

# A review of gold occurrences in the Northern and Central Zones of the Damara Orogen and the underlying mid-Proterozoic basement, central Namibia

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Historically, late Proterozoic/early Palaeozoic Pan-African terranes have never been large producers of gold. The discovery of Damaran carbonate- and skarn-hosted gold mineralisation in the Karibib District in the 1980s came as a major surprise and the Navachab Gold Mine (10.4 million tonnes at ~2.4 g/t Au; annual production of approximately 1800 kg of gold) was opened in 1989. Further exploration in central Namibia has subsequently revealed that the underlying mid-Proterozoic basement, Damaran mafic volcanic rocks and turbidite sequences are also prospective for gold. This paper presents a geological and geochemical data base that has been compiled for gold occurrences in the Northern and Central Zones of the Damara Orogen with particular reference to mineralisation in the Usakos-Karibib-Omaruru area.

## Introduction

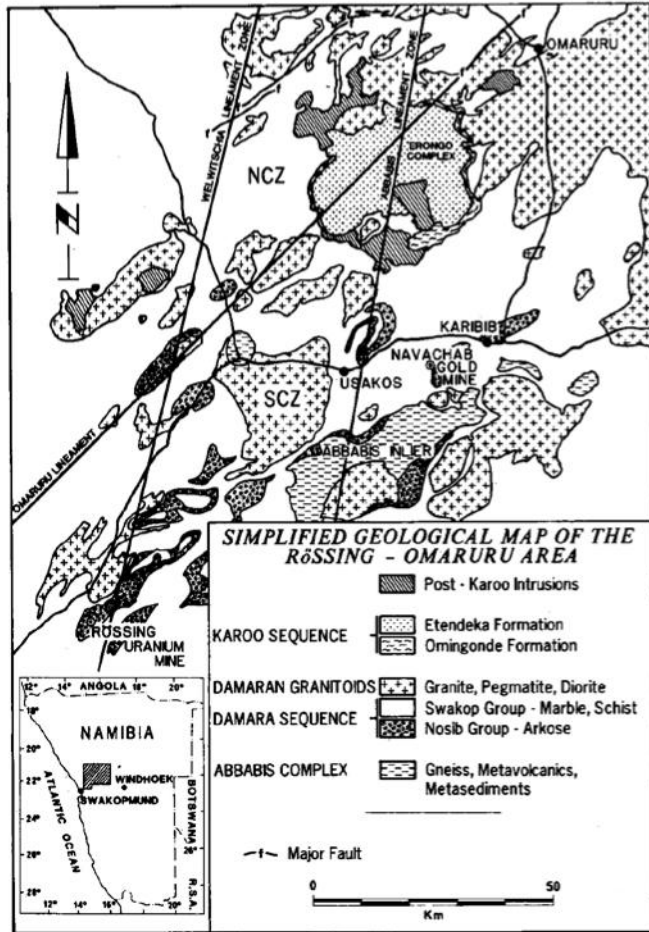
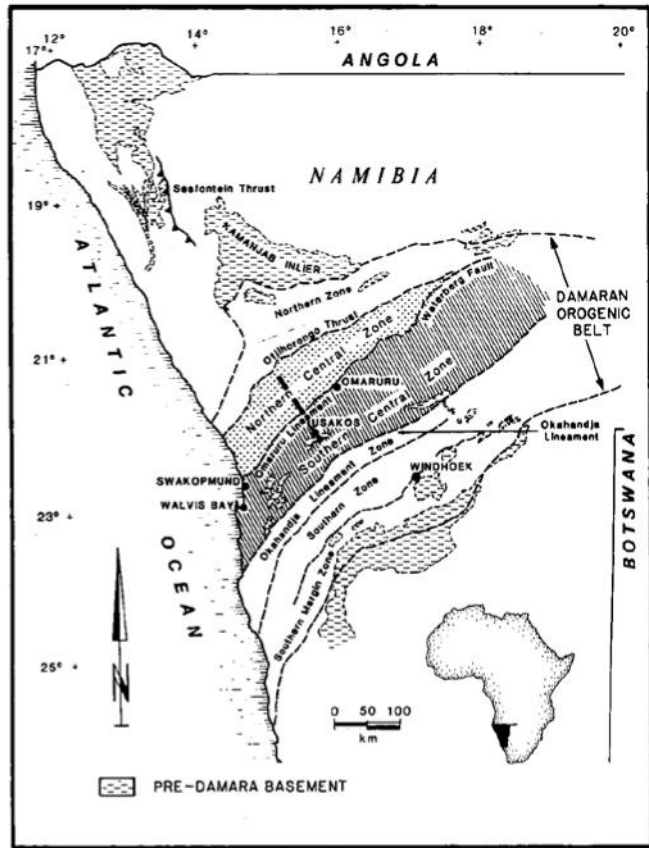
Interest in the gold potential of central Namibia was stimulated by a worldwide upsurge in gold exploration in the mid-1980s (Foster, 1993) and the discovery of Pan-African (late Proterozoic/early Palaeozoic) carbonate and skarn-hosted gold mineralisation on the farm Navachab near the town of Karibib by Anglo American Prospecting Services Namibia Pty. Prior to the opening of the opencast