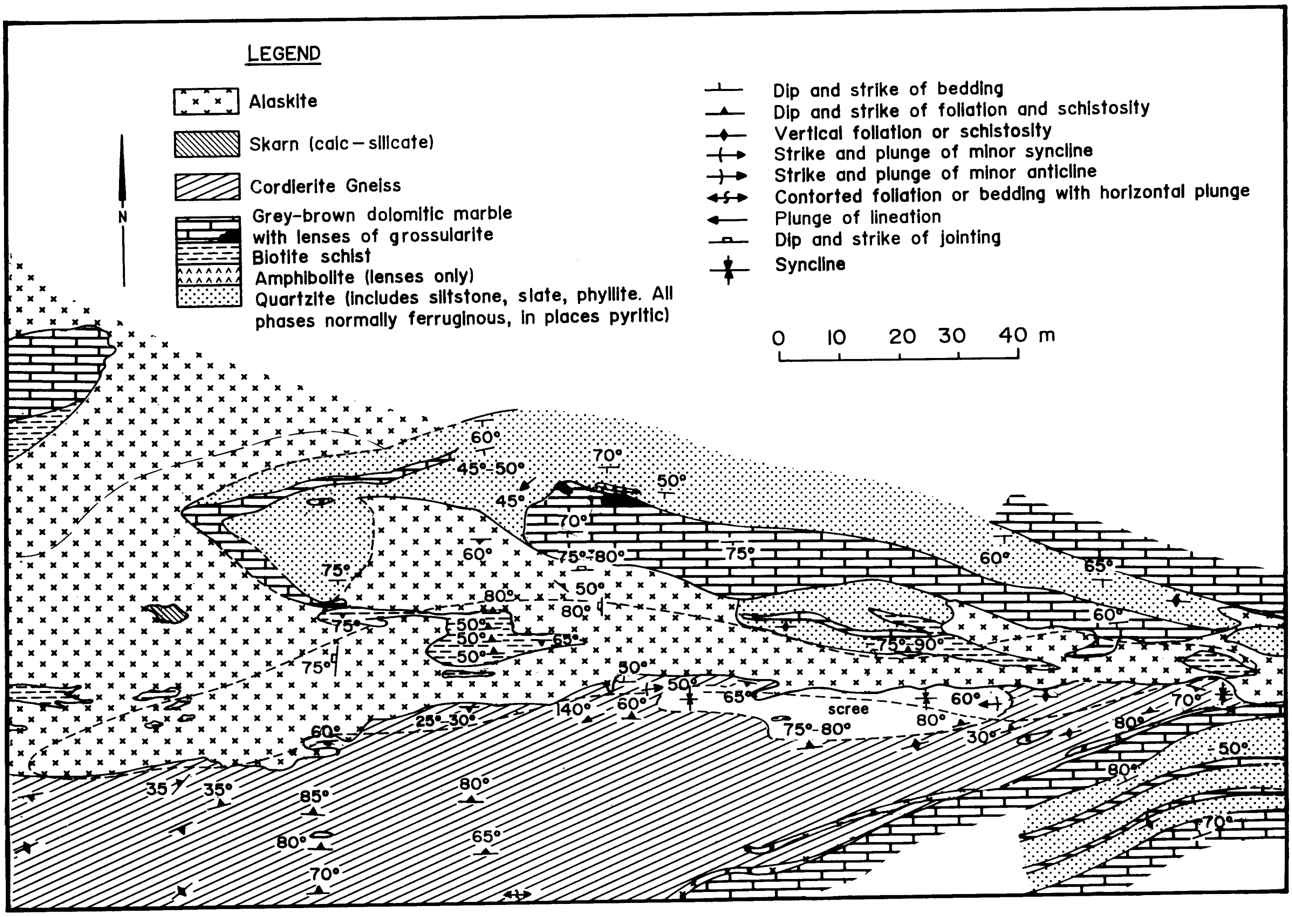

Figure 7: Geological map showing the setting of the SK4 alaskite body (after Rio Tinto Exploration Company)

cordierite gneiss, marble, quartzite, biotite schist of the Rössing Formation and amphibole schist, pyroxene- and amphibole gneiss of the Khan Formation.

The mineralisation was investigated by 62 diamond drill holes, totaling 6 038 m. This delineated an ore body with a strike length of 150 m and width averaging 12 m. The body dips steeply north and persists to 90 m below surface (Fig. 8).

SK3. The uranium mineralisation of this deposit is associated with an elongate, irregular alaskite emplaced along a zone of faulting. Country rocks consist of intensely folded cordierite gneiss, quartzite, marble, biotite- and amphibole schist.

A total of 3 908 m (36 boreholes) was drilled on sections 50 m apart. On surface the mineralised alaskite extends for 600 m along strike, dips 70^{o} northwest and the width varies between less than one metre to 25 m.

Z10. This mineralised zone is associated with an irregular, elongate body of alaskite emplaced along a zone of faulting and shearing. Country rocks are diamictite, marble, quartzite, amphibole schist and gneiss.

The deposit was investigated by 2 640 m (31 boreholes) of diamond drilling on sections 50 m apart. The main mineralized zone has a strike length of 350 m, with an average width of 7 m. The ore dips 60^{o} to 80^{o} north and extends to a depth of approximately 90 m.

Z21c. Situated within the Rössing Formation are irregular and elongated bodies of alaskite, which outcrop along a zone with a strike length of 1 700 m. The rocks dip 50^{o} to 80^{o} north, with the alaskite showing both intrusive and replacement relationships with the host rock.

A drilling programme consisting of 2 575 m

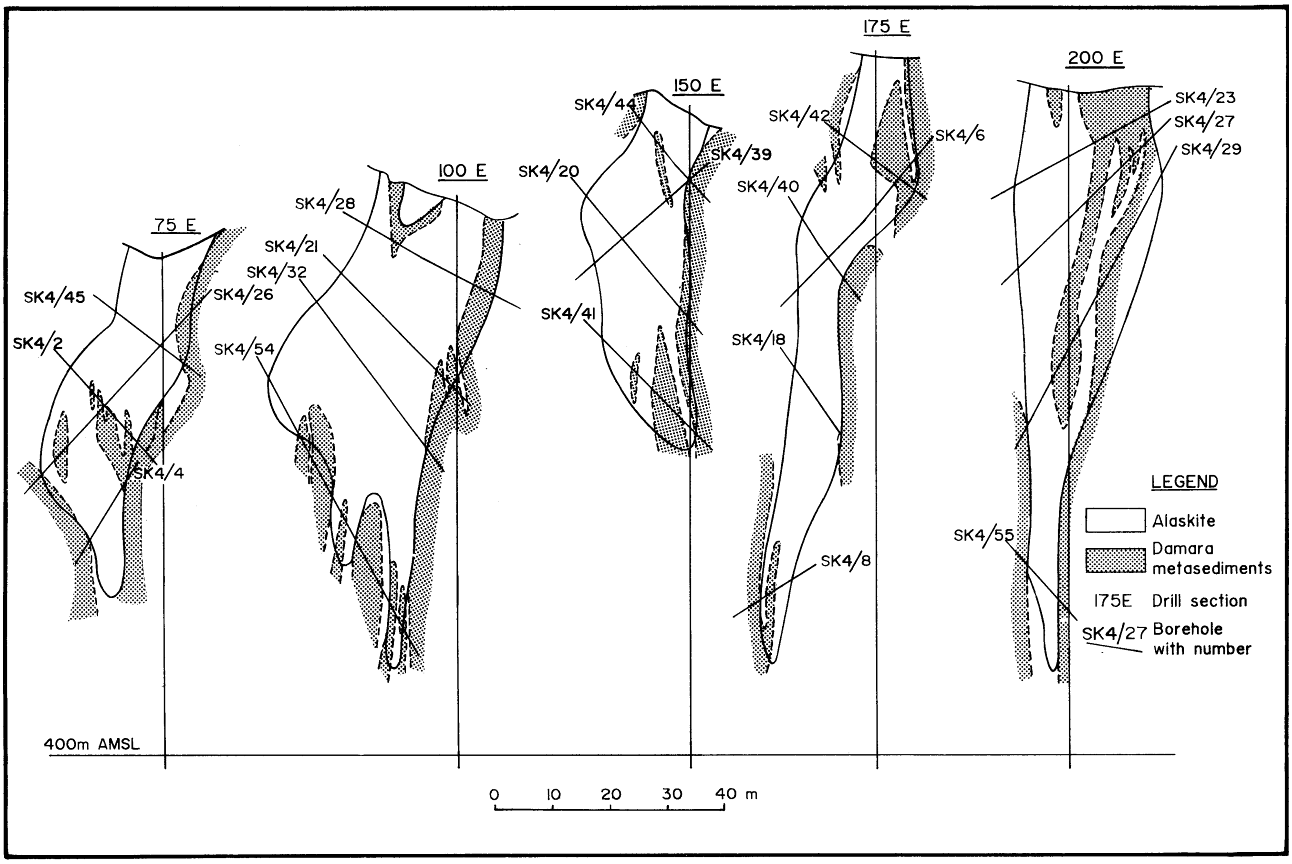

Figure 8: Drill section of the SK4 deposit (after Rio Tinto Exploration Company).

(27 boreholes) located two mineralised alaskite zones; an eastern zone which has a strike length of 250 m and average width of 25 m, and a western zone which has a strike length of 140 m and an average width of 30 m.

Z19. Anomalous radioactivity is present in a zone 4 000 m long and varying in width from 30 to 300 m. Alaskite occurs as broadly concordant, irregular masses, bands and lenses within mixtite and marble units. High radioactivity is commonly associated with zones of hematite staining and with concentrations of biotite.

Z17. Radioactive alaskites are present in marble, calc- silicate rocks, cordierite gneiss and biotite schist. The area lies on the southern flank of the regional Khan Syncline. Traces of secondary uranium minerals are present as isolated specks within biotite and occasionally as narrow fracture fillings in alaskite.

Z21d. Mineralised alaskite has been emplaced along the contact between the Chuos and Karibib Formations. The country rock consists of biotite-garnet schist, marble and pyritic quartzite. Two small zones of mineralisation, measuring 180 by 12 m and 75 by 18 m respectively, are present at the surface.

Z28. Mineralised alaskite is found in marble dipping 65° to 85° north, calc-silicate skarn and biotite schist of the Karibib Formation and in red granite gneiss. The area is largely scree covered.

Z32. Alaskite has intruded marble, biotite schist and garnet-biotite schist of the Karibib Formation. Structurally the anomalous zone lies within a synform. Dips are generally steep to the south with the marble being strongly deformed. Traces of beta-uranophane are present in outcrop and under leached exfoliated cappings. Smoky quartz is associated with the anomalous zones. Large areas are covered by sand and scree.

Z34. Alaskites occur in mixtite, pyritic quartzite and marble of the Chuos Formation. The alaskites are broadly conformable with the regional structural trend.

Two low grade zones of mineralisation, measuring 350 by 10 m and 275 by 10 m respectively, were outlined by surface radiometric surveys (Cooke,1981).

2.1.4 The Valencia Deposit

The deposit is situated on the farm Valencia 122, about 75 km southwest of Usakos. The Valencia radiometric anomaly (Anomaly 26) is manifest on the 1968 Geological Survey airborne radiometric map, but the significance of the anomaly was only realised in 1973 after a detailed helicopter radiometric survey was conducted across the area. Between 1973 and 1983 exploration in the form of mapping and diamond drilling was conducted by the Trekkopje Exploration and Mining Company.

The rocks occurring in this area are basement rocks of the Abbabis Complex and the Etusis, Khan, Rössing (referred to as Dome Gorge Formation by Labuschagne, 1979), Chuos, Karibib and Kuiseb Formations of the Damara Sequence (Fig. 9).

Grey porphyritic Salem Granite is emplaced in the Khan Formation and locally into the other formations around the major anticlinal structure.

Vast areas in the basement inlier and the surrounding Damaran rocks have been invaded by granitic pegmatites, generally referred to as alaskites. The alaskites are present as massive stock-like bodies, dykes of varying thicknesses and veins and veinlets which can be either conformable with or transgressive to the host rock (Fig. 9).

The basement inlier represents the core of an eroded anticlinorium, which plunges to the northeast. The surrounding limbs vary in dip from almost flat to steeply overfolded. Isoclinal folding is evident on the southeastern limb of the anticlinorium as well as over the central portion of the adjoining synclinorium. The latter is recumbent with both limbs dipping to the southeast. The uraniferous alaskite has been emplaced on the northwestern limb of this recumbent synclinorium. The emplacement of the alaskite seems to have been controlled by a younger north-northwesterly to south-southwesterly trending anticlinal fold which cuts through the older folding at more or less a right angle.

The alaskites vary in grain size from truly aplitic, through fine- and medium-grained phases to pegmatitic. The phases are haphazardly intermixed. Misiewicz (1984) correlated different alaskite pulses from four boreholes sunk at the corners of a proposed prospect shaft. He identified eight alaskites based on textural and other descriptive qualities and quantities which included uranium content. Only two of these alaskites could categorically be identified as separate pulses. Within each of these alaskites textural changes occur, suggesting additional pulses, but in only eight instances could these be correlated over the space of four boreholes.

The different grain size phases are usually all leucocratic, but the biotite content often increases in the fine- and medium- grained phases and also in the pegmatitic phases. The general composition of these phase types is quartz and alkali- feldspar with or without biotite. Accessory minerals are tourmaline, apatite, garnet and iron- and copper sulphides. The accessories tourmaline, apatite and garnet locally may become so abundant that they form a major constituent of the alaskites.

The conformable nature of relatively thin veins in tightly isoclinally folded schist sequences suggests a pre- or early- syntectonic genesis. The strongly transgressive nature of certain dyke-like bodies may indicate a later syn- to post-tectonic history, which means that the alaskites may possibly represent two distinct periods of intrusion (Labuschagne, 1979). Körner (1978) ascribed ages of 470 and 510 million years respectively to the transgressing and conformable intrusion types.

The alaskites contain xenoliths of the host rocks in which they were emplaced, and these xenoliths may vary in size from tiny fragments to bodies several tens of metres long. They have an almost perfectly conformable relationship

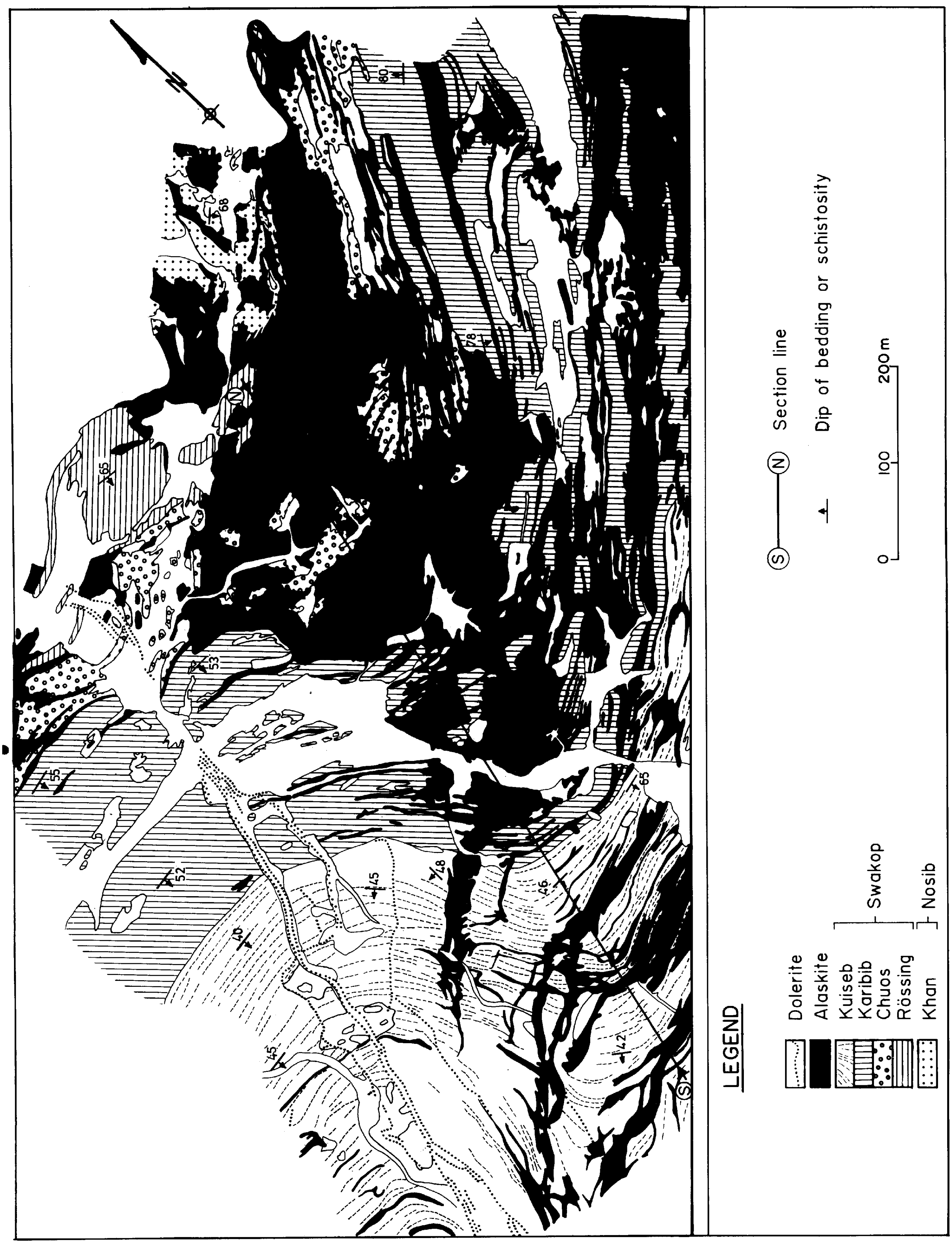

Figure 9: Geological map of the Valencia deposit (after Gold Fields of South Africa).

with the local structure, with their strikes and dips not varying significantly from those of the country rock. It appears as if little tilting and disorientation took place during emplacement of the alaskite. However, vertical movement cannot be ruled out.

A number of basic dyke-like bodies of

doleritic composition occur on and around the prospect. They have dips varying from fairly flat to almost vertical, and two main azimuths, viz. north - south and southwest - northeast. These dykes only rarely excede a few metres in thickness.

Pneumatolitic pegmatites and quartz veins occur throughout the area. They are usually relatively thin and short and do not form conspicuous outcrops.

The secondary uranium minerals uranophane $[Ca(UO_2)_2Si_2O_7.H_2O]$ and uranothallite $[Ca_2U(CO_3)_4.10H_2O]$ are present in the upper few metres of the alaskite bodies as yellow coatings on exfoliation planes and joints, where they form specks and tiny flakes on feldspar, quartz, biotite and apatite. The uraninite present is usually fresh, with only sporadic very minor alteration rims.

Uranium mineralisation usually occurs in the finer-grained alaskite and only occasionally in the coarse pegmatitic phases. It has been established that the degree of darkness of the quartz is usually directly indicative of the relative uranium content. A close direct relationship also exists between the uranium and biotite content as well as between the degree of uranium mineralisation and apatite content. These minerals account for the increase in total Fe, CaO and PO_4 at the expense of SiO_2, Al_2O_3 and K_2O in the alaskite (see Table 3). Reddish-brown feldspar colouring often indicates a higher uranium content.

The uranium is variably distributed through the alaskite and in many places high-grade ore is in contact with barren or very poorly-mineralised material. However, enriched alaskite zones are commonly found on or near the contacts between marble or schist xenoliths.

A feasibility study of the Valencia deposit was completed in 1989 (Kruger, 1990).

Table 3: Major element whole rock analyses of alaskites from Valencia

Sample No.	1	2
SiO_2	74.50	66.30
TiO_2	0.08	0.42
Al_2O_3	13.10	10.18
Fe_2O_3*	1.46	5.15
FeO*	0.86	3.23
MnO*	0.01	0.23
MgO*	0.10	1.40
CaO	0.44	5.40
Na_2O	2.80	2.20
K_2O	6.42	3.23
P_2O_5#	0.13	4.01
CO_2	0.30	0.40
H2O+	0.60	1.10
L.O.I.	0.29	0.78
	101.09	104.03
U_3O_8(kg/T)	0.06	3.09

* biotite # apatite

Table 4: Ore reserve calculation of the Valencia occurrence. (after Labuschagne 1979)

Wall cut-off kg/t U_3O_8	Block cut-off kg/t U_3O_8	Ton x 106	Grade kg/t	Total U_3O_8 kgx10^3
0.30	0.78	1.05	1.00	1 048
0.30	0.46	5.01	0.68	3 274
0.30	0.34	10.08	0.53	5 304
0.30	0.30	12.86	0.48	6 176
0.20	0.25	17.06	0.43	7 301
0.20	0.20	25.21	0.36	9 116
0.10	0.15	36.16	0.30	10 936
0.10	0.12	47.15	0.26	12 371
0.10	0.10	50.27	0.25	12 760

Table 5: Summary of ore and waste calculations (after Labuschagne, 1979).

Ore t x 106 U_3O_8	Grade kg/t t x 106	External waste t x 106	Internal waste t x 106	Total waste	Ratio waste: ore
1) 53.1	0.22	127.7	35.0	162,7	3.1:1
2) 42.5	0.23	82.1	23.5	105.6	2.5:1
3) 30.9	0.23	54.0	15.7	69.6	2.3:1

1) pit depth = 300 m
2) pit depth = 210 m
3) pit depth = 150 m

2.1.5 The Goanikontes Deposit

During 1974, an airborne radiometric survey located a prominent radiometric anomaly along the western flank of the Goanikontes Dome, which is situated immediately south of the Swakop River, some 4 km east of Goanikontes (Fig. 10). Subsequent investigation of the radiometric anomaly led to the discovery of the Goanikontes uranium deposit.

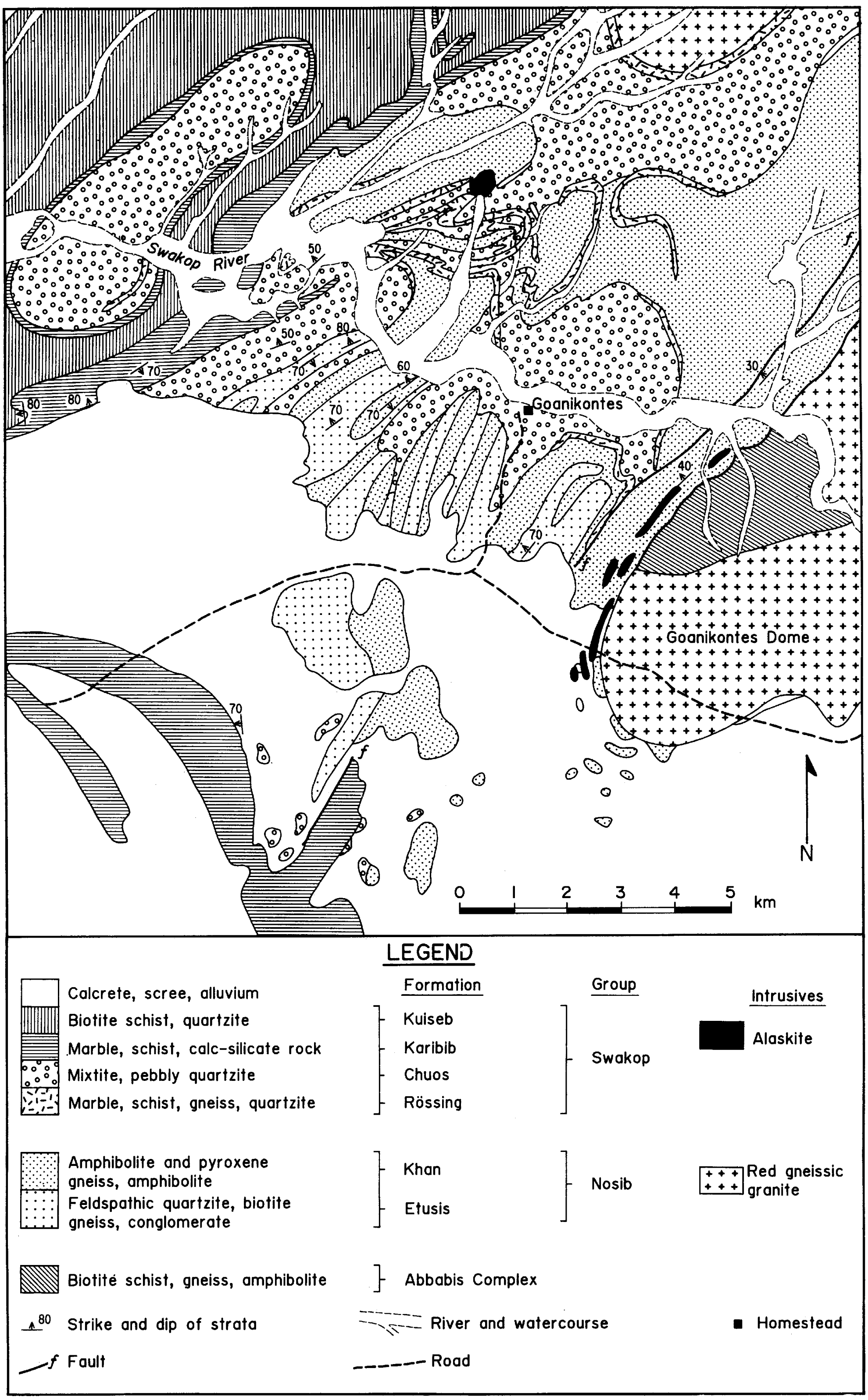

Figure 10: Geological map of the Goanikontes area.

The Goanikontes dome is a marginal lobe of a larger and deeply eroded basement structure containing pre-Damaran rocks (Abbabis Complex) and red granitic gneiss. The sedimentary rocks immediately surrounding the dome comprise arkosic quartzites of the Etusis Formation. The contact with the underlying units is transitional and of a migmatitic nature. The Etusis Formation rocks are overlain by the Khan Formation which consists of a lower dark-grey biotite-amphibolite-pyroxene schist and gneiss with intercalations of amphibolite and calc-silicate beds. The upper unit is characterised by scattered quartz pebbles and generally has a lighter colour than the lower unit. The Rössing Formation is not prominent in the Goanikontes area. Various beds of restricted lateral extent make up an alternating sequence of diopside marble, quartzite and biotite-garnet schist (Mouillac et al., 1986).

In places the strata are intricately folded and two major thrusts involving large-scale displacement are present. The thrust faults divide the Goanikontes area into three domains, viz. an eastern domain occupied by the domal structure, a central domain occupied by rocks of the Khan Formation and a northwestern domain underlain by strata of the Nosib and Swakop Groups (Barbour, 1980).

The stratigraphy and structural history of the area is complicated and was interpreted differently by Smith (1965) Mouillac (1976), Barbour (1980), Mouillac et al., (1986) and Brandt (pers.comm. C.P. Schreuder).

The first tectonic episode F1 of the Damara Orogen is not well defined in this area but the initial quartz - feldspar mobilisation is related to this early episode. The second tectonic episode F2 was not identified in this area. The third episode F3 resulted in the major structural framework consisting of northeast striking fold axes with axial planes dipping to the southeast. The fourth episode F4 resulted in updoming and was accompanied by open folding. These folds, tens of metres in amplitude, affect the rocks of the dome and adjacent metasediments but decrease in amplitude with distance from the dome.

The major alaskite bodies appear to be related to the F4 structural episode. The alaskite intrusions largely follow S3 foliation planes which were folded around the dome structure during the upward movement. Three major radial fractures with minor horizontal displacement transect the dome. One of these concentric fractures appears to have played an important role in the distribution of the uranium mineralisation.

The thickness of the alaskites can vary from a few millimetres to nearly 100 m. On surface the major alaskite dykes can be followed along strike for several hundred metres although continuity with depth is quite unpredictable (Fig. 11). The alaskite dykes are generally concordant with, but sometimes transgress the main S3 foliation. Field evidence suggests that the recrystallisation of the alaskite occurred during and after F4 deformation.

The uranium mineralisation in the Goanikontes area is restricted to alaskite granites and in particular, to those of post-F3 generation. Locally, uranium may be found in calc- silicate rocks in contact with mineralised alaskite, but this type of occurrence represents a negligible proportion of the mineralisation.

The alaskite bodies are not uniformly mineralized. The mineralized bodies are characterized on surface by reddish colouring and the presence of frequent alteration rings. These comprise irregular reddish-brown rings, a few centimetres to a metre in diameter, surrounding fresh, grey alaskite, and are interpreted as oxidation fronts affecting the alaskite and the distribution of uranium within it. Uranium occurs as erratic disseminations in rock fractures, at crystal interfaces, on cleavage planes and cracks and as inclusions in different minerals. There is no evident correlation between uranium content and texture or mineralogical composition of the alaskite. However biotite-rich zones are often more highly mineralised than the normal alaskite.

The major mineralised bodies are restricted to the lower part of the Khan Formation and occur within 400 m of the contact between the Etusis

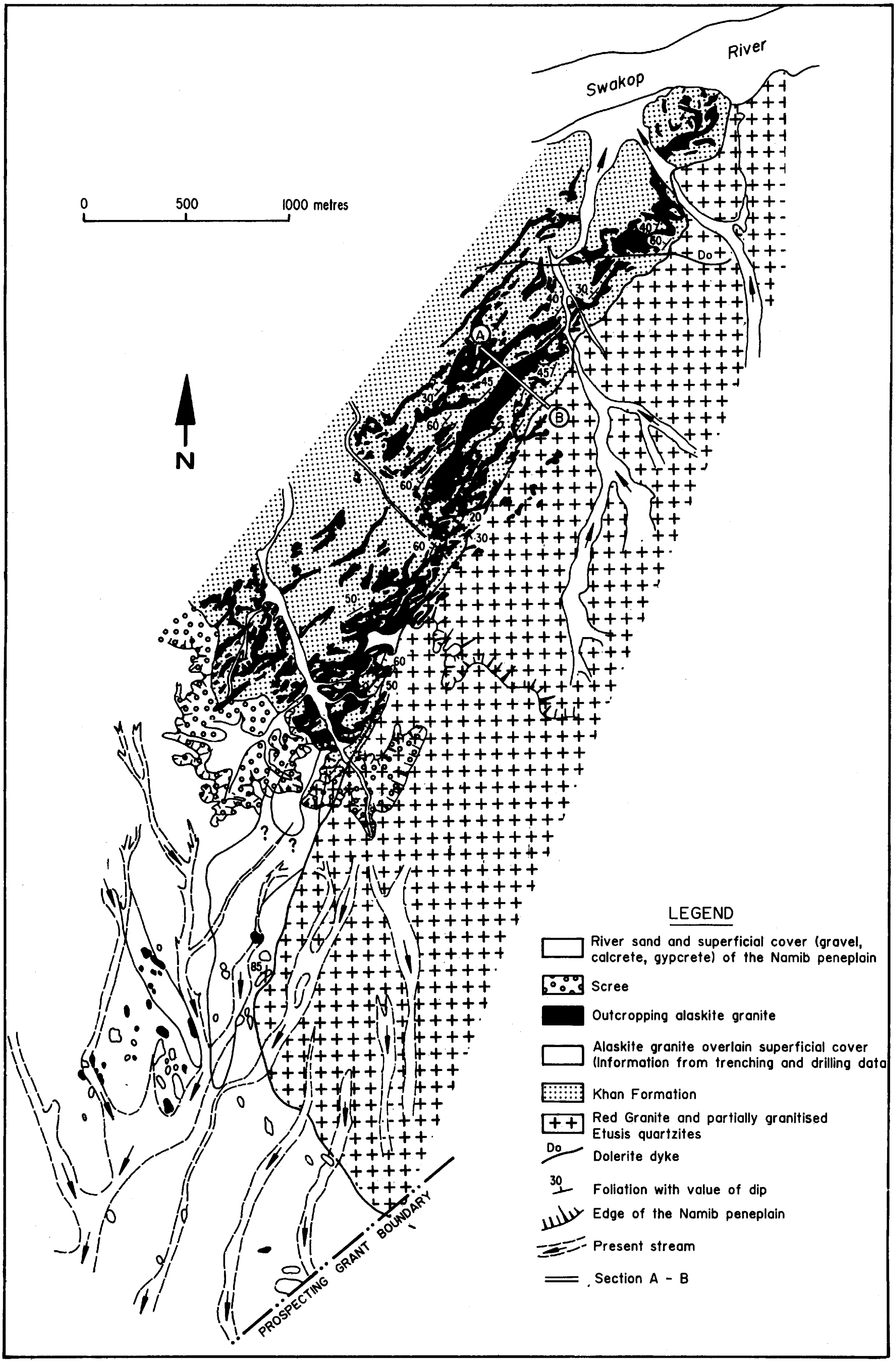

Figure 11: Generalised geology of the Goanikontes deposit showing the distribution of the alaskite (after Mouillac et al., 1986).

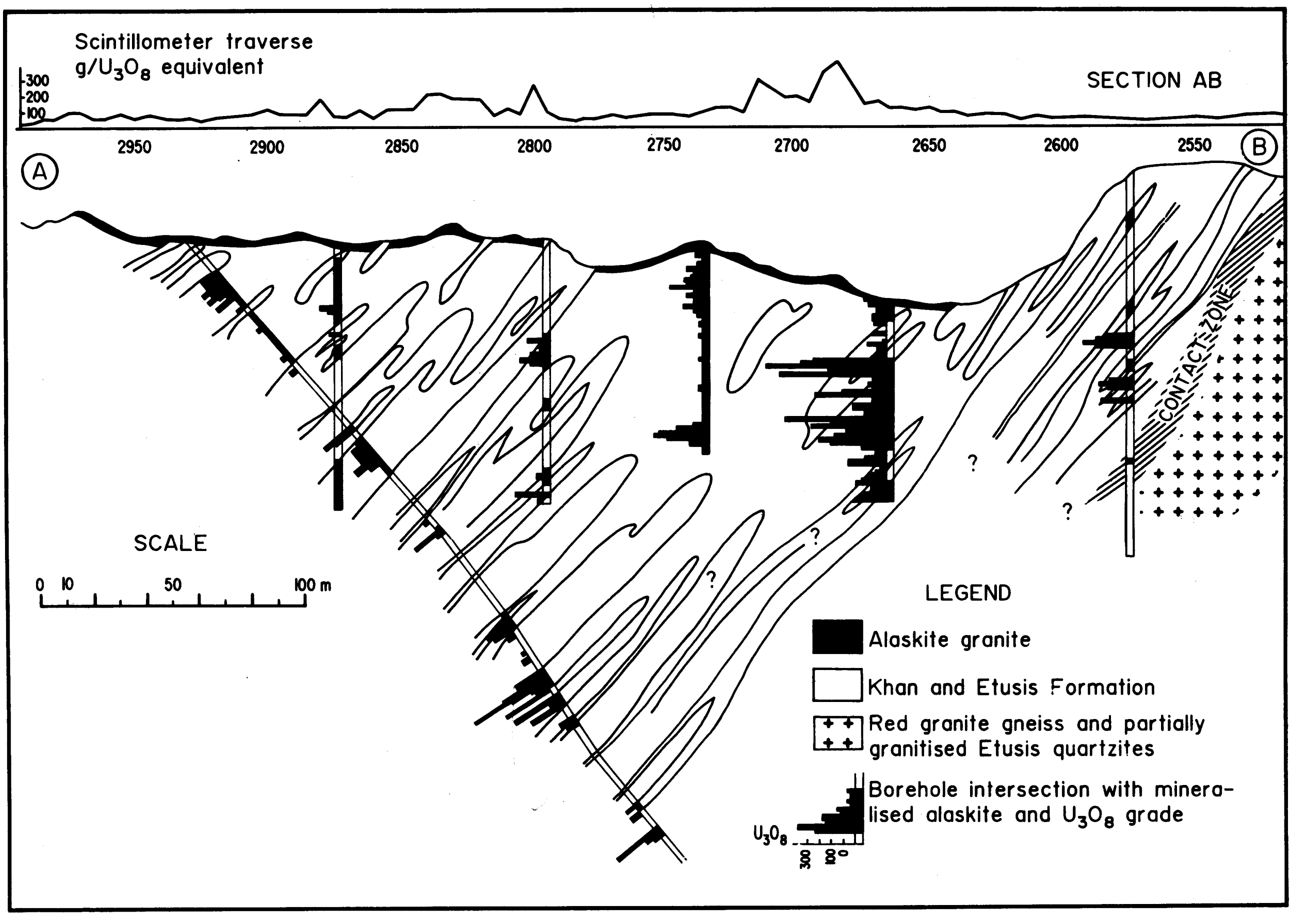

Figure 12: Cross-section of the Goanikontes deposit based on borehole information (after Mouillac et al., 1986).

and Khan Formations (Fig. 12). The amount of alaskite decreases rapidly outward from the centre of the dome and only a few thin dykes occur in the upper Khan and Rössing Formations.

The Th/U ratio of a typically mineralised alaskite, with a grade in excess of 50 g/t U_3O_8, varies between 0.05 and 2.00. The correlation between uranium and thorium is not linear and the Th/U ratio decreases as uranium grades increase. In the 400 g/t U_3O_8 range this ratio is between 0.05 and 0.3.

The most abundant primary uranium mineral is uraninite, but betafite is also present. The uraninite is commonly associated with chloritized biotite in the alaskite of the lower Khan Formation and with titanium-bearing oxides in foliated alaskite.

Secondary uranium minerals such as autunite, occur as replacements of the primary minerals or as films and coatings along microfractures. These secondary minerals are not restricted only to near-surface zones but have also been encountered in drill cores at depths of more than 200 m.

The potential ore reserves have been estimated to be several tens of millions of tones with a low average ore grade (Mouillac et al., 1986).

2.1.6. The Ida Dome Area

Mineralisation in the Ida Dome area is confined to the southern, southeastern and eastern side of the Ida Dome. Mineralised alaskite occurs along the contact between the Khan Formation and marbles of the Husab Formation. Radioactivity detected is patchy over a distance of 9 km along strike, on either side of the Swakop River (Fig. 13).

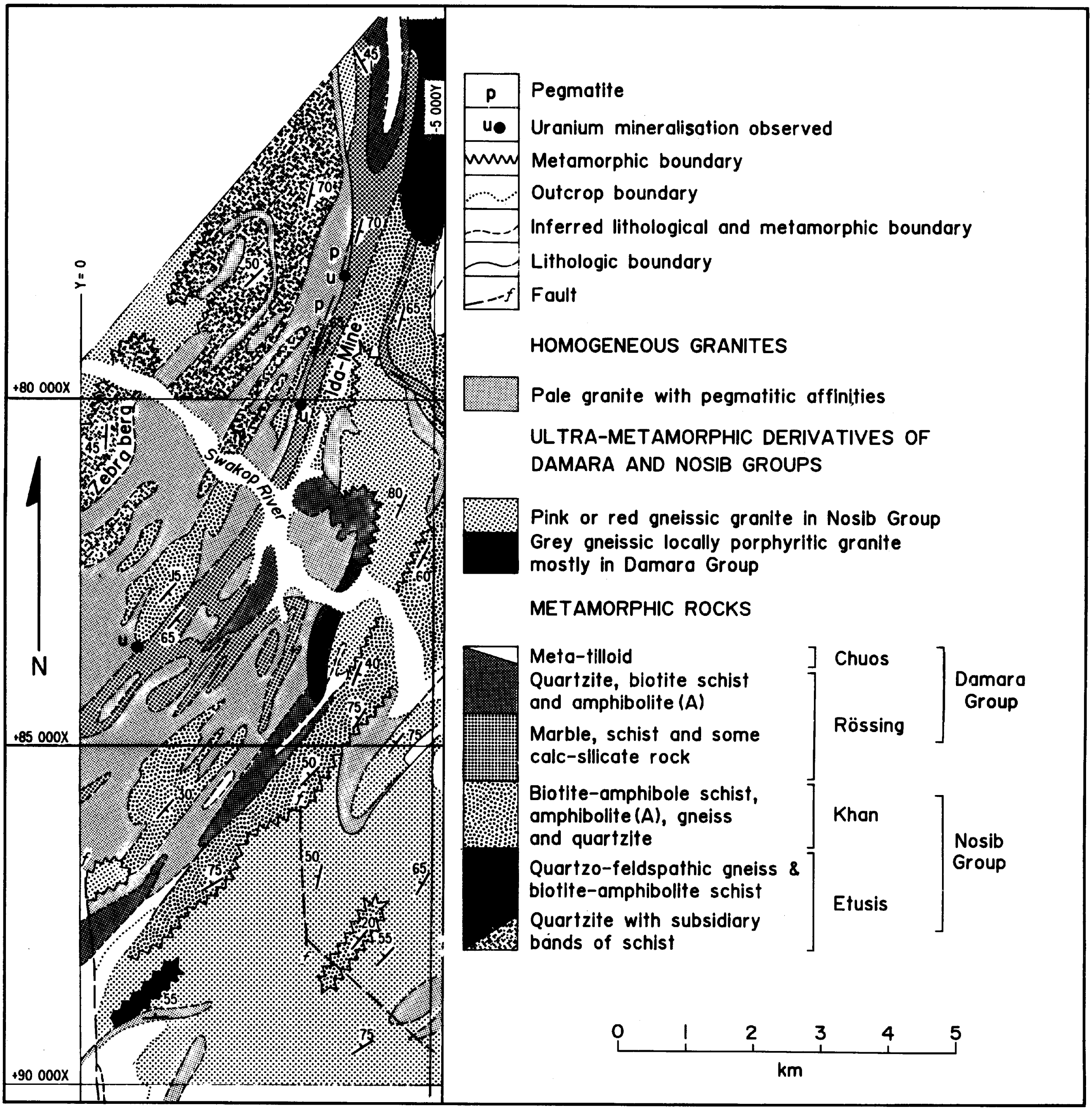

Figure 13: Regional geology of the Ida Mine area (after Anglo American Corporation of South Africa).

The alaskite is well exposed over much of its length and at the defunct Ida Mine the width of the mineralised zone is about 60 m. A shaft and several gullies and trenches have been excavated in cupriferous biotite-hornblende schists and banded gneisses of the Khan Formation, which are preserved as xenoliths in the alaskites. The xenoliths vary considerably from less than 1 m to more than 1 km in length. The alaskite has incorporated some copper mineralisation from the schists and contains smoky quartz, red feldspar and a variety of uraniferous minerals including uraninite and uranophane. The schist xenoliths are highly mineralized and yield scintillometer readings of 3 000 cps. Readings of up to 1 700 cps have been recorded over the alaskite. To the north of the shaft the mineralisation becomes patchy. Further northwards, irregular xenoliths of red granite gneiss have greater radioactivity than the alaskites. Younger, less radioactive red granite/ aplite veins transect the alaskite. The very patchy mineralisation persists up until a point where a north-northeasterly trending dolerite dyke cuts across the alaskite, 3 km north of the Ida Mine.

To the south of the shaft, in the direction of the Swakop River, the mineralisation rapidly becomes more patchy, although the width of the mineralised zone increases. South of the Swakop River mineraliation is patchy for nearly 2 km, but beyond this the alaskite is more uniformly mineralised and smoky quartz and yellow secondary minerals are widespread. The mineralised zone varies between 80 and 90 m in width. On the eastern side, scarn zones are developed against the marbles and to the west the mineralisation within the alaskite rapidly diminishes.

To the west of this occurrence, towards the Zebraberge, banded gneisses of the Khan Formation have been extensively invaded by alaskite dykes, several of which are patchily mineralized. The alaskite is reddish to pinkish in colour and contains irregular to more-or-less circular pods and patches of coarse-grained segregations of smoky quartz, minor feldspar, magnetite, some biotite and visible secondary gummite. The edges of these patches are marked by iron staining. The pods vary in diameter from several centimetres to more than 2 m but they are scattered and large areas of barren alaskite are exposed.

Biotite-schist xenoliths in the mineralised alaskitic pegmatitic granites are normally enriched in uranium relative to the alaskites and have acted as precipitants or traps for radioactive minerals. Similar effects characterise the immediate country rocks of mineralised alaskite. In many places the schists surrounding the alaskite bodies are more heavily mineralised than the intrusives for distances of up to one or two metres from the contacts. The presence of isolated porphyroblasts of K-feldspar derived from the alaskite melts and abundant quartz veining in the schists attests to metasomatic activity.

Skarn bodies are developed along the contact between intrusive granitic rocks with mostly alaskite and calcareous metasediments. They are generally small and sporadically developed, but southeast of the Ida Dome some of them reach several hundred metres in length and more than ten metres in width. Where the skarn bodies have formed adjacent to mineralised alaskite they are mineralised as well and small amounts of gummite are visible (Jacob, 1974).

2.1.7 The Rössing Mountain deposits

A large number of radiometric anomalies have been located immediately to the south and west of the Rössing Mountain (Fig. 14). The anomalies were investigated in detail to determine their economic potential and to establish whether a possible genetic relationship exists between them and known base metal deposits in this area.

Radiometric anomalies were located over a variety of lithologies of the Nosib and Swakop Groups and over red gneissic granite. Evaluation after field investigations reduced the initial 15 anomalies to only 3 namely Anomalies 3, 5 and 11. These were tested by detailed geological mapping, surface radiometric surveys and diamond drilling.

Anomaly 3: The northern portion of the area is essentially covered by gypsum scree, whereas the southern area contains numerous small exposures of isolated granitic rock and quartz-biotite schist. No uranium mineralisation was observed, but high scintillometer readings were found to be associated with granitic rocks containing smoky quartz.

Boreholes intersected mainly granite and biotite schist with uranium grading between 10 and 30 g/t.

Anomaly 5: This anomaly is located on the northern limb of a southwesterly- plunging synform, consisting of marble and biotite schist of the Swakop Group. The formations strike northeast and dip between 54^{o} and 75^{o} southeast. Several zones of alaskite, varying in width from a few centimetres to about 30 m, occur parallel to the strike of the country rock.

High radiometric readings were found to be associated with alaskite outcrops. No uranium mineralisation was observed and only isolated occurrences of smoky quartz are present.

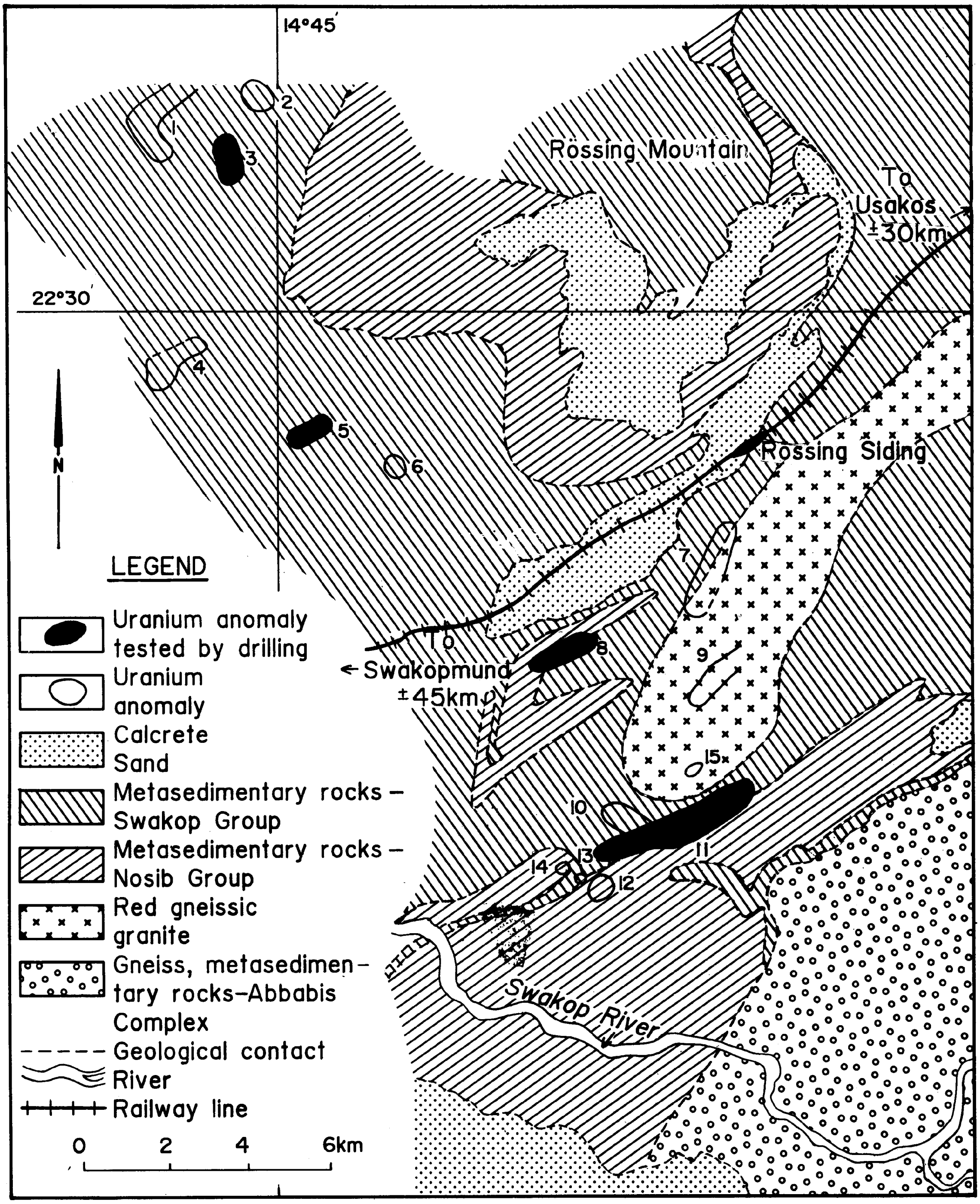

Figure 14: Location and geological setting of the Rossing Mountain radiometric anomalies (after Rio Tinto Exploration Company).