Navachab Gold Mine (10.4 million tonnes at 2.4 g/t Au, annual production approximately 1800 kg of gold; Badenhorst, 1993a, 1993b) in 1989, only small-scale extraction of gold had been undertaken in Namibia (Hirsch and Genis, 1992). The subtle and regionally extensive nature of the gold skarn mineralisation of the Karibib district was a major surprise in an area with no known significant gold deposits in spite of a 125 year-long exploration history. A 'gold rush' was precipitated in the late 1980s. Numerous showings of gold have subsequently been discovered (and some rediscovered) in the past five years in central Namibia and it is now evident that not only the carbonates of the Damara Sequence, but also the underlying mid-Proterozoic basement (Steven, 1992, 1993a), Damaran mafic volcanic rocks (Pirajno *et al.*, 1990a, 1991) as well as turbidite sequences (Steven, 1991, 1993a, 1993b) are prospective for gold. It is the aim of this paper to present the empirical, descriptive data on type examples of the gold occurrences in the vicinity of the towns of Usakos, Karibib and Omaruru (i.e. the Northern and Central Zones of the Damara Orogen, Figs. 1 and 2) which would be of most practical use in further exploration. The stratigraphic setting of the gold occurrences has been emphasised, but the paper does not purport to be a genetic synthesis for the central Namibian gold deposits: the fluid inclusion and stable isotope data base for this style of Namibian mineralisation is virtually non-existent.