Subsequent drilling intersected alaskite, marble and calc-silicate rocks. Average uranium grades recorded were 30 g/t, with high values of up to 360 kg/t recorded over short intersections.

Anomaly 11. The uranium mineralisation is associated with alaskite emplaced into marbles of the Rössing Formation and mixtite of the Chuos Formation. No uranium mineralisation was recognised on surface, but abundant smoky quartz was observed in areas of high radioactivity.

A borehole drilled to a depth of 70 m intersected alaskite, marble, calc-silicate rock and mixtite. The average uranium grade was about 200 g/t, although short intersections assayed as high as 660 g/t.

The surface extent of the anomalous area measures 100 by 185 m, with the southern portion being covered by desert scree and soil.

The individual deposits are associated with small, low-grade alaskite bodies (Cooke, 1978).

2.1.8 Minor Occurrences

2.1.8.1. The Wolfkoppe deposits

Airborne radiometric surveys indicated a number of radiometric anomalies on the farms Wolfkoppe 105, Bergrus 94 and Tsawisis 16, in the Karibib District.

The area is underlain mainly by quartzite of the Nosib Group and mixtite and marble of the Swakop Group. Alaskitic granite and tourmaline-rich pegmatites have subsequently intruded the bedded formations of this area.

Although some sedimentary units (especially the quartzite of the Etusis Formation) are radioactive, it is mainly the alaskitic granite and alaskite which show anomalous radioactivity. In addition, the pegmatites on Wolfkoppe 105 are decidedly more radioactive than those further east on Bergrus 94 and Tsawisis 16 and average scintillometer readings 2 to 3 times higher than over the enclosing sedimentary strata are common. A number of highly radioactive localities have been encountered. These, however, are extremely limited in extent (1 to 2 m2 or less) and at best occur within moderately radioactive zones which themselves are only a few tens of metres in extent.

Inspection of the promising areas has shown that the radioactivity is caused mainly by thorium with subordinate uranium (Cooke, 1977).

2.2 Granites and Gneisses

Even though the uranium occurrences in this type of setting can be regarded as sub-economic, they contribute an important uranium source for the sedimentary deposits.

2.2.1 Pre-Damaran Rocks

2.2.1.1 Huab Metamorphic Complex

A radioactive anomaly was located over gneisses of the Huab Metamorphic Complex on the farm Hochland 56, northeast of Franzfontein. The anomaly was percussion drilled and the following results were obtained (Hartleb, 1980):

Table 6: Summary of drillhole results

Borehole No	HL2	HL3	HL4
Depth drilled (m)	40.5	44.5	28.0
Metres mineralized	18.0	28.5	1.5
Average grade (g/t)	150	250	133

2.2.1.2 Abbabis Complex

The basement gneissic granites and augen gneisses of the Abbabis Complex are the oldest granitic rocks of the Central Zone (Fig. 1). Outcrops of these rocks occur in the same general area as the uraniferous deposits and they display a higher radioactivity than average granites, probably due to the presence of thorium. Values of 3 to 5 ppm U_3O_8 and 38 to 50 ppm ThO_2 have been reported (Jacob et al., 1986).

2.2.2 Damaran Granites

2.2.2.1 Red Granite-gneiss Suite

Very closely associated with the Abbabis rocks is a group of red granitic rocks (Fig. 1), which also exhibits a higher than normal radioactivity. Uranium and thorium values are generally of the order of 2 to 20 ppm and 10 to 50 ppm, respectively, although much higher localised values have been recorded. The suite consists of gneisses, gneissic granites, leucogranites and pegmatitic granites of the Rössing Mine-type, varying in age from syn- to post-tectonic. Most members of the suite are found either below or at the level of the Etusis Formation but some intrude to higher levels. In areas of lower metamorphic grades the red granite gneiss fills ductile shear zones but is volumetrically small, whereas in the high-grade core of the belt around the Khan-Swakop river confluence this suite makes up the bulk of the rocks and basement augen gneisses occur as xenoliths and skialiths.

Preliminary dating of the suite yields ages between 950 and 550 million years, the oldest of which may represent partial resetting of basement ages as a result of Damaran metamorphism (Jacob et al., 1986).

2.2.2.2 Salem Granitoid Suite

Rocks of this suite crop out over a wide area in the Transition and Central Zones of the Damara Orogen and comprise a number of granitic rocks that have intruded over an extended period (Fig. 1). 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/adamallite. Early members are strongly foliated and are pre-tectonic and syn-tectonic, whereas later members appear undeformed and are post-tectonic. The youngest members are less porphyritic, contain more K-feldspar and are leucocratic in appearance. In places the suite is anomalously radioactive and such areas are normally underlain by late leucogranite. No economic concentrations of uranium have been found in the granites but at certain localities, superficial calcareous sediments overlying the Salem granite are mineralised, their uranium content having been derived from the granites (Jacob et al., 1986).

2.2.3.3 Very late- to post-tectonic granites

Most of the other granitic rocks are regarded as being very late- to post-tectonic in age. Amongst this group are a number of stocks and bosses of mesocratic granodiorite. These bodies yield a very low level of radioactivity, cut across fold structures and also deform the country rocks.

Numerous other bodies of post-tectonic granite occur, including the red homogenous granite, the Bloedkoppie Granite, which is the source rock for the Langer Heinrich superficial-uranium deposit, the Sorris Sorris granite and several others not yet named. The largest body of post tectonic granite in the Damara Belt is the Donkerhuk Granite which is emplaced along and immediately south of the Okahandja Lineament.

Vast amounts of pegmatite are associated with this muscovite-bearing Donkerhuk Granite which has a relatively low uranium content. Values of less than 5 ppm U_3O_8 and between 20 and 90 ppm ThO_2 have been recorded. The granite has tentatively been dated at 528 ±7 million years (Jacob et al., 1986).

2.2.3 Post Damaran Rocks

2.2.3.1 The Erongo

As a result of an airborne radiometric survey, anomalous radioactivity was detected at the western corner of the farm Omandumba West 137 and at the common boundary of the farms Omandumba West 137 and Anibib 136, in the Omaruru District (Fig. 15).

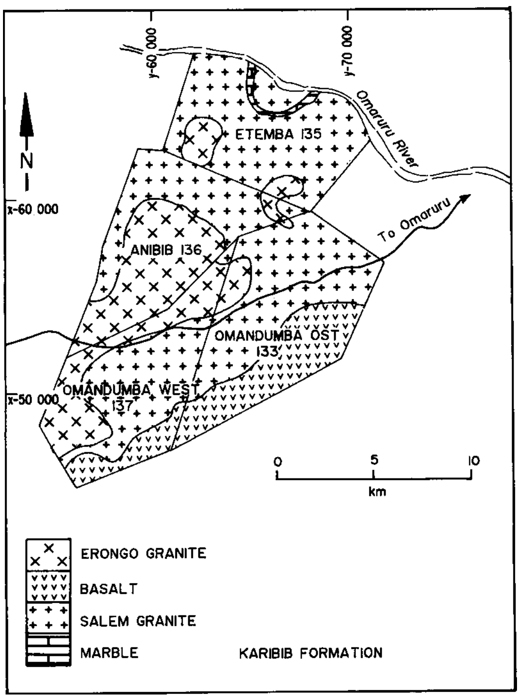

Figure 15: Simplified geology of the Erongo Prospect (after Trekkopje Exploration).

The anomalous areas are underlain by white to pinkish granite of the Erongo Complex. The granite is medium to coarse grained, commonly contains biotite and nests of black tourmaline, and in places displays a pegmatitic phase.

Ground radiometric surveys on the southwestern anomaly revealed erratic uranium mineralisation and localised highly radioactive zones (up to 380 g/t U_3O_8) associated with jointing. The set of joints is vertical to subvertical and commonly strikes northeast - southwest. Percussion drilling confirmed the close correlation between joint zones and mineralisation, however, there is a decrease in mineralisation below 30 m (Bertram, 1981).

2.3 Mineralisation associated with pegmatites and quartz veins

2.3.1 Pre-Damaran Rocks

Small specks of a yellow uranium mineral have been were detected in a zoned pegmatite in the lower Fish River area, southern Namibia (Anon., 1967).

2.3.2 Damara Sequence

2.3.2.1 Auris

The Auris grant area is situated ±60 km west of Khorixas. A regional radiometric survey delineated anomalies on the southern part of the farm Austerlitz 515. The geology of the area consists of folded metasedimentary rocks of the Damara Sequence which are overlain by sediments of the Karoo Sequence. The dominant structural feature in this region is the east - west trending Austerlitz anticline (Fig. 16).

The radiometric anomalies are situated on the northern and southern limb of the anticline. On the northern limb, the mineralisation is hosted by iron oxide-stained quartz- and calcite veins which occur within dolomitic limestones of the Karibib Formation. Chip samples taken from this area assayed between 500 and 1 000 ppm U_3O_8 and 30 ppm thorium. The limestone anomaly is 10 by 60 m in outcrop and the reserves calculated for this area are 16 000 t at a grade of 300 g/t U_3O_8.

The anomaly on the southern limb is situated in feldspathic quartzites of the Kuiseb Formation. It is 13 by 30 m in size and the calculated reserves are 10 000 t at 200 g/t U_3O_8 and 5 000 g/t thorium (Quoix, 1980).

2.3.2.2 Minor Occurrences

Quartz-flourite veins at the Husab Mine are radioactive and occur as an en echelon set of lenses and dykes over a distance of 4 km, northeast and southwest of the Husab Mine. Field relationships suggest that both fissure-filling and replacement processes have occurred. The veins are associated with certain zoned pegmatites but the relative ages are difficult to determine. Patchy uranium mineralization was deposited with flourite (Jacob, 1974).

Chip samples collected from a pegmatite in the Otjimbingwe area assayed up to 324 g/t U_3O_8 (Bothe,1981).

In the Horebis area, 100 km east of Swakopmund, a pegmatite assayed average values of 445 g/t U3O8 and high values up to 675 g/t U_3O_8 (Pienaar, 1975).

North of Usakos, on the farm Davib Ost 61, values of up to 7 370 g/t U_3O_8 were recorded from a pegmatitic rock (Hiemstra, 1968).

A zoned pegmatite, containing radioactive minerals, forms a conspicuous hill 3 km northwest of the Husab Mine. The radioactive mineralisation occurs in the wall zone, where yellow secondary minerals, smoky quartz and red feldspar are found in areas which yield scintillometer readings of more than 1 000 cps. The wall zone is not uniformly mineralised. Secondary uranium minerals occur along fracture planes and as thin films on crystals in other parts of the pegmatite (Jacob, 1974).

Three kilometres east-southeast of the

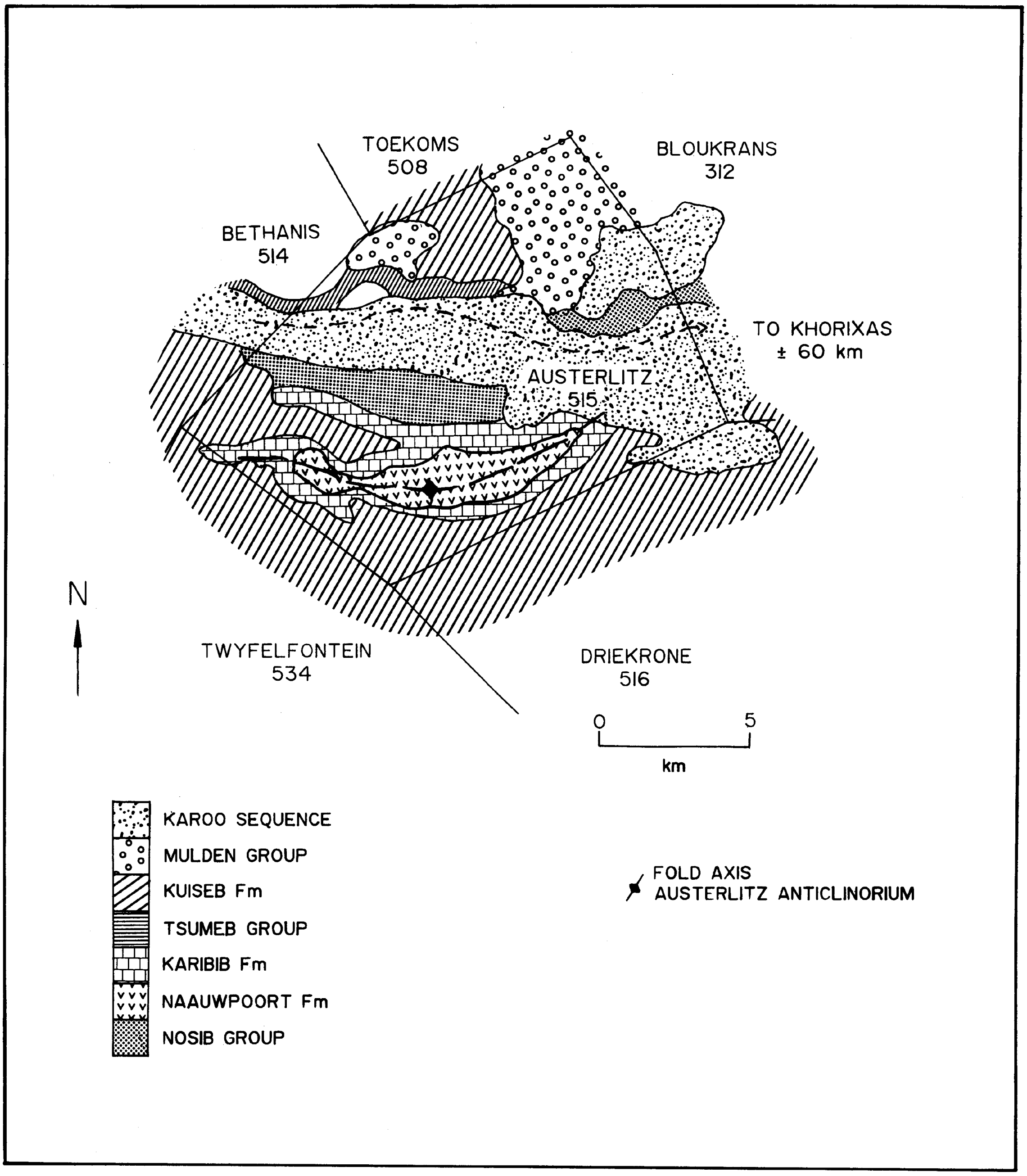

Figure 16: Simplified geology of the farm Austerlitz 515 (after Geological map of Damara Orogen 1:500 000).

western corner of the farm Modderfontein 131 in the Usakos District, a large zoned pegmatite with a northwesterly trend is developed. This pegmatite is several hundred metres in length and about 20 m in width. A wall zone, two intermediate zones and a quartz core are recognizsable. Small patches of smoky quartz containing radioactive minerals occur in the intermediate zone near the core where scintillometer readings have recorded 1 000 cps. Small amounts of beryl and minor amounts of calcite are present in this pegmatite.

The Bloedkoppie Granite, southeast of Langer Heinrich, contains many narrow zoned pegmatites. Close to the cores of the narrow pegmatites, concentrations of magnetite occur, together with reddened feldspar and small amounts of secondary uranium minerals. The general trend of the pegmatites is east to east-southeast and many of them are more highly radioactive than the Bloedkoppie Granite itself, which produces count rates almost three time higher than the surrounding Tinkas Formation and pegmatites of Donkerhuk type (Jacob, 1974).

Several layered pegmatites occur in the vicinity of the Gawib valley between the Langer Heinrich Mountain and the Bloedkoppie Granite. Local low-order anomalies were recorded over some of the pegmatites, generally between 90 and 120 cps, but in one place, up to 250 cps were recorded (Jacob, 1974).

3. Pedogenic Occurrences

An overlap between these and primary deposit types exists as the decomposition of primary alaskite by weathering produces pedogenic deposits. Most of the primary deposits have associated with them a zone of supergene enrichment which in places contains more uranium than the primary source. The transport mode and distance travelled of the liberated uranium therefore determine if a deposit can be classed as a sedimentary or pedogenic.

3.1 The Mile 72 deposit

The Mile 72 uranium occurrences are situated immediately east of the coastal road approximately 100 km north of Swakopmund (Fig. 17). The topography in this area is slightly undulating with dolerite sills, dykes and quartz veins forming positive erosional features.

The basement metasedimentary rocks belong mainly to the Khomas Subgroup and consist of marbles, metaquartzites, calc-silicates and schists, into which various granites such as the syntectonic Salem Granite and post-tectonic pegmatites and alaskites were intruded. Primary uraniferous minerals such as uraninite and betafite, as well as monazite and apatite, occur mainly in the alaskite. The thin veneer of Tertiary to recent surficial material overlying the basement rocks consists of aeolian sand, isolated remnants of fluvial gravel and desert soil, all of which have been cemented by gypsum and to a lesser extent by halite and calcite. The secondary cementing minerals extend down into the basement rocks, filling joints, fissures and cleavage planes.

A ground radiometric survey indicated that anomalous radiation was confined to a granite area and its contact zone towards the northern boundary of the original grant area. It was found that the radiation was caused by carnotite and subordinate uraninite, possibly leached out of the underlying granite. The upper 50 to 100 cm of the bedrock formations are intensely cracked and gypsum after calcite is present in abundance in these openings, including the foliation and cleavage planes. Carnotite has been precipitated in the gypsum veins by evaporitic processes. Selective samples of uraniferous gypsum analysed as high as 50 kg/t U_3O_8, although large tonnages would probably average less than 50 g/t.

Regional and detailed radiometric surveys indicated about 8 anomalies in the area. The uranium mineralisation was found to be patchy and occurs in several pockets associated with metasediments, granite and dolerite. Secondary minerals, such as carnotite (the dominant phase) and minor amounts of phosphuranylite [$Ca(UO_2)_3(PO_4)_2.6H_2O$], occur principally above the water table. Phosphuranylite is closely associated with apatite.

Potential ore bodies of irregular shape and erratic mineralisation were delineated (Fig. 18). One specific occurrence in metasediments varies from 1 to 30 m in width and extends to 18 m in depth. Trenching operations indicated that the uranium mineralisation occurs near the contact between calc-silicates and schists in association with quartz veins and alaskites. The metasediments are deeply weathered in places and replaced by crystalline and powdery gypsum and carnotite. Alaskites within this zone tend to be more radioactive than those occurring in less-weathered material. However, this could be caused by either primary or secondary enrichment (Hambleton-Jones, 1984).

Estimated ore reserves of the best-mineralised zones are 386 000 t U_3O_8 averaging 230 g/t (Labuschagne, 1976).

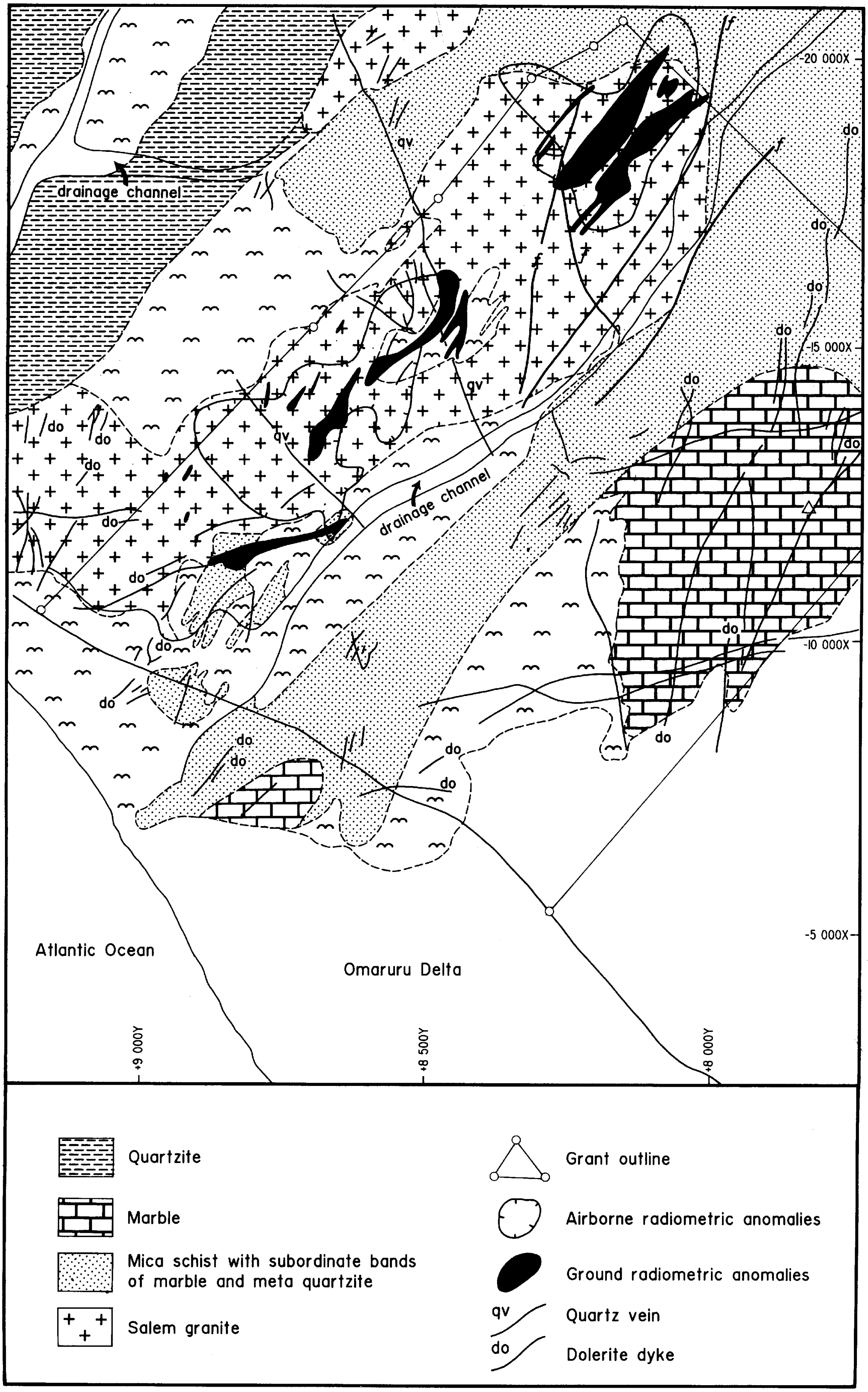

Figure 17: General geology of the Mile 72 area (after General Mining and Finance Corporation).

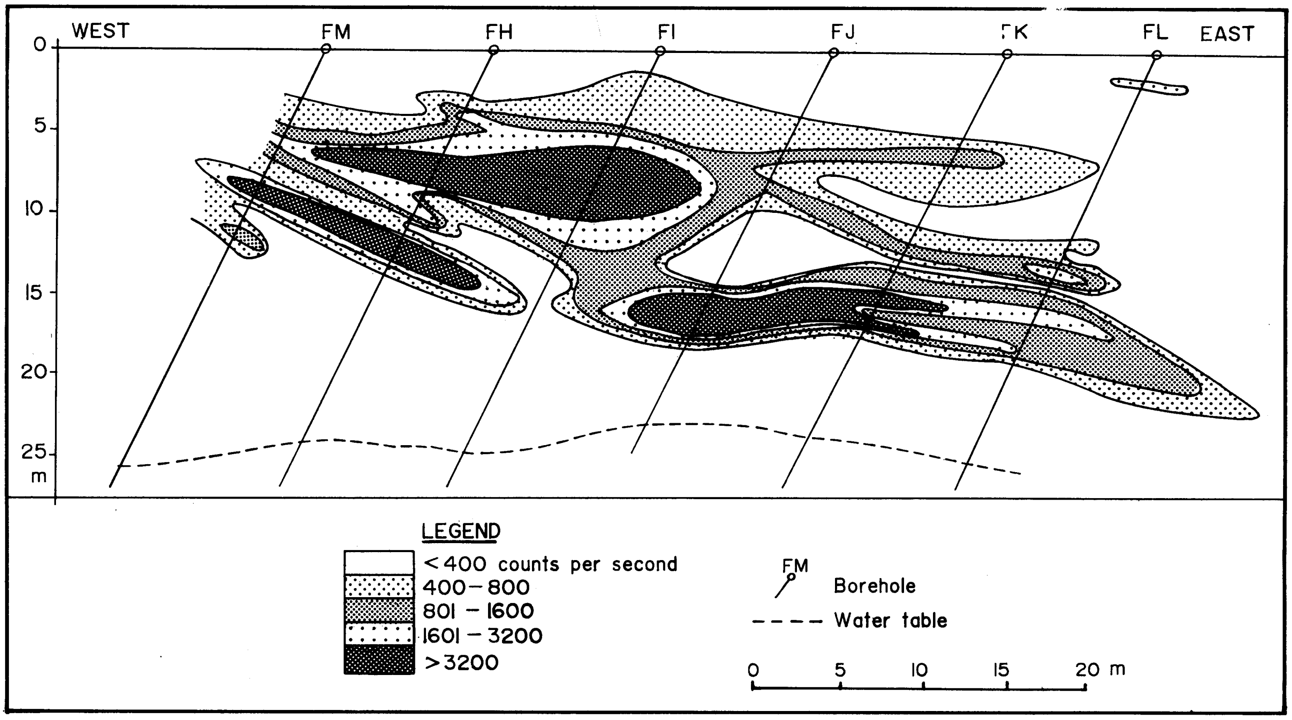

Figure 18: Radiometric profile showing irregular mineralisation of the Mile 72 deposit (after General Mining and Finance Corporation).

4. Sedimentary Occurrences

4.1 Syngenetic Occurrences

4.1.1 Karoo Sequence

4.1.1.1 The Engo River Occurrence

The Engo Valley is situated along the northern Kaokoland coast in the extreme northwest of Namibia. The prospect area lies approximately 200 km north of Möwe Bay to the north of the defunct Angra Fria Radio Station.

A radiometric survey detected uranium on the eastern flank of the Engo river valley.

The succession of rock types found in the Engo Valley consists of rocks of the Damara Sequence which are unconformably overlain by Karoo Sequence rocks.

The Damara Sequence in this area comprises schists, gneisses and calc-silicate rocks which are considered to be the equivalent of the Kuiseb Formation in central Namibia. The rocks are highly metamorphosed and structurally complex. The Kuiseb Formation is intruded by numerous small irregular bodies of syn- and post-tectonic granites, with a high radioactive response. Large post-tectonic granite intrusions occur on the western flank of the Engo Valley. These granites are thought to be the source of the uranium mineralisation in the area (Fletcher 1981).

In places the Damaran basement is unconformably overlain by sedimentary strata of the Karoo Sequence. The basal Dwyka Formation consists mainly of tillite, shale, pebbly shale and lenses of conglomerate, grit, marl, mudstone and sandstone (Fig. 19).

The coarse clastic material has a black, dense argillaceous matrix, but this becomes arkosic in places, whereas the medium-to -large pebble conglomerates generally have an arenaceous grey matrix. Pebble sorting varies from poor to fairly good. The pebble sizes range from 3 mm in diameter to large cobbles and boulders, where the polimictic pebbles and boulders are generally subangular (Fletcher, 1976).

The individual rock units in this succession are generally lensoid and discontinuous.

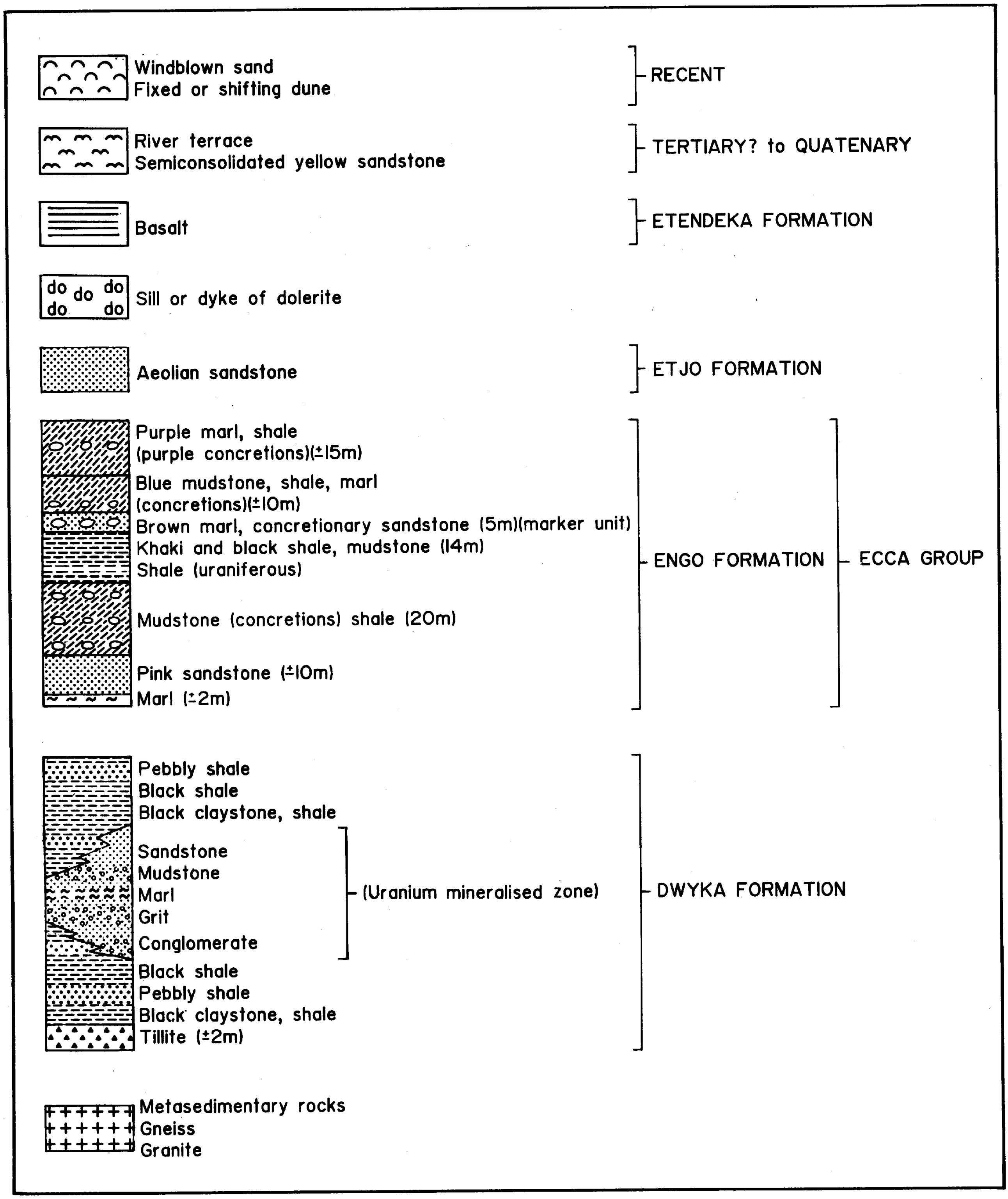

Figure 19: Lithology and stratographic subdivision of sediment in the Engo Valley (after General Mining and Finance Corporation).

Detailed field studies have suggested a possible fluvio-glacial to lacustrine depositional environment.

The overlying Engo Formation of the Ecca Group is made up of a succession of pink sandstone, mudstone, shale and marl. The presence of concretions throughout virtually the entire succession is diagnostic. A prominent sandstone containing concretions up to one metre in diameter near the middle of the succession serves as a useful marker horizon.

A number of sporadic prominent radiometric anomalies have been recorded in the valley over a distance of some 20 km (Fig. 20). Follow-up ground radiometric surveys delineated four anomalous areas, termed D1, D2, D3 and the "main uranium occurrence".

No direct correlations between anomalies and lithologies could be established. However, the uranium mineralisation was found to be confined to the Dwyka and Engo Formation of the Karoo Sequence.

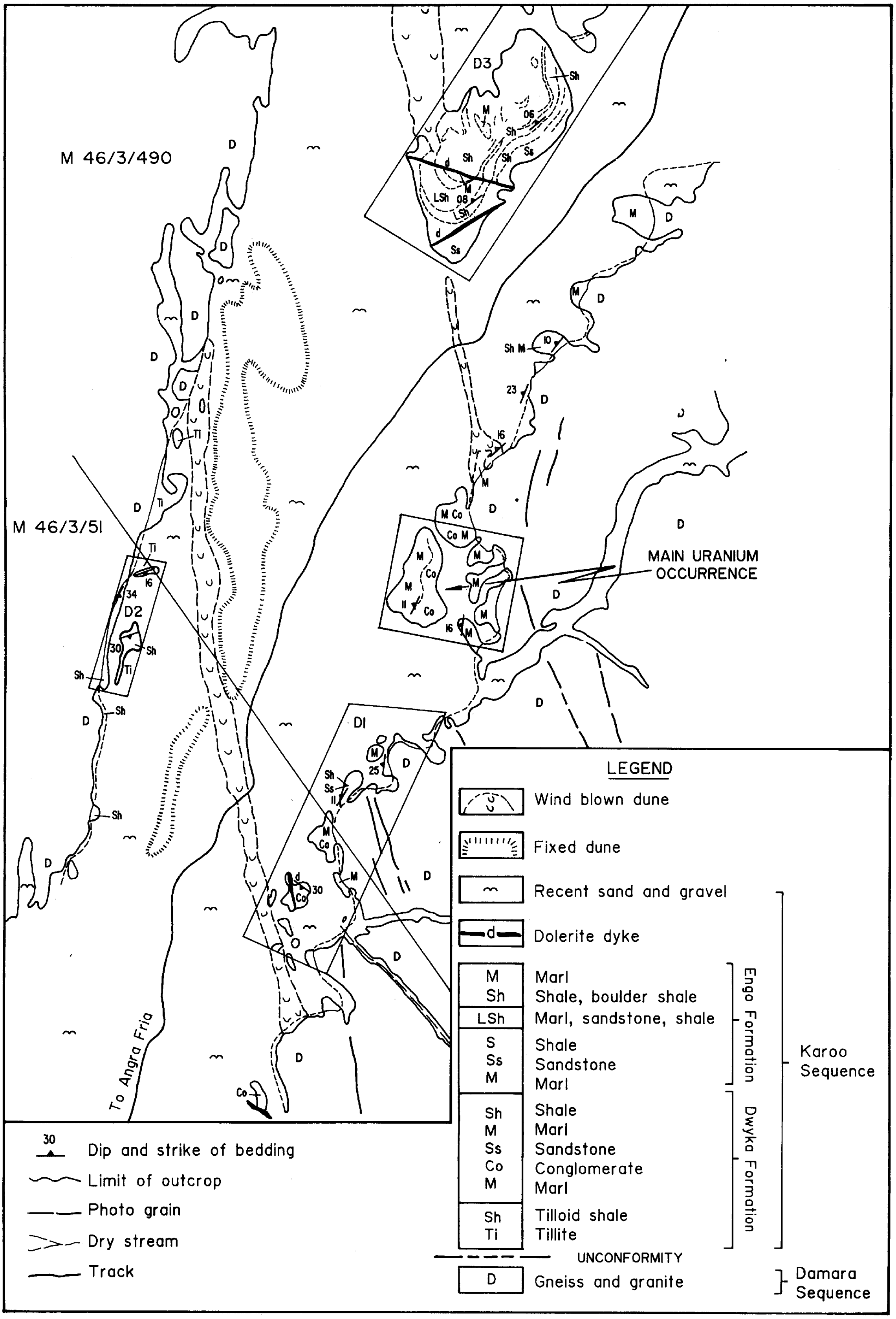

Figure 20: Geological map of the Engo Valley area (after General Mining and Finance Corporation).

In the Dwyka Formation, discoformity-type uranium mineralisation occurs in fluvio-glacial alluvial fan-type deposits. At the “main occurrence” (Fig. 20) visible uranium mineralization (carnotite) is disseminated in the coarse clastic strata of the Dwyka Formation. The black shale of the Dwyka Formation contains large amounts of sulphides, mainly pyrite. The general uranium background content tends to be higher in this unit than in other lithotypes. In the shale band of the middle Engo Formation the uranium occurs as very fine-grained uraninite associated with pyrite and chalcopyrite.

The ore reserves calculated for two mineralised zones termed M.U.O. (Main Uranium Occurrence) and D1 Extension North are as follows:

M.U.O.	3.20 million t at 331 g/t
D1	2.48 million t at 352 g/t
Total	5.68 million t at 34 g/t

The grade within the mineralised zones varies greatly over small distances. Therefore the whole mineralised section would have to be mined to take out patches of high grade ore (Fletcher, 1981).

4.1.1.2 The Huab deposit

In 1976 the General Mining and Finance Corporation conducted an airborne radiometric survey over the area north of the Doros Crater. The area covered comprises of the farms Twyfelfontein 534, Verbrande Berg 725 and Probeer 535. A number of radiometric anomalies were detected and these were subsequently investigated (Fig. 21).

Horizontal beds, mainly of the Karoo Sequence, unconformably overlie folded schist and dolomitic marble of the Damara Sequence. The sedimentary formations of the Karoo Sequence have been intruded by numerous dolerite dykes and sills, and are capped covered

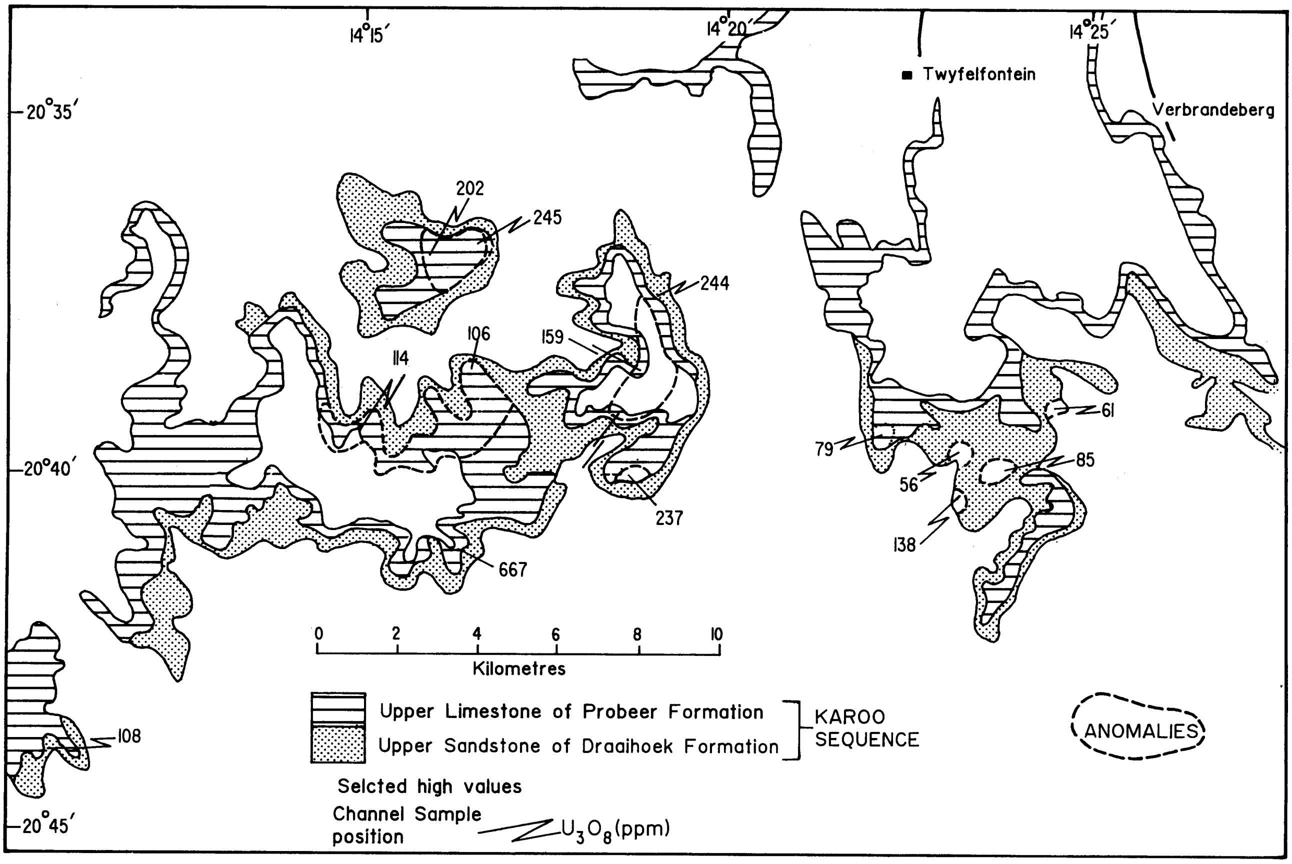

Figure 21: Simplified geology of the Huab area showing outcrops of the uranium-bearing strata (after Hartleb, 1979).

by several hundred metres of lava flows of the Etendeka Formation.

The Prince Albert Formation is the lowest unit of the Karoo Sequence in the area. It consists of an occasional basal breccia which fills depressions on the eroded Damaran surface. The breccia is succeeded by shales with a total thickness of 70 m. The shales consist of 35 m of black shale at the bottom, overlain by 10 m of white shale and an upper 25 m of varicoloured shale.

The upper Prince Albert Formation consists of the Draaihoek Sandstone Member, which contains intercalations of impure, sandy and concretionary sandstone. The member is usually 8 to 15-m-thick and serves as a useful marker horizon. The upper 1 to 2 m of the Draaihoek Sandstone are calcareous and uranium-bearing.

The Probeer Formation overlies the Draaihoek Sandstone Member and it consists of an alternating sequence of limestone, shale and marl. The basal portions are made up of about 8 m of grey and blue impure shale and claystone, overlain by a hard, 2-m-thick limestone bed, containing calcareous concretions up to 25 cm in diameter. This unit is overlain by 8 m of shale which are topped by alternating bands of grey, dark yellow, brown or purple limestone. The uppermost limestone bed varies in thickness from 1.0 to 3.6 m and is uranium-bearing. The uraniferous limestone is overlain by a “disc limestone” consisting of 30-cm-long limestone discs and lenses, which are contained in a purple gritty matrix. The “disc limestone” also contains uranium and serves as a marker horizon.

The succeeding Gai-As Formation consists of a rapidly alternating succession of red-bed sequence, purple siltstone and shale beds. In places, conglomerate intercalations are developed in the siltstone. The red-bed sequence is capped by at least 5 m of soft purple, red or blue shale. Concretions ranging in diameter from 0.5 to 2.0 m are developed in shaley units near the base of the Gai-As Formation.

The aeolian sandstone of the Etjo Formation overlies the Gai-As Formation. The massive sandstone is pinkish to yellow in colour and displays bedding. In places, reworking of the sandstone by flowing water is evident (Hartleb, 1979).

Geological mapping and ground radiometric surveys have revealed a stratigraphic control on the mineralisation. Two uraniferous lithological units have been recognised. These are the “uranium sandstone” of the Draaihoek Member and the “uranium limestone” at the top of the Probeer Formation (Fig 21). However, within these units the uranium content varies significantly.

Ground radiometric responses over the uranium sandstone were encouraging. However, the results of the follow-up geochemical sampling revealed lower equivalent values than those expected. Subsequent statistical analysis on the data indicated that the uranium is in disequilibrium with its daughter products; i.e. the radioactivity was mostly caused by daughter products. Only four samples contained more than 100 g/t U_3O_8 and the highest recorded value was 138 g/t. The 1-50 g/t anomaly covers an area of 0.3 km^2 at an average grade of 92 g/t. The mineralisation in the uranium sandstone was found to be confined to numerous small isolated patches within the top layers. The combined tonnage of these patches, of which only a few exist, is less than 1 000 t at a grade well below 100 g/t.

All anomalous uranium occurrences within this limestone are confined to an area immediately west of the farm Probeer 535 and about 10 km north of the Doros Crater. Mineralisation is very erratic and the grade varies. Averages are given below in Table 7.

Table 7: Average grade of limestone-hosted uranium mineralisation

U_3O_8 ppm	Area km^2	Thickness cm	Average Grade g/t	Tonnage mt
+ 50	2 580	106	122	6.833
+100	0.234	92	198	0.539

The mineralisation in both the above settings is confined to palaeochannels within a sedimentary basin. The expected source of the uranium is granite, from which it was transported in the solid state. No uranium minerals were observed even in a sample assaying 600 g/t U_3O_8 (Hartleb, 1979).

4.1.2 Offshore Marine Deposits

A series of offshore marine basins, filled with diatomaceous muds, is situated on the Namibian continental shelf (Fig. 22). Bathymetric and echographic techniques were used to map the area from latitudes 19°00'S to 25 ° 30'S, extending some 100 km offshore.

The shelf was found to have a smooth gradual slope from a depth of 50 m at 10 km offshore to a depth of 150 m at 70 km offshore. No relationship was found to exists between the morphology of the shelf and the distribution of the diatomaceous muds (Meyer, 1973). Four basins with a total areal extent of 19 000 km^2 and a maximum depth of 15 m were identified. The largest basin is centred off Swakopmund and lies between 21 ° 00'S and 24 ° 00'S. A palaeo-submarine channel of the Swakop River forms a protrusion normal to the strike of the basin. Two boreholes (SWA 30 and SWA 50) have been drilled in this area (Fig. 22).

The diatomaceous mud from the basins is olive green in colour with slight colour variations causing laminations. The mud is composed of skeletal diatoms, organic matter (19% - 40%), terrigenous constituents (6% - 34%) (Calvert and Price, 1970) and water (77% - 93%) (Meyer, 1973). Below the diatomaceous mud are silty to sandy layers and fossil shell layer containing gastropods, lamellibranchs and shark teeth (Meyer, 1973). Palaeontological investigations date the muds to be of Holocene age, but the lower fossil shell layer is late pleistocene (Hambleton-Jones, 1983). For further information see also the diatomite and phosphate chapters.

The uranium values recorded from borehole samples vary between 15 g/t to 45 g/t (Fig. 23).