## The geology of central Namibia with reference to gold mineralisation

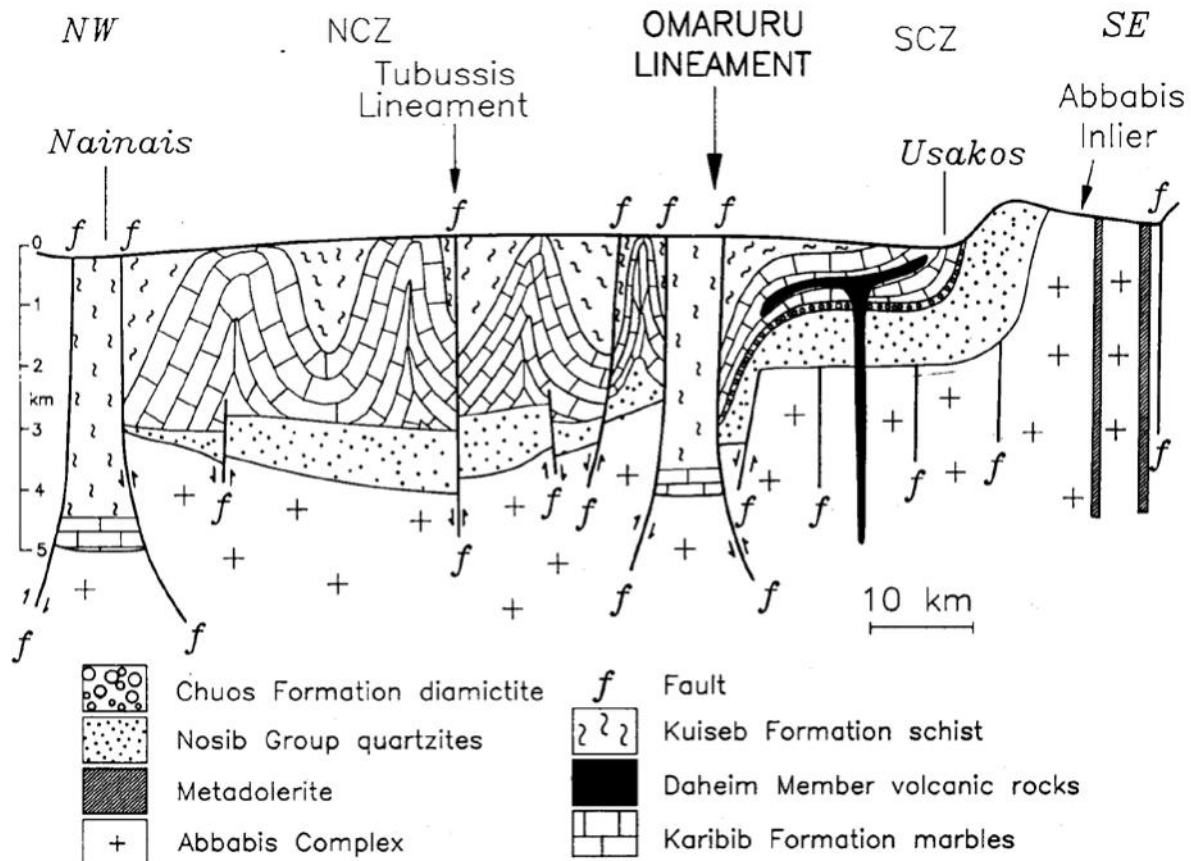
Central Namibia is essentially underlain by the inland, NE-trending, ensialic branch of the well-documented late Proterozoic/early Palaeozoic, Pan-African Damara Orogen (Fig. 1; Martin and Porada, 1977; Martin, 1983; Miller, 1983a). Early Proterozoic (1.8-2.0 Ga) basement gneiss lithologies crop out in a series of inliers that floor the orogen, the most prominent being the Abbabis Inlier (Fig. 2; Jacob *et al.*, 1978). The pre-Damara basement comprises both metasedimentary and metavolcanic rocks, but the most common lithotype is granite gneiss (Brandt, 1987). The Abbabis Inlier is cut by a metadolerite swarm that was probably intruded during the rifting that initiated the Damaran episode (Fig. 3; Steven, in press). The overlying Damara Sequence (Table 1) comprises the metamorphosed equivalents of fluviatile quartzites, limestones, marls, turbidites and shales. Within the Damara Sequence, the proportion of mafic volcanics and banded iron formations, both well-documented hosts of gold mineralisation (Groves *et al.*, 1990), is small (Table 1; Fig. 3).

Central Namibia has been intruded by numerous granitoids which define the magmatic belt of the orogen and are concentrated in the Central Zone (CZ; Miller, 1983a). In the lower metamorphic grade terrane of the Northern Zone (NZ), the plutons have wide thermal aureoles. Intrusions range in composition from I-type diorites, through S-type granites to rare-element pegmatites (Miller, 1983a; Haack *et al.*, 1983; Badenhorst, 1986; Steven, 1993a), but the overwhelming number of plutons are granitic (*sensu lato*) in composition (Miller, 1983a). The Damaran igneous suite possesses a 'within-plate' rather than a calc-alkaline geochemical character. There is virtually a complete lack of intrusion hosted sulphide and precious metal mineralisation in central Namibia (Steven, 1993a). In post-Damara times, swarms of Karoo dolerite dykes, post-Karoo granites

**Figure 1:** Tectonostratigraphic zones of the Damara Orogen with Northern Central Zone (stipple) and Southern Central Zone (shading) highlighted (after Miller, 1983a). Thick black line shows location of NW/SE cross-section shown in Fig. 3.