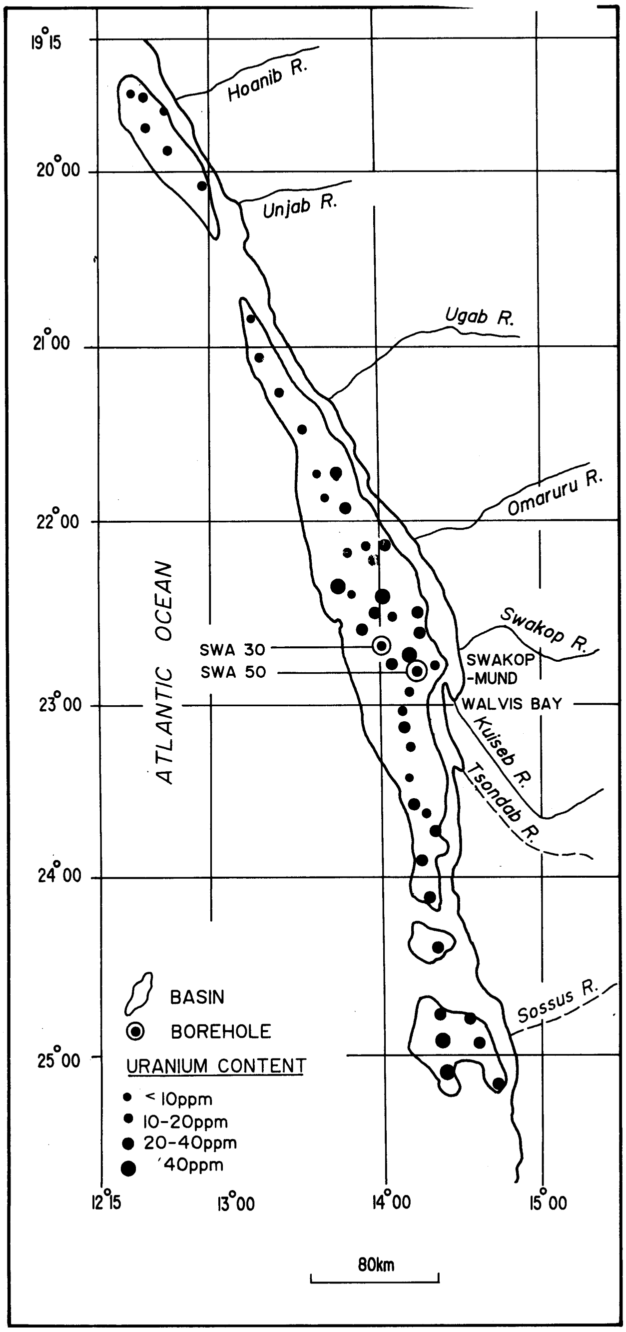

Figure 22: Offshore uranium occurrences (after Hambleton-Jones, 1983).

The highest uranium concentrations in the submarine basins are situated opposite palaeo- and recent river mouths (Fig. 22). South of Walvis Bay these are off old choked river mouths of the Tsondab and Tsauchab Rivers respectively and north of Walvis Bay, the highest uranium concentrations lie opposite the Kuiseb, Swakop, Omaruru, Ugab, Unjab and Hoanib River mouths (Hambelton-Jones, 1983).

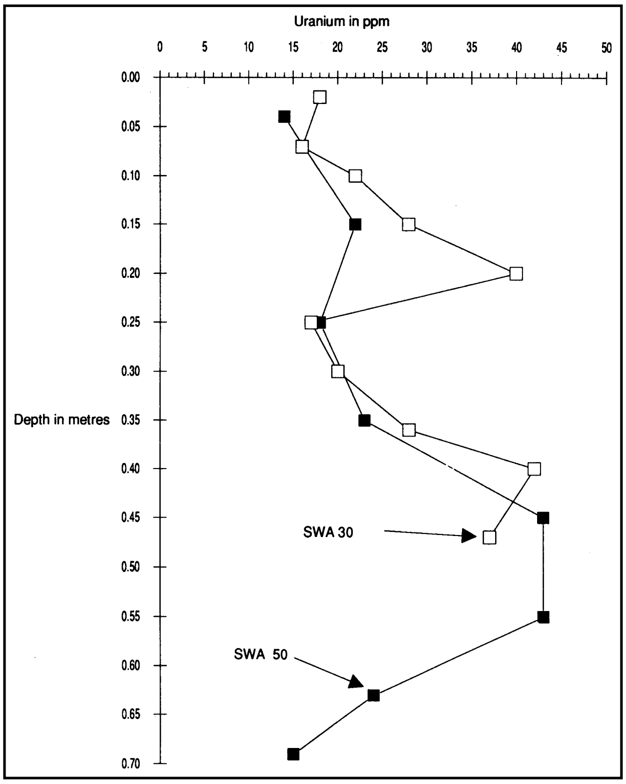

Figure 23: Uranium content in boreholes (after Hambleton-Jones, 1983).

4.2 Epigenetic Occurrences

4.2.1 Karoo Sequence

A coal sample from a drillcore from the Ovambo Basin assayed 2530 g/t U_3O_8 (von Backström, 1968).

4.2.2 Tertiary occurrences in the Namib Desert

Surficial uranium deposits in Namibia occur on the coastal plain of the Namib Desert, mainly between the Great Escarpment in the east and the “western cutoff line” in the west (Fig. 24). The deposits are associated with fluviatile environments within palaeovalleys of ancient rivers that flowed westwards from the Great Escarpment during Upper Cretaceous and Lower Tertiary times (88 to 25 million years).

Climatically the Namib Desert is extremely dry, and all of the major surficial uranium deposits occur within the 100 mm isohyet. The arid environment has preserved these uranium deposits.

Uranium in the Namib Desert occurs chiefly in the form of the mineral carnotite, but soddyite [$(UO_2)_5Si_2O_9.6H_20$] has also been reported from the Welwitschia Flats occurrence. Carnotite occurs interstitially along grain boundaries, filling cavities and has maximum development in zones of high porosity.

The age of the uranium mineralisation is difficult to establish, but determinations using the disequilibrium technique indicate that it is greater than 0.5 million years. However, geological relationships suggest that an Upper Tertiary age (2 to 5 million years) is more likely (Hambleton-Jones 1983).

Numerous secondary uranium deposits occur in this area and to facilitate the description of the deposits they have been divided into 3 geographic regions (Fig. 24): 1. the Namib Park Region which covers the area between the

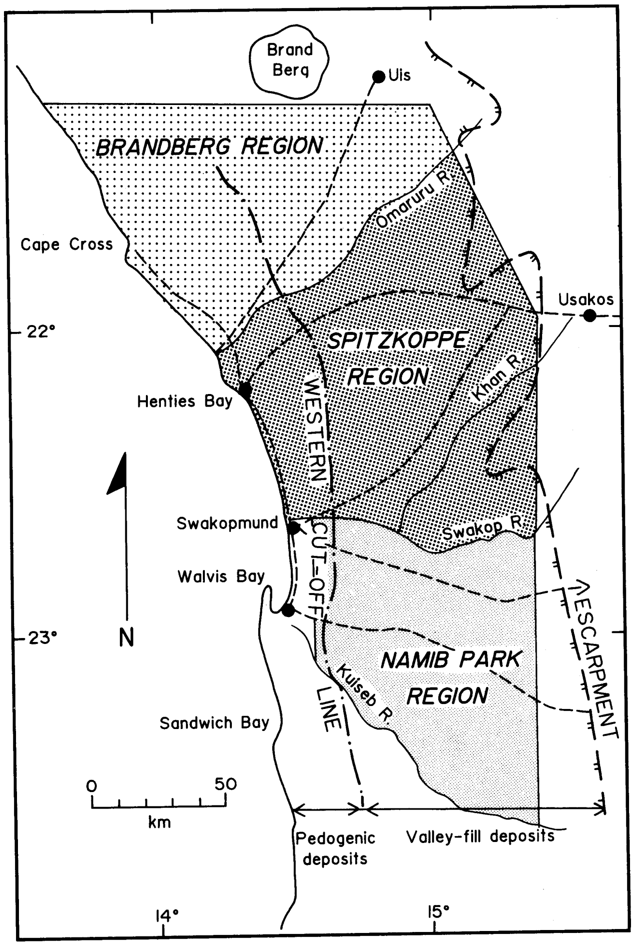

Figure 24: General map of the Namib indicating geographic regions and sedimentary uranium deposits.

Swakop River in the north and the Kuiseb River in the south; 2. the Spitskop Region which covers the area between the Omaruru River in the north and the Swakop and River in the south and 3. the Brandberg Region which covers the area north of the Omaruru River.

4.2.2.1 The Namib Park Region

An overview of the Namib Park Region is given in Fig. 25.

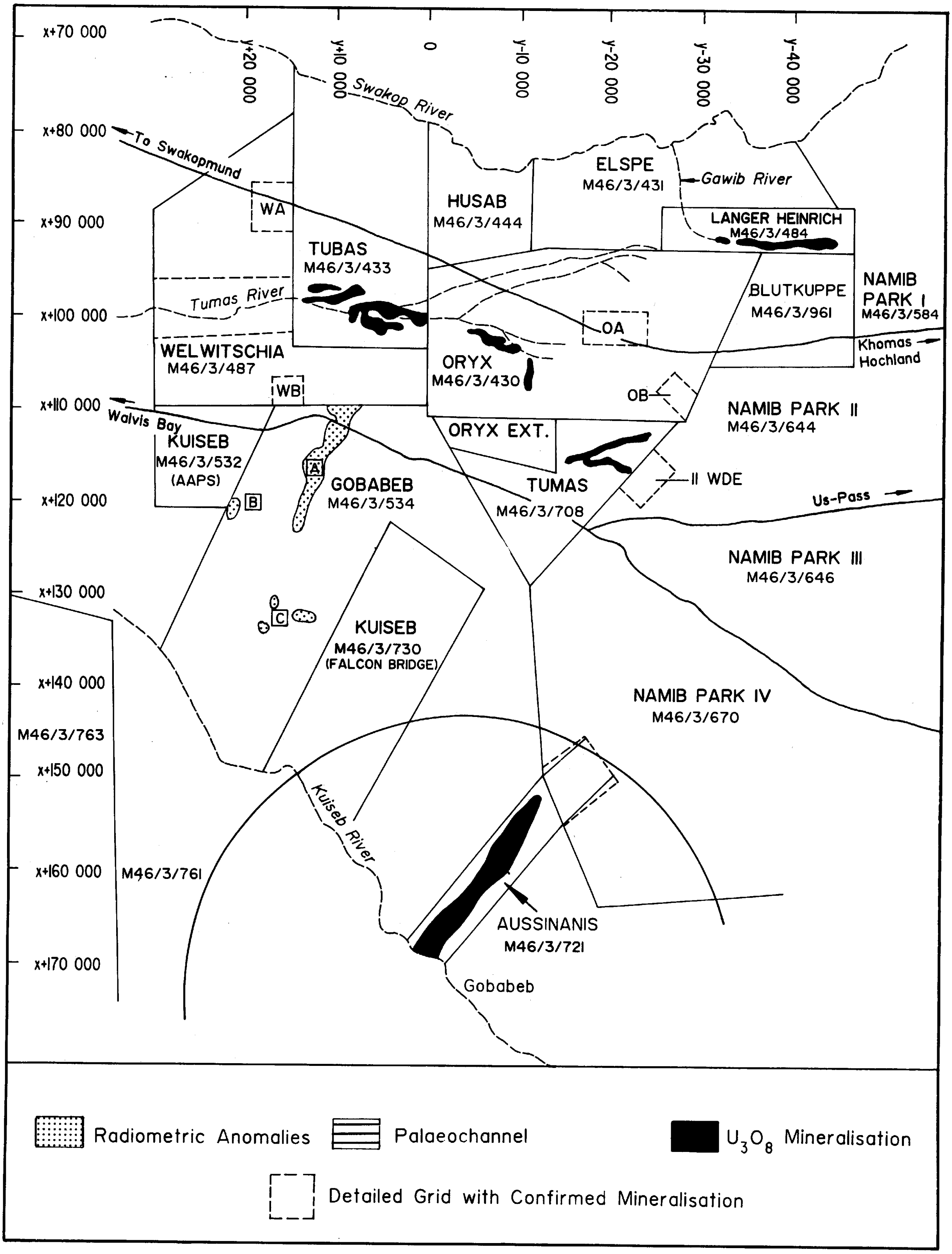

Figure 25: Uranium occurrences in the Namib Park region.

4.2.2.1.1 The Langer Heinrich Deposit

The Langer Heinrich grant area is situated in the Gawib River valley on the southern side of the Langer Heinrich Mountain, 90 km east of Swakopmund.

Carnotite was first discovered in the Gawib valley, 90 km east of Swakopmund by A.H. von Stryk in the late 1950s and the radioactivity in the area was confirmed by J. Klein. However, no active prospecting has been undertaken.

An airborne radiometric survey located a linear radiometric anomaly in the Gawib River near the Langer Heinrich Mountain.

The lowermost rocks of the Damara Sequence outcropping in this area are pink quartzites of the Etusis Formation, Nosib Group. The quartzites form the Langer Heinrich anticlinorium, which is a major structure in this area (Fig. 26). Unconformably overlying these quartzites are rhythmically interbedded fine-grained metapelite, metagreywacke and calcsilicate beds of the Tinkas Member (Khomas Subgroup).

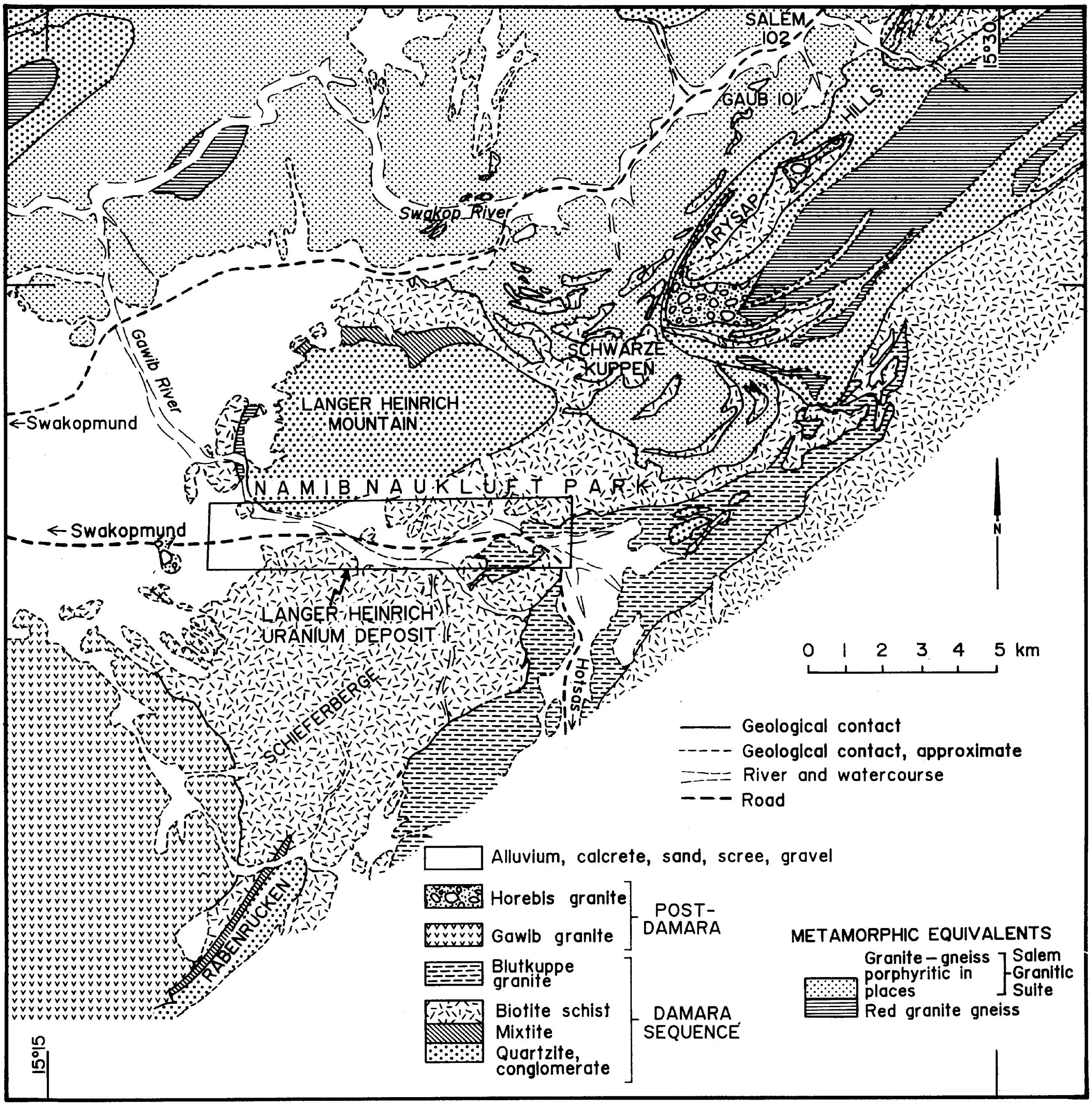

Figure 26: Generalised geological map of the Langer Heinrich area (modified after Jacob, 1974).

The orogenic Salem Granite has intruded the metasediments and covers large areas north of the Langer Heinrich Mountains. Southeast of the mountains, the Bloedkoppie Granite, which is a leucocratic late to post-tectonic member of the Salem Granite Suite, has intruded the metasediments and covers an area of about 25 km^2. The Bloedkoppie Granite is medium grained and consists of quartz, microcline and plagioclase with about 5% biotite. On average it contains 10 to 15 g/t U_3O_8 and values up to 100 g/t U_3O_8 have been measured radiometrically. The Bloedkoppie Granite is of the same age as the alaskites and may be genetically related to them.

The Langer Heinrich valley is a portion of a 13-km-long east-west trending palaeochannel which transects the Bloedkoppie Granite in the east, and the Khomas Schist in the central and western parts. The northern bank of the palaeochannel is formed by the Nosib Quartzites.

Climatic changes, which probably occured during the Tertiary, led to a switch from erosional to depositional conditions. During the onset of the depositional cycle the palaeomorphology of the channel was very rugged and formed a constriction between the Langer Heinrich Mountain and the Schieferberge in the south. Calcrete terraces within the Langer Heinrich valley indicate an original sediment thickness of 60 m and a channel width ranging from 200 to 1000 m. However, subsequent headwater erosion in the central and eastern portions of the paleochannel by the Tinkas and Gawib rivers removed 30 to 40 m of the original sediment. In the Langer Heinrich valley the sediments are only exposed in a few places, being mostly covered by 1 to 3 m of scree.

Bedding of the fluvial sediments within the palaeochannel is sharp and lenticular. Crossbedding is present, with vertical lithology changes being rapid and irregular. Sorting is poor to moderate and there is a general upwards decrease in grain size. The characteristic sediments are siltstones, conglomerates and breccias with either a silty or calcareous matrix. Sedimentation normally began with a basal conglomerate or breccia, followed by an alternation of siltstone, conglomerate, breccia and calcareous arkose. The beds vary from a few decimetres to a few metres thick. Towards the top, calcareous arkose (calcrete) becomes a major component (Hartleb, 1988).

The mineralisation is hosted by fluvial sediments of the palaeochannel (Figs 27 and 28).

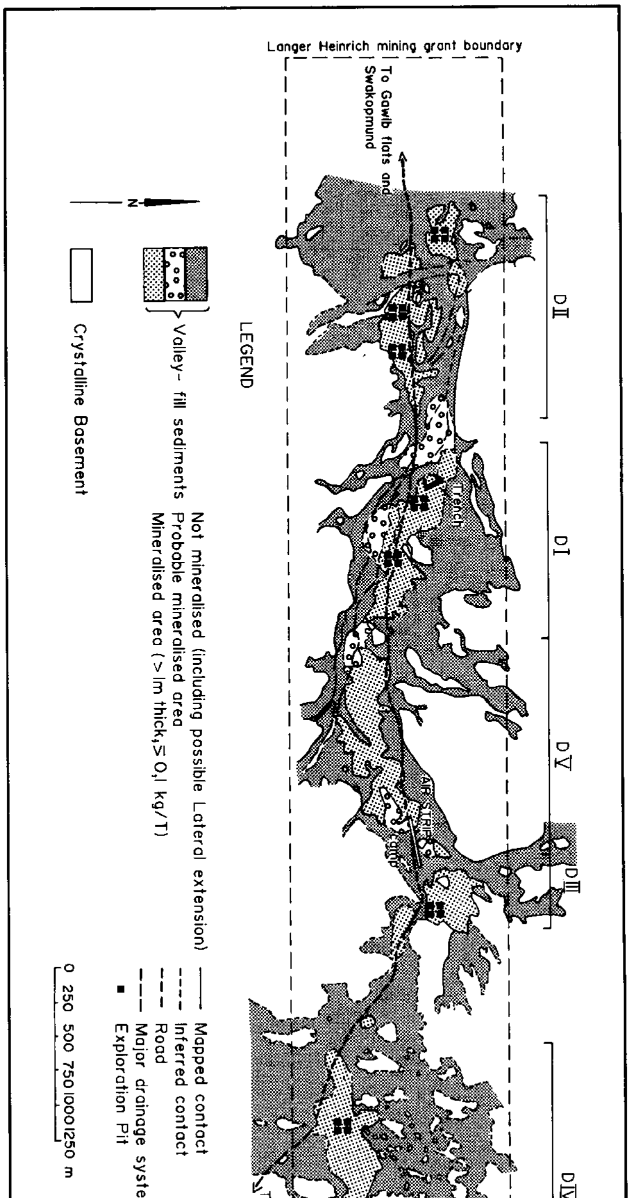

Figure 27: Horizontal projection of mineralised areas (after General Mining and Finance Corporation).

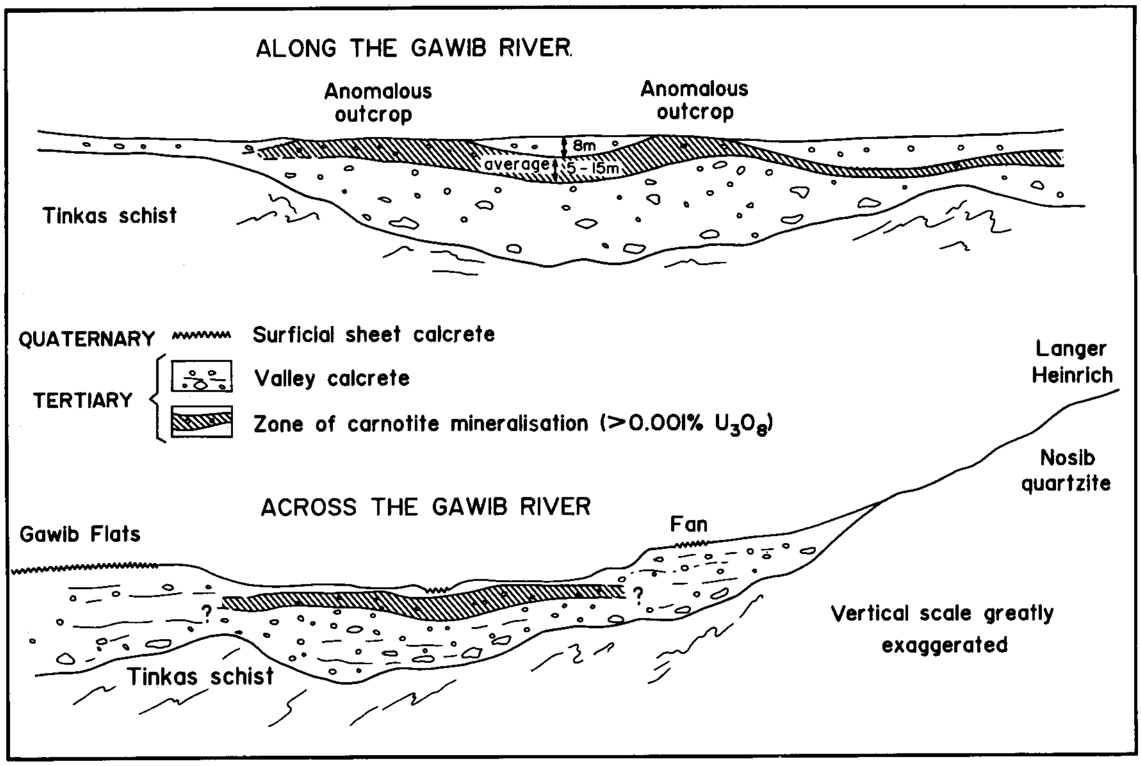

Figure 28: Diagrammatic cross-sections showing the relationship of the mineralised calcrete to bedrock, terraces and fans at Langer Heinrich.