**Figure 2:** Simplified geological map of the Rössing-Omaruru area. Note location of Navachab Gold Mine.



**Figure 3:** Schematic NW/SE cross-section through the Central Zone of the Damara Orogen to illustrate the distribution of the Damara Sequence across the Omaruru Lineament. Basement profile and thickness of Nosib Group in NCZ taken from Corner's (1983) computer-model section. Granitoids have been omitted for clarity.

and volcanic complexes were emplaced. No significant precious metal mineralisation nor hydrothermal alteration of the type associated with gold mineralisation has been recorded at any of the post-Karoo complexes (Pirajno *et al.*, 1990b), though some anomalous gold contents were recorded in a variety of lithotypes at the Erongo caldera (Roesener, 1988).

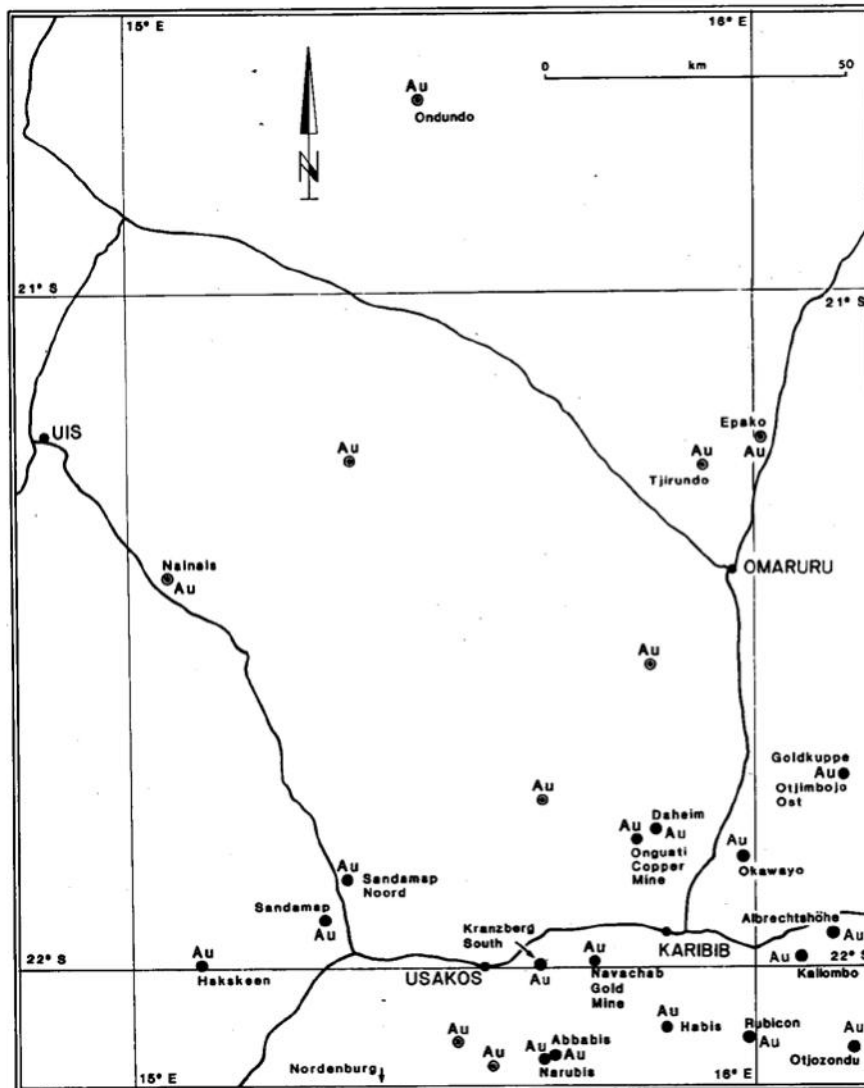
#### A review of gold mining in central Namibia