It is confined to several thin tabular bodies along the length of the palaeochannel and is generally situated a few metres above the bottom of the channel fill. In vertical section there is only one ore-bearing zone which has irregular gradational hangingwall and footwall contacts. The grade of mineralisation tends to be higher in the centre of the zone. Mineralisation is not controlled by lithology and occurs throughout the different sediment types. The mineralisation extends westwards, crosses the northward-flowing Gawib River and continues under the recent sediment cover for 2.5 km.

Yellow carnotite is irregularly distributed throughout the uraniferous sediments. It occurs as small patches and lenses, around pebbles and in cracks and may be finely disseminated in the host rock.

The poorly calcium-cemented sandy grits tend to contain the highest grades of mineralisation. Carnotite is concentrated in irregularly shaped calcium-carbonate concretions in the silty sediments. Carnotite specks, up to 2 mm in diameter are irregularly distributed within the calcium-carbonate matrix (Hartleb, 1988).

Table 8: Ore reserve calculation of the Langer Heinrich occurence (after Linning, 1976)

Area	Tonnage	Grade kg/t	Overburden width (m)	Ore width (m)	Overburden :ore	Probable depth ext. tonnage	Grade kg/t
I	7 729 687	0.44	6.64	7.39	1:1.19	1 553 125	0.438
II	10 050 000	0.46	5.28	5.94	1:1.13	853 125	0.527
III	4 931 250	0.30	6.90	8.05	1:1.2	681 250	0.389
IV	11 575 000	0.30	10.38	6.34	1:0.61	1 250 000	0.304
V	11 000 000	0.33					
Total	35 285 937	0.36				4 337 500	0.409

Ore reserves were calculated for the different areas and are presented in Table 8. The grade of the ore decreases and the overburden ratios decrease from west to east.

The geometry of the deposit and the ore to overburden ratio are such that the most feasible mining method envisaged would be by a shallow opencast operation. An alkaline leach process was proposed because of the high carbonate content of the ore (Linning, 1976).

4.2.2.1.2 The Tubas Uranium deposit

The Tubas deposit is situated along the Tumas River some 40 km east of Walvis Bay. The deposit was located during exploration conducted over the Tubas Grant (Fig. 25).

Anomalous zones were located in the southern part of the grant which is transected by the westwards-flowing Tumas River. T-cup survey anomalies were percussion drilled and this located secondary uranium mineralisation associated with the palaeochannel of the Tumas valley.

The Tumas valley is in excess of 40-m-deep and the rock types occupying the palaeovalley consist of red to brick-red sand or sandstone, grits, conglomerates, gypsum and calcrete. Red sands occur up to 10 m below surface. Calcretes of ranging shades are present below the red sands. Within the calcretes are loosely consolidated grits and gravels (Fig. 29).

Uranium mineralisation in the Tumas River drainage is present mainly in tabular bodies of the upper 20 m. The mineralisation is

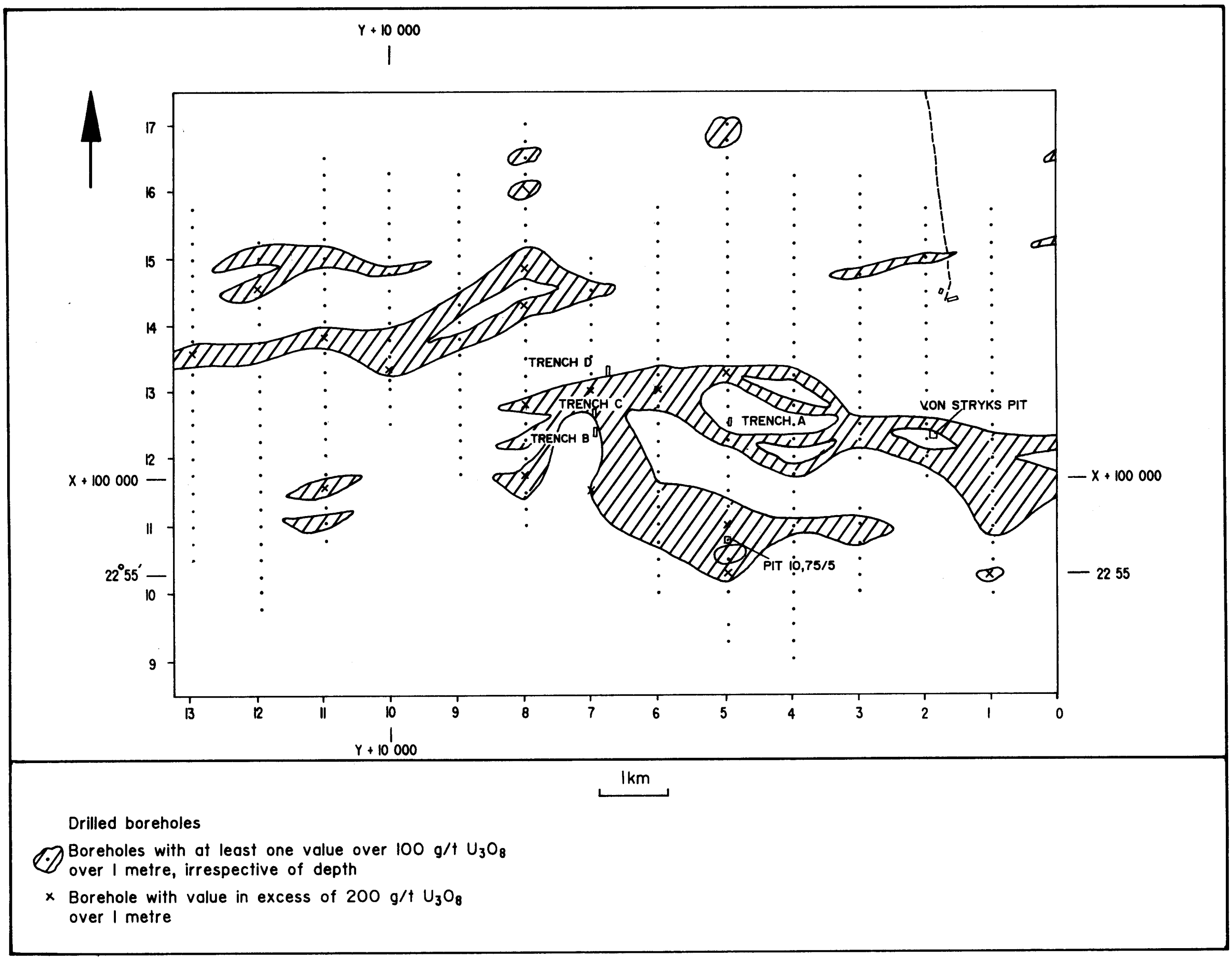

Figure 29: Plan showing drillhole positions in the Tubas River area (after Anglo American Prospecting Services).

predominantly associated with red sands but values in excess of 100 g/t have also been recorded from calcretes and gravels.

Carnotite occurs as yellow specks and streaks, or coats worm burrows or shrinkage spaces around larger clasts. Traces of uranium have also been identified in refractory heavy minerals.

Anomalous U_3O_8 results have been intersected in 41% of the boreholes drilled in the Tumas River (Fig. 30). These values range between 50 to 200 g/t. The highest individual assay result recorded was 951 g/t U_3O_8 over one metre, some 11 m below surface. The same borehole returned an average value of 639 g/t U_3O_8 over three metres.

A preliminary estimate of the results of this programme indicated 130 million t at 90 g/t U_3O_8 over an average thickness of 7 m with an average overburden of 3 m.

An additional percussion-drill programme was conducted over selected small areas and confirmed the gypsiferous red sandstone as the main host for mineralisation. Higher grades were also indicated with values in excess of 1 000 g/t U_3O_8 being returned from boreholes on three of the twelve lines drilled. The single highest assay was 8 177 g/t over 1 m (Wagener, 1977b).

Pitting and trenching in selected areas indicated extreme variability of mineralisation over small areal separations of ±2 m. During the later phases of exploration, metallurgical tests were undertaken on the ore but the unfavorable uranium market led to the termination of exploration activities (Wagener, 1983).

4.2.2.1.3 Oryx

The Oryx Grant area is situated in the Namib Desert Park, 70 km east of Walvis Bay (Fig. 25).

Rocks of the Damara Sequence overlie red granite and metasedimentary rocks of the Abbabis Formation, which form dome-like structures in the western part of the grant area. The Damara Sequence is represented by quartzites, biotite gneisses and conglomerates of the Nosib Group in the west and the Chous Formation and Tinkas Member of the Swakop Group in the east. The Swakop Group rocks are intruded by a north-south trending oval-shaped mass of post tectonic granite.

The grant area is characterised by northerly-to northeasterly-trending structures. Folding has produced large-scale basin-and-dome structures as well as smaller isoclinal folds. The major axes and plunge directions of the fold structures parallel the regional fabric of the area.

Two anomalies termed OA and OB were defined by the initial exploration programme and subsequent follow-up surveys focused on these areas (Fig. 25).

Anomaly OA is covered by superficial deposits of alluvium, residium, calcrete and gypsum. The area is bounded in the east by outcrops of the Tinkas Member and in the west by red granite gneisses of the Abbabis Formation. Projecting through the surficial cover are numerous small outcrops of pegmatite and marble. A radiometric survey defined a northwesterly-trending anomaly over surficial material. The anomaly is defined by a 20 g/t U_3O_8 isoline and contains areas of higher values which peak at 80 g/t U_3O_8.

Soil samples were analysed for U_3O_8 and ThO_2 and anomalies of these were found to coincide with the total-count radiometric anomalies. In the eastern part of the detailed grid only, U_3O_8 anomalies occur and are due to the presence of secondary uranium in calcrete and gypcretes. Uranium anomalies were defined as being greater than 25 g/t U_3O_8, with the highest value recorded being 137 g/t U_3O_8. Thorium anomalies are defined by the 30 g/t ThO_2 isoline and peak in the western part of the grid at 127 g/t ThO_2.

Anomaly OB is covered by alluvium, calcrete, gypcrete and scree, through which frequent outcrops of Tinkas Member schist,

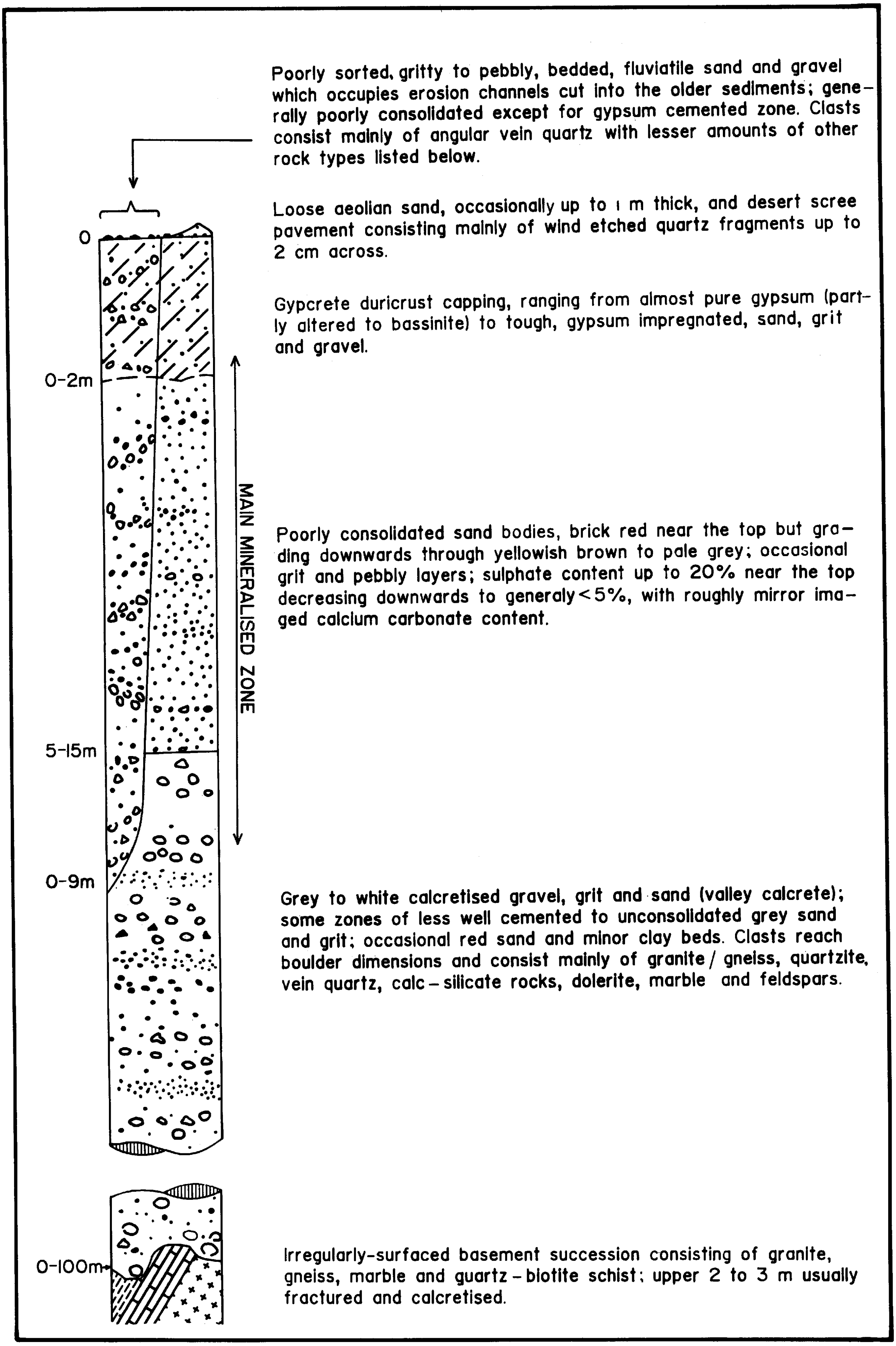

Figure 30: General stratigraphic column of the Tubas secondary uranium deposit (after Anglo American Prospecting Services).

Chuos Formation mixtite and Nosib Group quartzite protrude. The eastern part of this anomaly is underlain by late tectonic granite. Structurally the area is complex with fold areas trending both east-west and north-south.

Two anomalies were defined by a radiometric survey. The first measures 300 by 130 m with a peak value of 180 g/t equivalent U, and is located over weathered outcrop of Tinkas Member schist. The second anomaly is 400 by 60 m in extent and is located over surficial sediments. It has a peak value of 90 g/t equivalent U.

An assessment of all results led to the shift of exploration emphasis towards secondary uranium mineralisation in the Tumas drainage and its tributaries.

A drilling programme located secondary uranium mineralisation in the calcrete and gypcrete surficial sedimentary deposits. The mineralisation consists of sporadic anomalous U_3O_8 which occurs at variable depths and is confined to the palaeochannel.

Metallurgical testwork on selected percussion-drill samples indicated that wet scrubbing could upgraded the secondary mineralization (Marsh, 1984).

The anomalies associated with the Tumas River were found to extend southwards into a major tributary channel and the Oryx Extension Grant was subsequently taken out to investigate these.

Six small weakly-mineralised areas covered by 6.2 m of overburden were delineated. They indicated approximately 8 000 000 t U_3O_8 at a grade of about 140 g/t (Bothe, ca. 1975).

4.2.2.1.4 Tumas Deposit

The Tumas grant is situated 70 km due east of Walvis Bay and covers a portion of the Namib Desert Park (Fig. 25).

The area is underlain mainly by biotite schists, quartzites, meta-greywackes, marbles and silicates of the Tinkas Member of the Karibib Formation. The rocks have been intensely folded and locally have a north-northeast - south-southwest strike and steep dips. Intrusive Salem type granites and pegmatites occur mainly in the west. Karoo age dolerite dykes have intruded parallel to the regional foliation trend of the Damaran metasediments.

Aeromagnetic surveys located one major and three other significant anomalies. A detailed block, termed Block A, was designed to cover these anomalies.

Block A is situated in the northeastern part of the grant area. A marked ridge of Tinkas Member metasediments on the western boundary of the grant has given rise to a restriction in the east-west drainage resulting in only one outlet to the west. This has resulted in a damming effect to the east and sedimentation of mainly calcareous lithologies took place within the palaeochannels (Fig. 31).

The calcareous grit is a mature sediment containing grains of rounded to sub-angular quartz and feldspar cemented by calcium carbonate. Clasts of Damaran metasediments

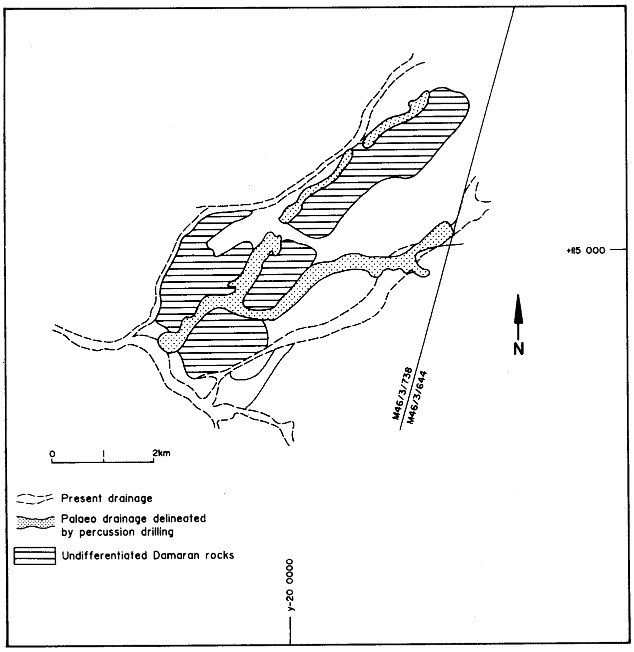

Figure 31: Simplified geology of the Tumas deposit (after Falconbridge of SWA).

and Karoo dolerites are rarely present. The rock is very similar to the Langer Heinrich Formation found at the Langer Heinrich deposit. Carnotite mineralisation is generally sparsely distributed although rich patches associated with smoky quartz grains grade up to 510 g/t U_3O_8.

An immature brown calcareous siltstone, containing greater amounts of angular fragments and a higher percentage of mafic minerals, is considered to be younger than the calcareous grits described above. It is cemented by calcium carbonate and its brown colouring is due to the weathering of mafic minerals.

It crops out over an area of some 700 by 150 m, but radon cup surveys have indicated that it may extend for a further 1 000 m within the sand-filled present Tumas drainage system.

The rock is consistantly mineralised across the outcrop and carnotite occurs as cavity-fills and also as a finely disseminated phase. The grades vary between 315 and 770 g/t U_3O_8.

Surficial sands cover most of the plains in Block A. Calcretisation of these sediments has occurred and concretionary calcretes form a continuous capping beneath the sand-covered areas.

Gypcretes form the youngest of the sediments and occur as cements in river gravels and sedimentary breccias. Gypsiferous sedimentary breccias were found to contain up to 60 kg/t U_3O_8 (Borton, 1977).

Five mineralised zones were detected within the northern channel. The zones correspond well with the palaeochannel which has been dissected by metasedimentary barriers. The thickness of the palaeochannel varies between 1 and 15 m, averaging 10 m, whereas the thickness of the mineralisation itself varies between 1 and 5 m, averaging 3.2 m. The grades are constant and average 200 g/t U_3O_8.

The southern channel is far more consistently mineralised and presumably formed the main palaeochannel. Thicknesses of calcretized gritty fluvio-sediments vary between 1 m and >20 m, averaging 12 m. The thickness of mineralisation is also variable between 1 m and 11 m with an average of 3.5 m. The grade averages 260 g/t U_3O_8. However, a high-grade area containing approximately 1 million t at 560 g/t is present in the south of the southern channel.

The total reserves of the Tumas deposit have been estimated at 13 million t at an average grade of 244 g/t U_3O_8 (Ransom, 1981).

The southern channel extends eastwards into the Namib Park II grant area (Fig. 25). The area has been covered by a 1 by 1 km T-cup grid and a 0.5 by 1 km soil sample grid. Anomalous areas were then covered by a detailed T-cup grid.

The reserves calculated are presented in Table 9.

Table 9: Ore reserve calculation of the NIIWDE area (after Kotze, 1978)

Cut-off grade (g/t)	Tonnage	Grade g/t	Overburden (tons)
100	30 201 200	237	20 887 600
200	8 617 600	352	20 887 600
300	8 617 600	466	19 486 400

Two aero-radiometric anomalies situated over weathered schist were surveyed and drilled. No significant U_3O_8 mineralisation was encountered (Kotzé, 1978).

4.2.2.1.5 The Aussinanis Deposit

This deposit is situated north of the Gobabeb Desert Ecological Research station (Fig. 25) and was located during an airborne radiometric survey.

The pediplain consists of a more recent veneer of calcrete and in places, gypcrete, which attains a thickness of one metre. The pediplain is shallowly dissected by a recent drainage system draining towards the Kuiseb River.

A palaeochannel with a northeasterly trend was located in this area. Schists of the Kuiseb Formation and Salem and Donkerhuk Granites occur as shallow outcrops along the northern and southern fringes of the palaeochannel. Pedogenic calcrete forms a superficial cover to the palaeochannel which has a depth of not more than 20 m.

The palaeochannel has been infilled and choked with tertiary detritus, which consists largely of angular to sub-angular cobbles and fragments of a variety of granitic rocks and quartz pebbles of local derivation.

A ground radiometric survey conducted in this area delineated an anomalous area measuring 1 800 by 14 000 m.

Uranium occurs as irregular dispersed carnotite in blebs, reworked veinlets and as thin coatings surrounding pebbles. The mineralisation was found to occur with random and irregular frequency in a tabular horizon lying near surface and extending up to depths of between 7 and 10 m. The ore zone is some 15-km-long and varies between 2 km and 200 m in width. The thickness of the ore body is between 1 and 2 m and occasionally up to 5 m (Debaveye, 1981).

The ore body extends to the northwest, where field investigation of airborne radiometric anomalies led to the discovery of small showings of carnotite in schists, Salem Granite and drainage channels.

Selected secondary uranium anomalies associated with southwesterly-trending channels were investigated in detail by a percussion drilling programme. However, only 3 holes intersected grades of higher than 100 g/t U_3O_8 (Linning, 1976).

4.2.2.1.6 Minor Occurrences

Elspe Grant

Radiometric surveys located anomalous areas over river sediments, where carnotite occurs in joints. Values of up to 260 g/t U_3O_8 were recorded. Drilling focused on the palaeovalleys of the Gawib River and uranium mineralisation of less than 100 g/t U_3O_8 was found to occur in isolated mineralised zones (Linning, 1977).

Gobabeb Grant Area

Airborne spectrometer and magnetometer surveys conducted over this area located three anomalies which were termed A, B, and C (Fig. 25).

Anomaly A is 10-km-long and 1 to 2-km-wide, with some zones having more than 100 cps. Anomaly B has some values in excess of 100 cps. Anomaly C consist of 3 different small areas with values over 100 cps (Mouillac, 1978).

Bloedkoppie

The Bloedkoppie Granite contains between 10 to 15 g/t with a maximum of 100 g/t U_3O_8. Percussion holes were drilled into calcrete channels in the northern, eastern and southern part of the grant area. The average thickness of the calcrete was found to be 7 m and two holes assayed values grater than 100 g/t U3O8 (Hartleb, 1981).

Kuiseb Grant

A palaeochannel with a northeasterly trend was investigated. However, only small traces of carnotite were observed (Galloway and Ransom, 1982).

Ruimte 125

In the central-northwestern part of this farm an anomaly with an areal extent of 3.3 million m^2 was located. Surface chip samples from this area analysed between 340 and 540 g/t U_3O_8 (Kotzé, 1978).

4.2.2.2 Spitskop Area

4.2.2.2.1 The Klein Trekkopje Deposit

An airborne radiometric survey located the Klein Trekkopje uranium deposit, some 17 km northwest of the Trekkopje Siding (Fig. 32). The main uranium mineralisation is associated with a palaeochannel that extends from an area in

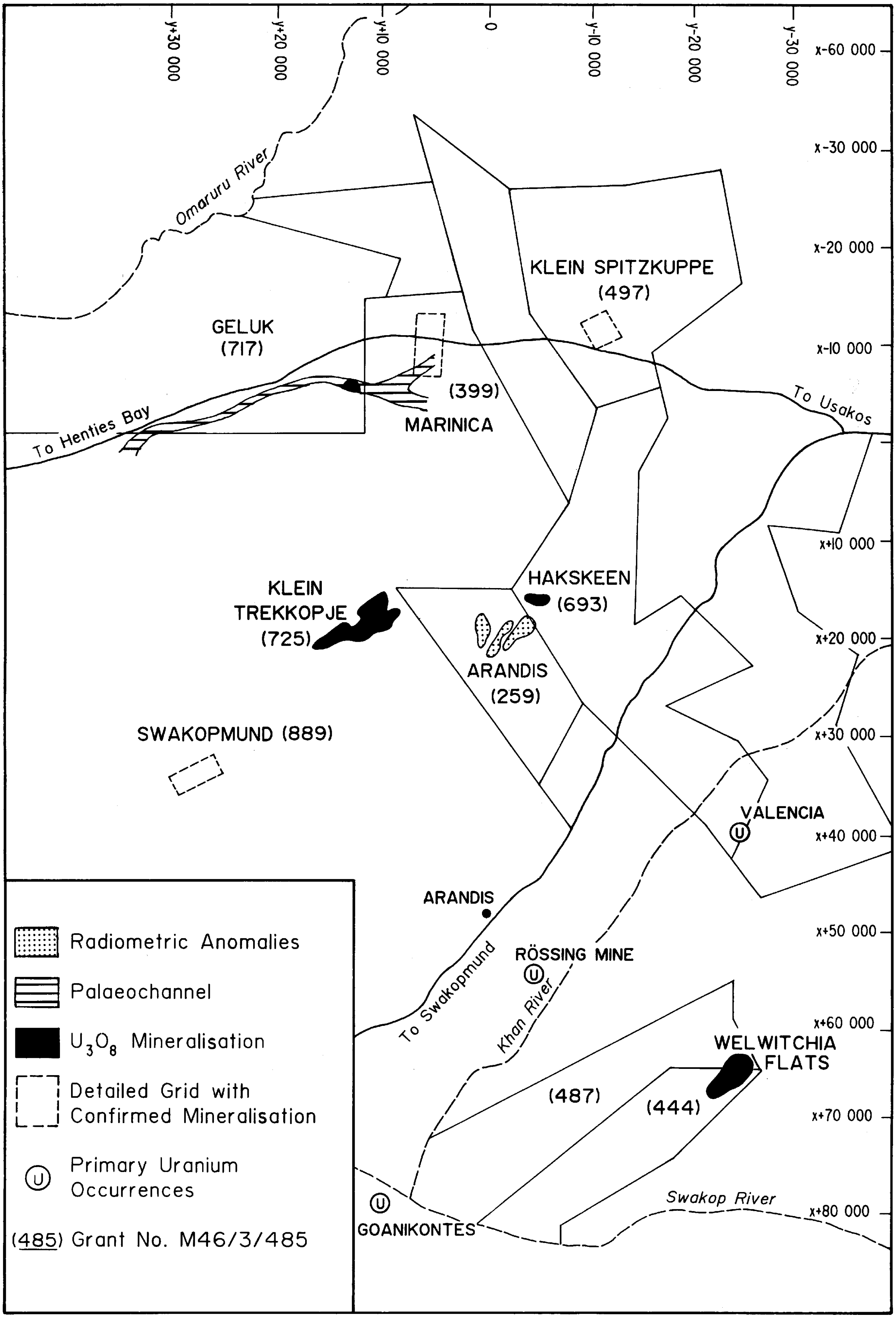

Figure 32: Uranium occurrences in the Spitzkoppe region.

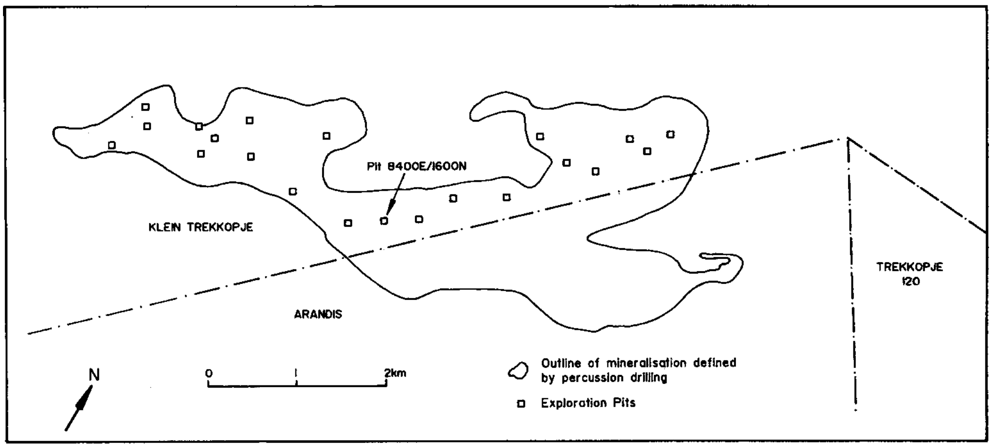

Figure 33: The Klein Trekkopje occurrence (after Omitara Mines).

Damaraland, immediately west of the farm Trekkopje 120, towards the farm Hakskeen 89 in the east (Fig. 33).

The area consists essentially of a flat pediplain shallowly dissected by a westward draining, reticulate, recent drainage system which trends southwest-northeast. In places inconspicuous outcrops of marble and biotite schist of the Khomas Subgroup delineate a palaeoriver system.

A crust of gypcrete, less than 3-m-thick, covers an extensive area underlain by calcrete (Fig. 34). The contact of gypcrete with the underlying calcrete is transitional. Textures and

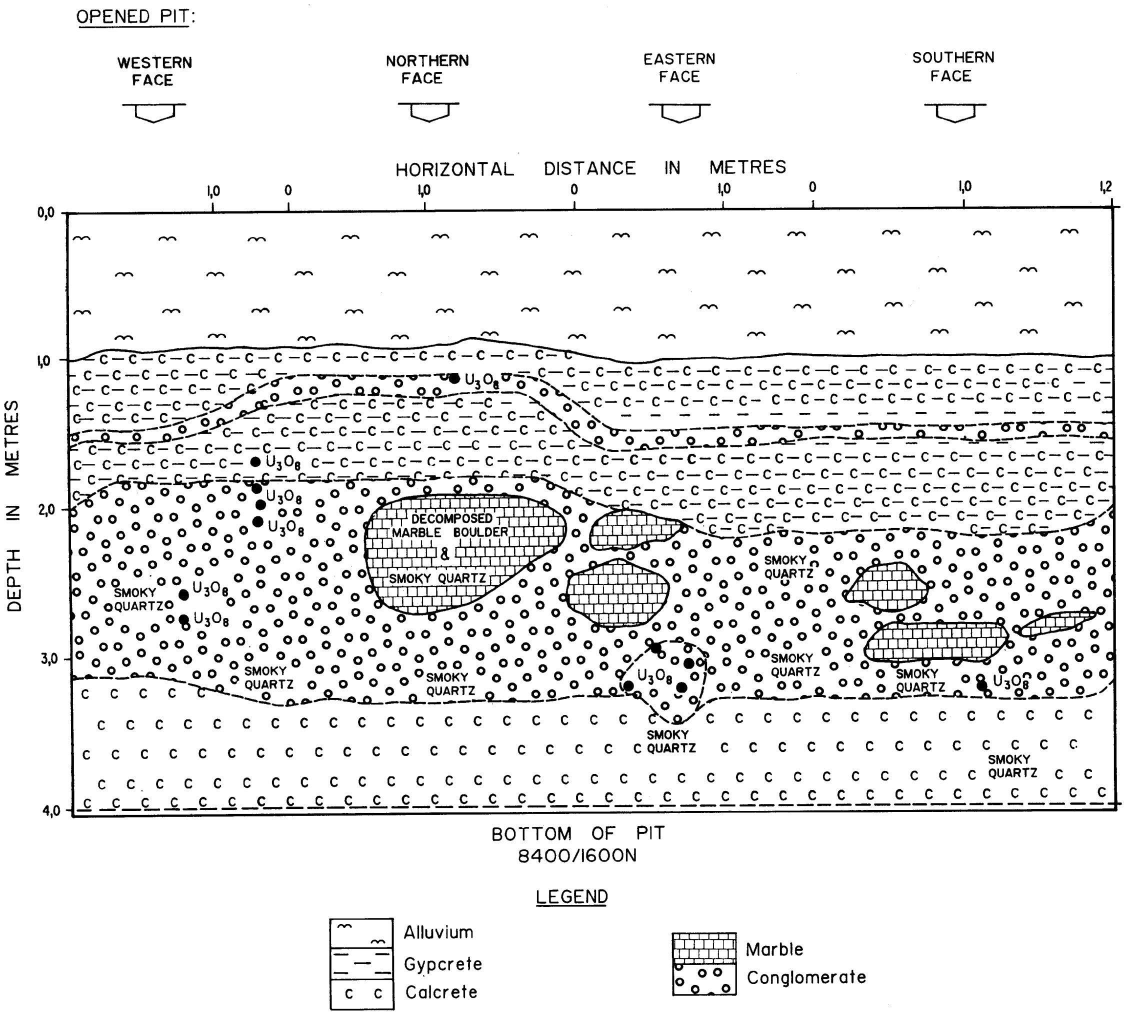

Figure 34: Section of pit 8400/1600N (after Omitara Mines).

structures in the gypcrete suggest that it is not a normal evaporite deposit but rather a combination of detrital and chemical sediments.

The calcrete consists predominantly of coarse, unsorted, angular to subrounded granitic and quartzitic fragments that have been cemented by lime. The rock was described as a moderately well cemented, open textured, permeable pebbly grit and conglomerate.

An airborne radiometric survey delineated an anomaly associated with an east-west trending palaeochannel, which has a maximum length of 15 km and a width of 1 to 2 km. The radiometric anomalies had a moderate to strong response in the uranium channel, but little or no effect was detected on the thorium and potassium channels.

The mineralisation is present as a 16-km-long and 2-km-wide tabular sheet, which occurs at depths ranging between 2 and 17 m below the present surface. The ore zone thickness ranges between 1 and 2 m and does not occur at a constant level or horizon. Carnotite is present as irregularly distributed blebs or veinlets and as thin coatings on mainly quartz cobbles and pebbles (du Plessis, 1983).

The ore reserves, using a cut off grade of 80 ppm U_3O_8, and including the eastwards extension into the adjacent Arandis Grant areshown in Table 10.

Table 10: Ore reserves of the Klein Trekkopje occurrence

Ore tonnage	360 000 000
U_3O_8 tonnage	39 500
Average grade (g/t)	100
Average stripping of overburden (m)	3
Average thickness of ore (m)	8

4.2.2.2.2 Arandis Deposits

An airborne geophysical survey conducted during 1971 as part of the evaluation of the Arandis tin prospect located five anomalous radioactive zones (Figs 32 and 35), all

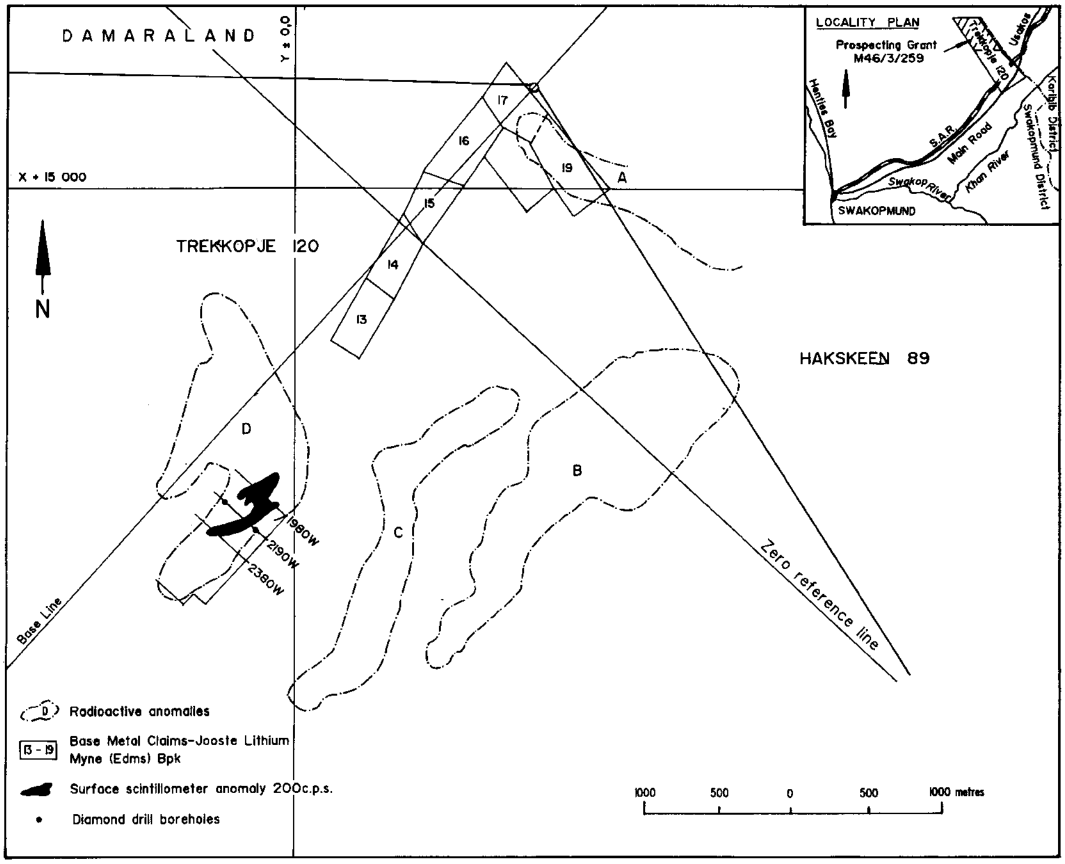

Figure 35: The Arandis occurrence (after Heath, 1973).

associated with the Klein Trekkopje palaeochannel. Zones B, C, and D measuring 156, 78 and 105 hectares respectively, appeared to be the most promising and were subsequently investigated.

Exploration results indicated the widespread existence of sporadic uranium mineralisation in the nearsurface portion of a thick (about 150 m) blanket of Tertiary calcareous conglomerate.

The mineralisation is primarily concentrated near the surface in portions of the recently-deposited host rock. Values slightly in excess of background were encountered in the vicinity of the water table (Heath, 1973).

4.2.2.2.3 Hakskeen

A radiometric survey located the eastern extension of the mineralized Klein Trekkopje palaeochannel on the farm Hakskeen 89 (Fig. 32).

Carnotite mineralisation appears to be surface accumulation confined to the northern side of a wide calcrete basin. A fair proportion of this mineralisation occurs in gypcrete which accounts for the prominent surface radiometric anomaly. The proven ore reserves are 361 250 t of U_3O_8 at 331 g/t (Johnston, 1978).

4.2.2.2.4 Swakopmund Grant

The grant area is situated in the Namib dessert between Swakopmund and Henties Bay (Fig. 32) and is mostly underlain by Kuiseb Formation schists and Karibib Formation marbles. The metasediments have a northeast-southwest regional trend but show local variations due to the doming effect of granites. Igneous rocks occurring in this area include Salem Granite, various pegmatites and dolerite dykes. Red granite gneisses area also common. The rocks of the Damara Sequence are often overlain by extensive deposits of Tertiary sands, gravels, gypcrete and calcrete.

Airborne radiometric and magnetic surveys indicated two anomalies, one developed over a palaeochannel located in the eastern part of detailed grid 2 (Fig. 32 and 36), and the second

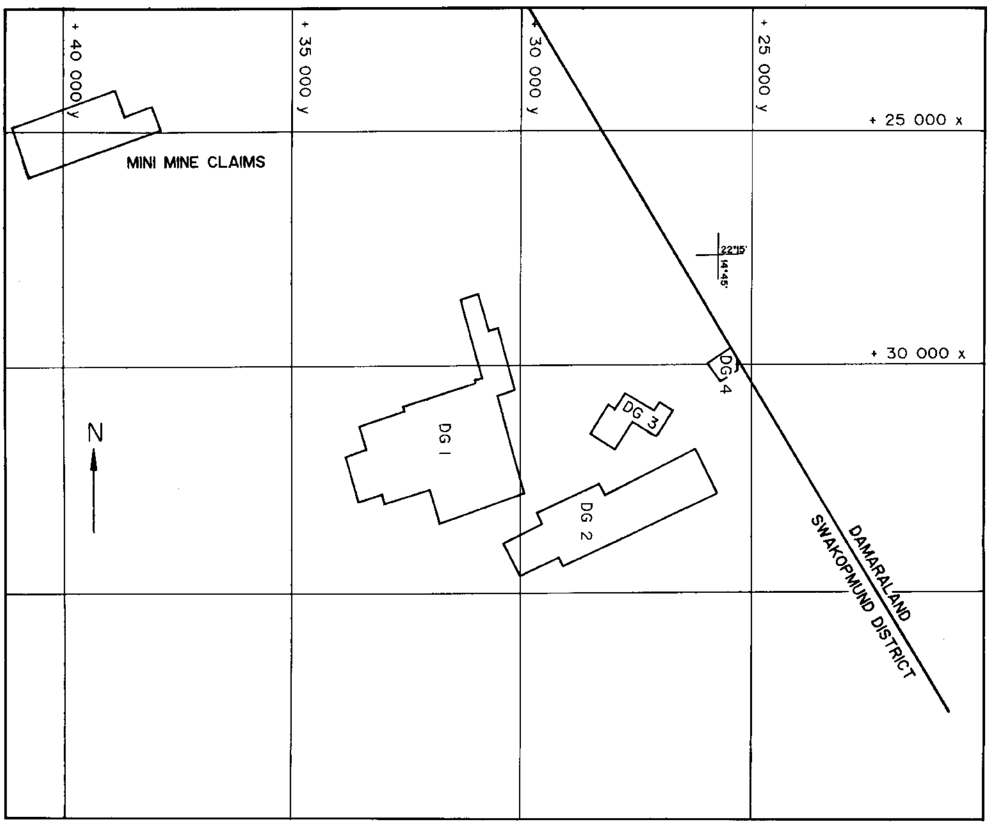

Figure 36: Locality map of the detailed grids on the Swakopmund Grant (after Rand Mines Corp.).

situated over granite in detailed grid 5.

Regional ground surveys were undertaken in the southern half of the grant. Several anomalies were located and investigated by detailed surveys in grids 1 to 6.

Grid 1: Uranium mineralisation was identified in several types of settings:

a) Secondary surface mineralisation occurs associated with red granite gneiss and alaskites. The uranium appears to have been leached from the underling rocks and precipitated in the weathered zone in joints and fractures lined with gypcrete and calcrete. A percussion drill sample from this area assayed 132 g/t U_3O_8 over the upper 5 m.

b) Secondary mineralisation occurs in shear zones between two red granite gneiss domes. The mineralised zones, assaying 200 to 11 300 g/t U_3O_8, are narrow and widely spaced. Towards the south of the shear zone, one particular shear with a strike length of 3 000 m and a width ranging between 1 to 10 m assayed as follows:

- 530 g/t U_3O_8 over 4.0 m over a strike length of 175 m.
- 370 g/t U_3O_8 over 1.25 m over a strike length of 450 m.
- 200 g/t U_3O_8 over 26.0 m over an unknown strike length.

Percussion drilling also indicated a number of 0.2-m-thick zones which occur over a width of 2 to 10 m. These assayed between 500 and 5 000 g/t U_3O_8, averaging 300 g/t U_3O_8.

No primary mineralisation was identified, but the close association between the secondary mineralisation and the red granite gneiss, alaskite and granite, favours these rocks as being the source of uranium.

Grid 2: Secondary uranium mineralisation is associated with an east-west trending palaeochannel. The mineralisation occurs in a zone between 25 and 50 m in width and 100 and 300 m in length. Ore reserves calculated for this area are 970 000 t U_3O_8 at 71 g/t.

Along the westward extension of the palaeo-channel a weakly mineralised zone of 16 by 400 m is present. The ore reserves calculated for this area are 1.87 million t at a grade of 70 g/t U_3O_8.

Secondary uranium also occurs within a shear zone developed along the northern margin of the red granites. Trench sample results from this area ranged between 150 and 500 g/t U_3O_8 over widths of 1.5 to 1.7 m (Dodd, 1980a).

4.2.2.2.5 The Klein Spitzkoppe Deposit

During 1968 an airborne radiometric survey indicated anomalous radioactivity on the farm Klein Spitzkoppe 70 (Fig.32).

The anomaly is situated over calcretes to the southeast of the Klein Spitzkoppe (Figs. 32 and 37). The regional geology of this area consists of

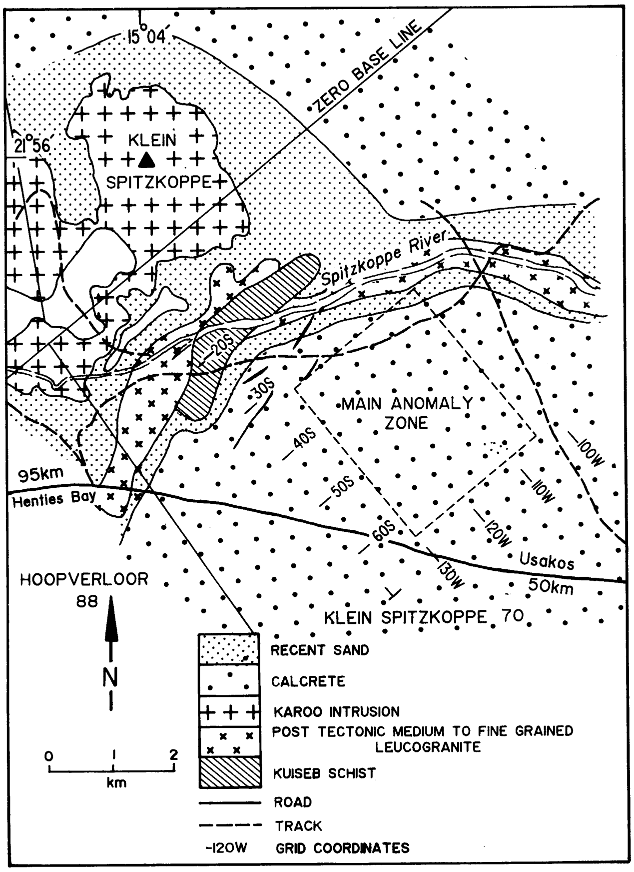

Figure 37: Locality map of the Klein Spitzkoppe Deposit (after General Mining and Finance Corporation).

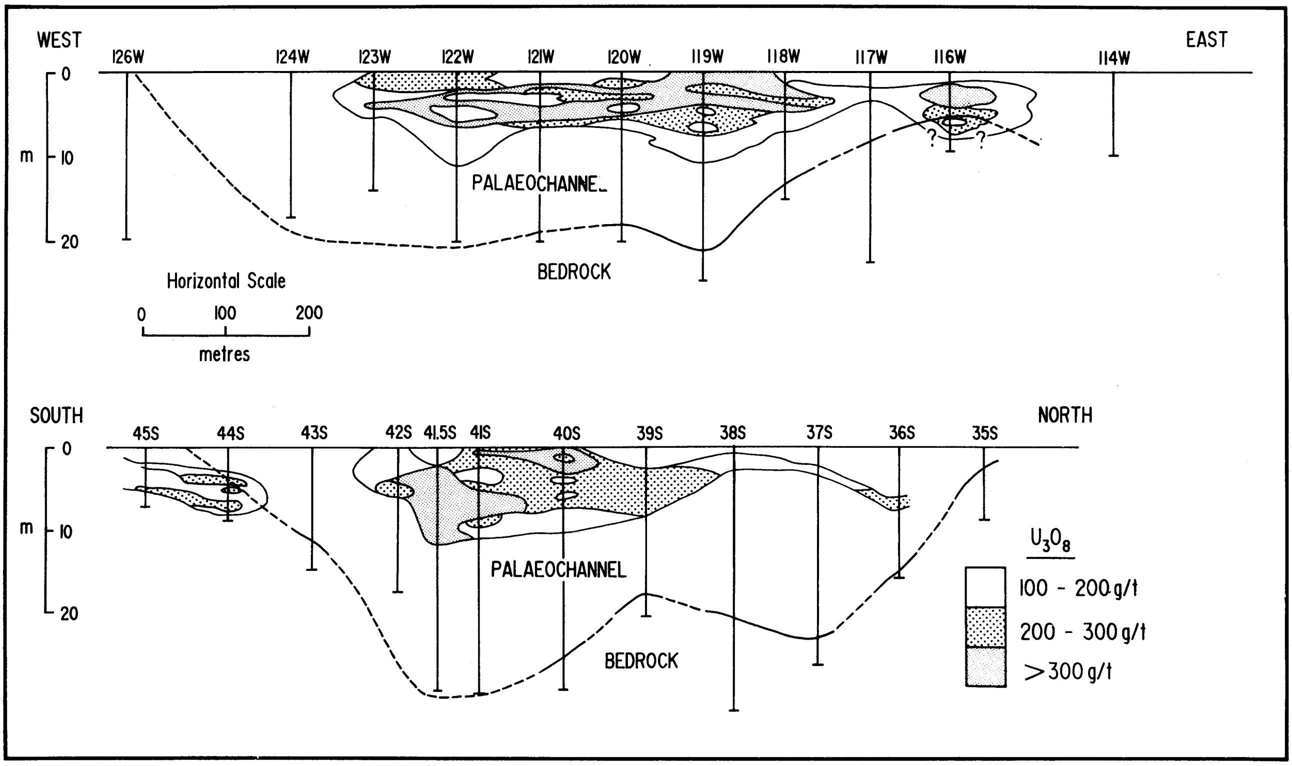

Figure 38: Section along line 2700E, detailed Grid 2 (after Rand Mines Corporation).