The central Namibian gold occurrences are shown in Figure 4 (after Martin, 1963 and Steven, 1993a). Prior to 1989, gold had only been mined profitably on a small scale from turbidite-hosted gold veins and associated alluvial deposits at Ondundo (Reuning, 1937) and from alluvial workings at Epako (Haughton *et al.*, 1939). Total gold production figures for Ondundo (both 'hard-rock' and alluvial) were approximately 700 kg of gold for the period 1924-1963 and 43 kg for Epako for the period 1937-1943 (Hirsch and Genis, 1992). It is unlikely that the combined gold production from all the prospects shown in Figure 4 exceeded one tonne prior to the opening of the Navachab Gold Mine.

#### Detailed geology of the known gold occurrences

The CZ gold mineralisation is mainly hosted by meta-sediments and, rarely, metavolcanic rocks, and appears to be epigenetic in nature. Gold mineralisation is structurally controlled: late-tectonic  $D_3$  (ENE/NE-trending) and  $D_4$  (NNE-trending) shear zones, faults (locally, thrusts) seem to be of particular importance (Steven and Hartnady, 1993). Gold is spatially associated with late-tectonic leucogranites and pegmatites and occurs in five main settings (in ascending stratigraphic order): (i) in ENE-trending megashear zones and chlorite-magnetite rocks on the margins of metadolerites in the Abbabis basement inlier; (ii) in minor auriferous veins in the Damaran Nosib Group quartzites; (iii) as Au-Bi-As-Te mineralisation in quartz veins and associated skarn alteration in the Swakop Group marbles and calc-silicate rocks; (iv) in alteration zones in the pyroclastic portions of the Daheim Member metavolcanic rocks; (v) as Au-As-W-B mineralisation in quartz veins and both dilational and mylonitic structures in Swakop Group metapelites and metaturbidites.

All information concerning the known and recently discovered gold mineralisation in central Namibia has



**Figure 4: Gold occurrences in central Namibia (ringed occurrences after Martin, 1963).**

been summarised in Table 2. Gold occurrences are listed in stratigraphic order using the revised stratigraphy for the CZ of the Damara Orogen proposed by Badenhorst (1987, 1988) and followed by Steven (1993a). Type localities are described for each Formation that hosts precious metal mineralisation. Localities are listed in alphabetical order within each Formation. The regional geological setting, host lithology, form of mineralisation, associated volcanic rocks, structural features, peak metamorphic facies, associated Damaran intrusions, suspected age of mineralisation, fire assay data, geochemical association, ore minerals, gangue and secondary minerals, associated alteration and provisional classification are given.

Of the five main styles of mineralisation, the gold in the basement lithologies, the Nosib Group quartzites and probably the Daheim Formation metavolcanic rocks appears to be too erratically distributed for commercial exploitation. By far the most significant discovery of the 1980s is the carbonate-hosted gold mineralisation of the Karibib area because it is amenable

to bulk mining (Badenhorst, 1993a). It can be referred to as skarn mineralisation only in the broadest sense. The proportion of skarn (i.e. silicate gangue) at these prospects is either very small (Navachab) or almost nonexistent (Ongwati). The recognition of the Kuiseb Formation as both a potential gold reservoir and host for gold mineralisation (Steven, 1993a) is important: gold has now been identified in turbiditic host rocks that have undergone a wide range of metamorphic conditions, from greenschist (Ondundo) to upper amphibolite facies (Sandamap Noord). Moreover, the concentration of auriferous mineralisation within high strain zones, the type of gangue minerals and the Au-As-W association in late Proterozoic turbidites is reminiscent of Palaeozoic turbidite- and shale-hosted gold deposits (Sandiford and Keays, 1986; Tomkinson, 1988) and, to a lesser extent, Archean greenstone belts (Colvine *et al.*, 1988; Phillips and Powell, 1993). This implies that the well-documented structural and geochemical criteria used by gold explorationists in Archean greenstone belt terranes (Groves *et al.*, 1990) would be of use in locat-

ing turbidite-hosted gold in central Namibia.

### The distribution and significance of the gold pathfinder elements As, Bi, Sb and Te in central Namibia

The elements that show the highest correlation with gold on a regional basis, regardless of host rock and stratigraphic position, are arsenic and, to a lesser extent, bismuth (Table 2, section 11). In the vicinity of the Abbabis Inlier (Figs. 2 and 3), bismuth is usually more effective than arsenic in assisting in the location of auriferous zones in the Etusis and Karibib Formations. In addition, both arsenic and bismuth commonly have large primary dispersion haloes in the vicinity of carbonate-hosted gold mineralisation. Somewhat surprisingly, antimony concentrations in areas of gold mineralisation are usually below the lower limit of detection throughout the CZ. In the light of the discovery of hessite at the Onguati Copper Mine, the tellurium anomalies in the Kanona Ost area (De Greef, 1988) are worthy of further investigation. Copper, lead and zinc concentrations are commonly anomalous in the vicinity of central Namibian gold mineralisation, but of all the so-called 'pathfinder' elements associated with gold, arsenic and bismuth are of the most use. Information on thallium and mercury contents in the central Namibian gold occurrences is not available.

Two gold provinces can be distinguished in the CZ, both of which are defined geochemically (Steven, 1993a). To the south of the Omaruru Lineament in the southern CZ (SCZ; Fig. 3), influx of auriferous fluids may well have occurred via major crustal structures

that penetrate deep into the granitic basement. *Gold-bismuth* mineralisation was concentrated in the vicinity of late-tectonic leucogranites and lithium pegmatites or in veins along major lineament systems. In contrast, in the northern CZ (NCZ) and NZ *gold-arsenic* mineralisation is located in ductile, semi-ductile and brittle structures in the pelitic sediments of the Oberwasser and the Kuiseb Formations. In the CZ, where peak metamorphic conditions (amphibolite facies) were notably higher than in the NZ (greenschist facies), the two metals were concentrated in the aureoles of late-tectonic granitic and pegmatitic intrusions.

### Structural analysis: the key to further gold exploration

It is now clear that gold mineralisation in central Namibia is located in late-tectonic, commonly linear, late-D<sub>3</sub> and D<sub>4</sub> structures. It is evident that, on the deposit scale at least, further delineation of gold ore will only come about with a clear understanding of the structural geology (Badenhorst, 1993b). An attempt to determine the regional structural controls on CZ gold mineralisation was made by Steven (1993a), though a more thorough integration of all the gold deposits in the Karibib district is necessary. Particularly favourable sites for gold deposition, such as at Sandamap Noord (Steven, 1991, 1993a), were late-tectonic high strain zones (and possibly associated structures) which may have resulted from movement on major structures such as the Welwitschia lineament zone.

A clearer understanding of the geodynamic setting of the inland branch of the Damara Orogen is also re-

Group	Formation	Lithologies
Swakop	Kuiseb	Metaturbidites and biotite schists and minor calc-silicate rocks and marble
	Onguati	Quartzite, schist, calc-silicate rock, marble
	Karibib	Calcitic and dolomitic marble and minor calc-silicate rocks and schist
		Daheim Member continental mafic volcanic rocks (only present in SCZ)
	Omusema Member amphibolites (only present in SCZ)	
	Oberwasser	Biotite schist, calc-silicate rocks and very minor felsic volcanic rocks
	Okawayo	Calcitic marble
	Spes Bona	Biotite schist, calc-silicate rocks and very minor felsic volcanic rocks
Chuoss	Glaciogenic mixite, Banded Iron Formation	
Rössing	Dolomitic marble, minor calc-silicate rocks and calcitic marble	
Nosib	Khan	Pyroble calc-silicate rocks, minor biotite schist, graphite schist and marble
	Etusis	Feldspathic quartzite, grit and minor calc-silicate rocks and schist