Damaran granites, marbles and schist and the Cretaceous Spitzkoppe Granite. The bedrock geology occurs as inliers in the calcrete as well as along erosion channels of the larger streams and particularly in the Spitzkop river channel.

Detailed percussion drilling and one diamond drillhole indicated calcrete depths of up to 30 m (Fig. 38). The calcretes are believed to be of fluviatile origin and occur in a palaeochannel, which extends southwards. Within the palaeochannel lenses of clay and sand/silt are interbedded with coarse grits and conglommerates, all of which were subsequently calcretised.

The mineralisation within the main anomaly zone consists of carnotite-enriched calcrete. The carnotite occurs interstitially within the carbonate matrix of the calcretes and also as grain coatings in the coarser calcrete types. The mineralisation has an average depth of 10 m, with a maximum of 20 m. The degree of mineralisation is isolated and variable. The total tonnages calculated for this area are 4 466 000 t at a grade of 239 g/t U_3O_8 (Johnston, 1978).

4.2.2.2.6. Marinica

The Marinica Grant is situated about 70 km west of Usakos on the gravel road towards Henties Bay (Fig. 32).

The regional geology of this area consits of basin-and-dome tectonic features, where massive marbles of the Karibib Formation form three domal structures, while steeply-dipping biotite schists (Kuiseb Formation) form the basins. Four uranium anomalies are associated with the domal structures and this indicates that these structures have extended a considerable influence over deposition of secondary uranium minerals.

Anomaly 1: Results obtained from this area were poor, with only a few boreholes encountering values in excess of 200 g/t U_3O_8. Only one hole exceeded 300 g/t. The best results were recorded from the south, and values decreased to the north and west. The mineralisation was found to be restricted to the uppermost 5 to 6 m.

Ore reserves:

Surface area (m^2)	49 600
Tonnes	432 000
Average grade U_3O_8 (g/t)	132
Average thickness of ore body	3.5 m

Anomaly 2: The mineralisation in this area is present in two zones, 2A and 2B.

Anomaly 2A trends east-west and one drillhole assayed 480 g/t U_3O_8 over 8.1 m. Secondary uranium mineralisation occurs in both granite and pegmatite.

Ore reserves:

Surface area (m^2)	80 000
Tonnes	839 500
Average grade U_3O_8 (g/t)	160
Average thickness of ore body	4 m

Anomaly 2B: This anomaly consists of a thick diffused body that thins out laterally.

Ore reserves:

Surface area (m^2)	80 000
Tonnes	976 800
Average grade U_3O_8 (g/t)	102
Average thickness of ore body	4.7 m

Anomaly 3: The mineralisation is concentrated in an elongated semi-horizontal lense, trending northeast.

Ore reserves:

Surface area (m^2)	50 400
Tonnes	500 000
Average grade U_3O_8 (g/t)	194
Average thickness of ore body	3.7 m

Anomaly 4: This anomaly is calcrete-covered. The values in the calcrete are erratic and most of the mineralisation was intersected in the upper 5 to 6 m. Locally high values of up to 500 g/t U_3O_8 over 2.5 m were recorded.

A second drilling phase on 120 m grid intervals and to depths of 15 m covered the areas of anomalies 1 to 3. The results of the programmes were combined and four main areas of mineralisation were located (Fig. 39). Mineralised Area 1 is situated to the east of Anomaly 1. Area 2 straddles the boundary of Anomalies 1 and 2. Area 3 lies in an elongated east-west configuration and was detected by the initial drilling programme. Area 4 lies in the northern portion of anomaly 3 and was also detected by the initial drilling programme.

Area 2 has the richest mineralisation. Values exceed 150 g/t U_3O_8 over a fairly large area and mineralised zones are wider than 3 m (Labuschagne 1976).

Two distinctly different types of secondary uranium mineralisation occur. In the northwestern portion of the mineralised area the mineralisation is present in weathered schist, granite and pegmatites. It fills joints, cleavage planes, fracture surfaces and schistosity planes. Calcite and gypsum have been observed in association with the uranium minerals (mostly carnotite). This mineralisation occurs at shallow depths and is rarely present below 12 m, with the bulk of it above 8 m.

The second type of mineralisation occurs in calcrete filling a palaeodrainage channel. The calcrete is mainly covered by sand and is only exposed in a limited number of shallow excavations. The best mineralisation observed in these excavations is also associated with the widespread development of gypsum. The carnotite tends to concentrate in nodular and tube-like structures in the host rock. Some fine disseminations of uranium minerals have also been noticed in other excavations.

On a regional scale the mineralisation tends to follow the outline of three marble dome structures. In the northern sector of the mineralised area, a correlation between the trend of mineralisation (palaeochannel) and the present drainage system exists (Bertram, 1975).

4.2.2.2.7 Welwitschia Flats

Secondary uranium mineralisation was discovered in the Welwitschia Flats (Fig. 32) in calcretes exposed by erosion channels. A T-cup survey indicated that the mineralisation extends northwards.

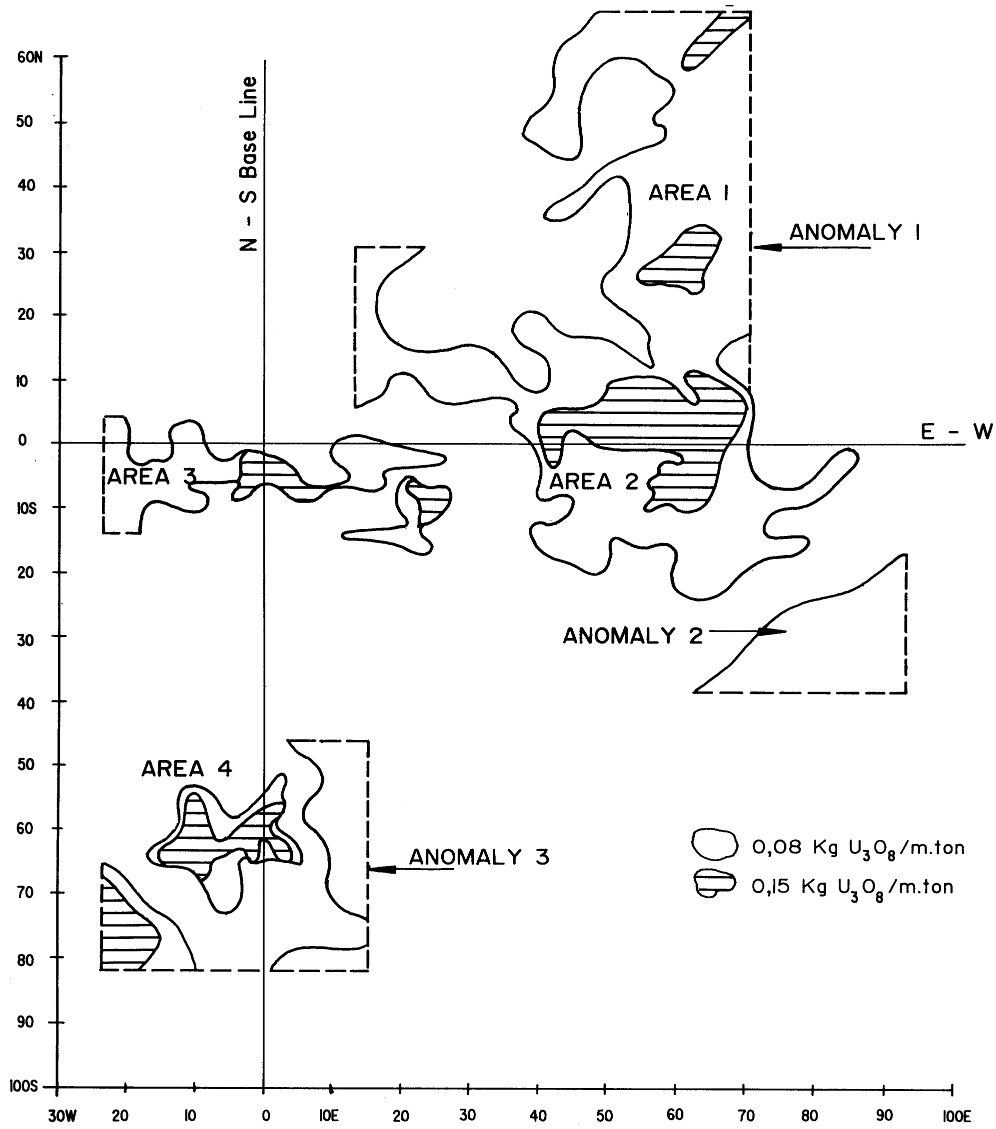

Figure 39: Precussion drillhole profiles of the Main Anomaly Zone, Klein Spitzkoppe deposit (after General Mining and Finance Corporation).

Percussion drilling in this area was done on a 250 m square grid and consisted of 127 holes totaling 1391 m. The ore reserves for this area, using boreholes containing at least one 1 m intersection of 100 g/t U_3O_8 with a lower cutoff grade of 50 g/t, are 35 million t at an average grade of 120 g/t U_3O_8. This mineralised zone has a thickness of 5.3 m and a stripping ratio of less than 1. Two alternative separate mineralised blocks containing a total of 5.4 million t at an average grade of 180 g/t, a thickness of 4.4 m and a cover of 4 m, were delineated using boreholes containing at least one 1 m intersection of 200 g/t with a lower cut-off grade of 100 g/t.

A pitting programe in this area indicated that the mineralisation is extremely variable (Bothe, 1980)

4.2.2.2.8 Minor Occurrences

Geluk

The Geluk Grant area covers 80 000 ha and is situated to the west of the Marinica grant, in the southwestern part of Damaraland. The Omaruru River bisects the northwestern portion of the area and the main road between Henties Bay and Usakos traverses the southeastern portion (Fig. 32).

Work within the grant area consisted of an areo-radiometric/magnetic survey which was followed up by ground exploration.

An area in the extreme southeastern portion of the grant, which covers the western extension of the Marinica palaeochannel, was investigated in detail. Results of the work performed indicated that carnotite is sporadically distributed within calcretised gritty sediments. Mineralisation occurs as blebs within the carbonate-rich portion of the matrix. It is sometimes finely disseminated or occurs as coatings around quartz, schist or clay fragments.

The estimated tonnage for this area is 4.5 million t at an average grade of less than 100 g/t U_3O_8 (Ransom, 1980).

Ootmoed

Percussion drilling on a few low-scintillometre anomalies associated with a palaeochannel indicated the existence of a few thousand tonnes with a grade of ±150 g/t U_3O_8 (Du Plessis, 1982).

4.2.2.3 Brandberg Area

4.2.2.3.1 Henties Bay Grant

The grant area is situated 20 km north of Henties Bay at 21°50'S and 14° 15'E (Fig. 40). Prospecting in this area was directed at secondary uranium mineralisation associated with palaeochannels.

The regional geology of this area consists of northeast-southwest trending Kuiseb Formation schists and gneisses of the Damara Sequence. Intrusive in this area are granite, pegmatite and dolerite.

Radiometric and magnetic surveys were conducted over the area. A radiometric anomaly with a U/Th ratio of more than 2:1 was located in the northeastern corner of the grant area. The anomaly is situated over red granite gneiss.

A regional T-cup survey over tertiary deposits located further uranium anomalies over palaeochannels and thorium anomalies over sandy delta regions. Trenching of the paleochannel anomalies exposed carnotite which assayed 48 g/t U_3O_8 on average . Assays from percussion drill holes returned 162 g/t U_3O_8 over 0.3 m some 0.95 m below surface.

A further palaeochannel was investigated by 49 percussion drillholes totalling 505 m. A mineralised zone with a length of 7 km and a with of between 0.2 and 0.5 km was located. The thickness of the mineralised zone varies from 0.3 to 3.8 m and grade between 60 and 140 g/t U_3O_8 (Dodd, 1980b).

4.2.2.3.2 Cape Cross

An aero-radiometric survey located several anomalous zones which coincided with a major palaeodrainage feature some 400 m in width and extending for ±30 km in a southwesterly direction (Fig. 40).

Surface radiometric surveys detected five target areas, four of which are associated with the paleo channel. The most promising of these, Block A, was percussion drilled. The results obtained indicated that sporadic uranium mineralisation with a low grade is associated with an upper gypsiferous layer and with underlying calcareous fluviatile sediments (Ransom, 1978).

The anomaly on the southern limb is situated in feldspathic quartzites of the Kuiseb Formation. It is 13 m by 30 m in size and the calculated reserves are 10 000 t at 200 g/t U_3O_8 and 5 000 g/t thorium (Quoix, 1980).

4.2.2.3.2 Namib Rock Grant

The grant area is situated 150 km northeast of Swakopmund and is underlain by Damara schists and granites. The bed rock is obscured for the most part by a thin veneer of gravels and sands which are sporadically calcretised (Fig. 40).

Regional scintillometer surveys isolated 8 anomalous areas of which the most promising were drilled. The results obtained show a

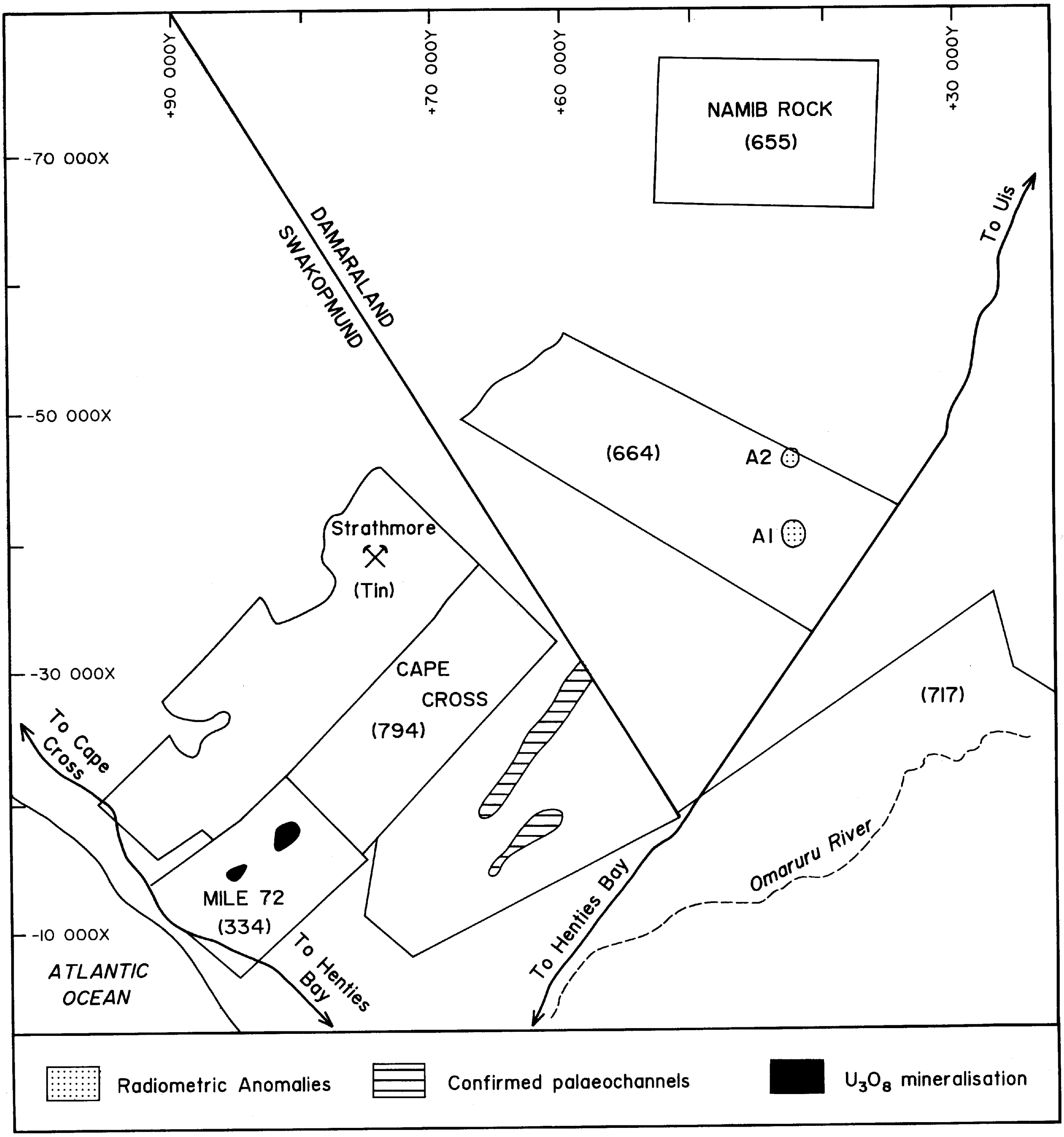

Figure 40: Uranium occurrences north of the Omaruru River.

uranium enrichment of the near-surface areas. The grades ranged between 200 g/t and 300 g/t U_3O_8. However, extensive tonnages could not be located (Keenan, 1983).

4.2.2.3.4 Brandberg South Area

A ground-radiometric survey located four anomalous areas which are associated with calcareous and gypsiferous palaeochannels with an average depth of 33 m (Fig. 40).

All anomalies were percussion drilled, but only one proved to be of economic significance. Ore reserves of 3 million t at an average grade of 212 g/t U_3O_8 were calculated. The deposit has an average thickness of 1.9 m and the highest result recorded during the drilling was 702 g/t U_3O_8. The overburden to ore ratio in the northern part is 3:1 and increases towards the south where it becomes 6.7 : 1.2 (Dippenaar, 1979).

4.2.2.3.5 Area NW of Henties Bay

This area (Grant M46/3/664) is situated 60 km northwest of Henties Bay (Fig. 40) and three radioactive anomalies, associated with calcrete-filled channels were located within it.

Anomaly 1 : Some 27 percussion holes, totaling 591 m, were drilled on this anomaly. The highest value recorded was 861 g/t U_3O_8 over 80 cm. The values were found to be erratic and average 90 g/t.

Anomaly 2 : This anomaly is underlain by coarse-grained granite, granitic pegmatite, smoky-quartz veins and occasional pelitic metasediment. Up to 3 000 cps were recorded over smoky quartz blows.

Anomaly 3 : Readings above 100 cps were recorded from an area 50 by 300 m in size (Veldsman, 1980).

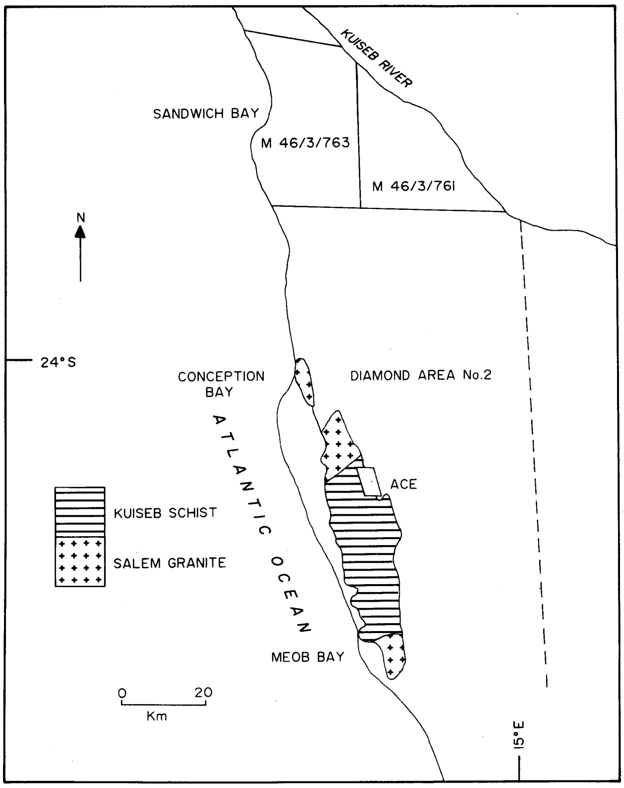

Figure 41: Simplified geology of the Meob Bay area (after Geological Map of Namibia 1:1 000 000

5. Secondary occurrences of uncertain origin

5.1 Meob Bay

In 1973 an airborne geophysical survey of the coastal portion of Diamond Area No. 2 outlined a number of high-grade radiometric anomalies approximately equidistant between Meob Bay and Conception Bay (Fig. 41). Ground examination of the anomalies revealed the presence of carnotite mineralisation in altered biotite schists and pegmatites beneath a thin capping of red and buff-coloured aeolian sands. The mineralisation is of high grade but covers a small surface area. A diamond drilling programme failed to intersect the mineralisation at depth showing it to be of purely secondary origin and of surficial extent. It is estimated that the main anomaly, termed ACE, has a total of 2 250 t of ore, at a grade of 1 424 g/t U_3O_8 adopting a 500 g/t cutoff.

The uranium is believed to have been deposited on an old erosion surface of probable Miocene age at the interface of weathered bedrock and the overlying red aeolian sands which acted as an aquifer for uraniumbearing meteoric waters (Wilson, 1978).

5.2 Uis Mine

The Uis Mine is situated 170 km north-northeast of Swakopmund and lies along a northeasterly-trending Sn-Li-Be-Nb-Ta pegmatite belt in Khomas schist. The pegmatites occupy tension fractures within a major north-south shear and are inclined at large angles to the foliation in the schist.

Calcrete up to 10-m-thick has formed in the lower parts of some narrow valleys in the mine area overlying at least one pegmatite dyke. Weathering extends to perhaps 10 to 50 m in depth. Weathered pegmatite and immediately adjacent schist are more strongly fractured than the main body of schist. Films of carnotite occur within the weathered and fractured pegmatite and schist up to 10 m from the contact and up to 20 m below the present erosion surface.

Carnotite also occurs along fractures confined to the weathered schist in association with “vein” calcrete and gypcrete (Carlisle, 1978). For a detailed description of the Uis Mine see the tin chapter.

5.3 Area south of the Kuiseb River

Aeromagenetic and radiometric surveys were conducted south of the Kuiseb River (Fig. 24). The surveys did not produce any reliable results due to the deep sand cover of the dune fields. Exsisting Water Affairs boreholes were then radiometrically logged and two target areas, Area 1 and Area 2, were delineated.

In Area 1 anomalous values (67 g/t equivalent U_3O_8) were recorded from weathered granites and schists.

The best intersection recorded in Area 2 was from the broad shallow Kuiseb palaeochannel were 104 g/t equivalent U_3O_8 over 12.2 m were detected (Fletcher, 1977).

5.4 Tsumeb Mine

Kasolite {$Pb(UO_2)(SiO_4).2H_20$] and metazeunerite [$Cu(UO_2)_2 (AsO_4)_2.8H_2O$] occur as minor constituents in the oxidation zone of the Tsumeb polymetallic orebody (Keller,1984; H.J. Laurenstein, pers.comm.).

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