Table 1: Stratigraphy of the Damara Sequence in the Central Zone, Usakos-Karibib-Omaruru District, central Namibia

quired. The CZ magmatic belt and its ensialic mineral deposits (U, Sn, W) have traditionally been thought to have formed from the interaction and/or collision between the Kalahari and Congo Cratons. Models that account for the formation of the inland branch of the Damara Orogen range from those proposing ensialic evolution in an aulacogen (Martin and Porada, 1977) to ensialic development followed by subduction as a result of delamination of the lower crust (Kröner, 1982) to those invoking extensive north-westward subduction of oceanic crust (Kasch, 1983; Miller, 1983a, 1983b; Stanistreet *et al.*, 1991). Any geodynamic model that equates the magmatic belt of the CZ with the magmatic/volcanic arcs of the Circum-Pacific is of very limited use in gold exploration in central Namibia: the CZ intrusions and associated mineral deposits are ensialic in nature (Steven, 1993a). The thermal metamorphic high

in the Walvis Bay-Swakopmund area (Masberg *et al.*, 1992), the NW-SE orientation of metamorphic isograds within the CZ (Steven 1993a), and the east-west orientation of D<sub>4</sub> compression (Steven, 1993a) suggest that hinterland magmatism behind the west-vergent Dom Feliciano calc-alkaline arc in Brazil and Uruguay may have played a more important role in Damaran gold metallogenesis (Steven and Hartnady, 1993). In general, the Central Zone gold deposits formed at the end of a prolonged tectonothermal event which culminated in voluminous igneous intrusion. Thus both metamorphic and magmatic fluids are implicated in the formation of central Namibian gold deposits.

#### Acknowledgements

This paper largely rests on a geochemical data base

Formation	1. Type locality	2. Regional geological setting	3. Host lithology
Kuiseb	10km east of Messum Mtns. Hakskeen 89 Okawayo 146 Ondundo Gold Prospect Sandamap Noord 115	tin belt graben tin belt graben tin belt graben 9,800m eugeosync. sediments tin belt graben	metaturbidite quartzitic metaturbidite metaturbidite (meta)turbidite metaturbidite
Karibib	Albrechtshöhe 44 Habis 71  Navachab 58 (Grid A)  Onguati Copper Mine and Otjimbojo Ost 48/Goldkuppe	shelf carbonates shelf carbonates overlying basement high shelf carbonates overlying basement high shelf carbonates deformed into regional ENE anticline	dolomitic/calclitic marble dolomitic marble  dolomitic and calclitic marble dolomitic and calclitic marble
Daheim	Daheim 106	see Onguati - Otjimbojo	mafic volcanic rocks
Oberwasser	Epako 38	shelf/pelagic muds and clays	biotite schist
Okawayo	Kranzberg South 113 Navachab 58 (Navachab GM)	shelf carbonates overlying basement high	dolomitic and calclitic marble
Spes Bona	Navachab 58 (Eastern Zones)	shelf/pelagic muds and clays	biotite schist
Chuos	no known occurrences		
Rossing	no known occurrences		
Khan	no known occurrences		
Etusis	Nordenburg 76	feldspathic quartzites over- lying basement high	(meta)arkose/grit
Abbabis Inlier	Rubicon Mine, Okongava Ost Narubis 67 Abbabis 70	granitic basement inlier granitic basement inlier granitic basement inlier	Damara pegmatite magnetite-chlorite rocks on edge of mafic dykes shear zones, quartz veins

Table 2: Gold occurrences in the Damara Orogen and the underlying mid-Proterozoic basement (17 subsections)

Locality	4. Form of mineralisation
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	discordant quartz-tourmaline veins (especially in kink bands) lenses of tourmalinite parallel to S <sub>1</sub> , discordant quartz-tourmaline veins auriferous gossanous quartz veins deformed quartz veins parallel to sedimentary layering quartz veins and mylonite rocks related to shear zone
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	disseminated gold in quartz-tremolite sulphide veins quartz-tremolite veins, massive tremolite zones quartz-tremolite (pyrite-pyrrhotite) gold skarn veins shear zones, skarn veinlets, quartz veins disseminated gold in quartz-tremolite veins
Daheim	sericitised tuff units
Epako	auriferous quartz veins
Kranzberg South Navachab Gold Mine	gold in chalcopyrite-bearing quartz veins auriferous quartz-garnet-pyroxene-pyrrhotite skarn and quartz veins
Navachab (Eastern Zones)	auriferous pyrrhotite/pyrite quartz veins in two crosscutting sets
Nordenburg	auriferous quartz veins
Rubicon Mine Abbabis/Narubis	bismuth ochre vug in pegmatite quartz veins, magnetite-rich gossan from edge of altered dykes

Locality	5. Associated volcanic rocks
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	none positively identified, minor chert/possible acid volcanic rock in vicinity none identified none identified none identified none identified
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	alkaline, continental mafic volcanic rocks of the Daheim Formation amphibolite may be tuffaceous equivalent of Daheim Formation none alkaline, continental mafic volcanic rocks of the Daheim Formation not in immediate vicinity, but Daheim Formation developed along strike
Daheim	mineralisation hosted by tuff units
Epako	none identified, but minor rhyodacite in Oberwasser Fmn. at Otjua
Kranzberg South Navachab Gold Mine	alkaline mafic volcanic rocks alkaline mafic volcanic rocks; hornfelsic amphibolite may be mafic sill
Navachab (Eastern Zones)	alkaline, continental volcanic rocks
Nordenburg	none identified, but minor rhyolites in Etusis Formation in SCZ.
Rubicon Mine	none identified
Abbabis/Narubis	none in immediate vicinity, but mafic volcanic rocks in Naob Formation



Locality	6. Structural features
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	mineralisation concentrated in kink bands zone of tourmalinisation trends NNE, parallel to Welwitschia Lineament Zone quartz veins concentrated in kink bands quartz veins tightly folded by upright, doubly plunging north-south folds mylonite zone formed during D <sub>3</sub> /D <sub>4</sub> doming runs parallel to NNE D <sub>4</sub> structures
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	mineralisation on edge of domal structure and in NW/SE-trending fractures mineralisation in metasediments that drape basement inlier mineralisation on edge of domal structure and in NW/SE-trending fractures ENE-trending monoclinial downfold (?over basement fault), vein swarm dips SE mineralis. in N/S fractures axial planar to F <sub>2</sub> folds: parallel to Abbabis Lin. Zone
Daheim	pyroclastic and epiclastic volcanic rocks erupted along ENE-trending vent
Epako	quartz veins oriented EW/ESE dip 60°-80° N (related to Omaruru Fault Zone?)
Kranzberg South Navachab Gold Mine	mineralisation on edge of domal structure and in NW/SE-trending fractures mineralisation in shallowly NNE-plunging shoot and NW/SE-trending fractures
Navachab (Eastern Zones)	mineralisation on edge of domal structure and in NW/SE-trending fractures
Nordenburg	none identified
Rubicon Mine Abbabis/Narubis	not applicable major ENE-trending shear zones, ENE-trending mafic dyke swarm

Locality	7. Peak metamorphic facies that affected host rocks
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	amphibolite amphibolite amphibolite greenschist upper amphibolite
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	amphibolite amphibolite amphibolite amphibolite amphibolite
Daheim	(greenschist?)-amphibolite
Epako	amphibolite
Kranzberg South Navachab Gold Mine	amphibolite amphibolite
Navachab (Eastern Zones)	amphibolite
Nordenburg	amphibolite
Rubicon Mine Abbabis/Narubis	amphibolite pre-Damara: granulite; Damara: amphibolite



Locality	8. Associated Damaran intrusions within 1 km of mineralisation
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	late- to post-tectonic granites and pegmatites late- to post-tectonic pegmatites syntectonic granite and late-/post-tectonic cassiterite-bearing pegmatites nearest exposed/outcropping intrusions >20km away, south of Otjihorongo Thrust syntectonic granite and late-/post-tectonic cassiterite-bearing pegmatites
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	late- to post-tectonic lepidolite-bearing pegmatite red gneissic granite in core of dome, small andesite plug and lithium pegmatites none late- to post-tectonic lepidolite-bearing pegmatite late- to post-tectonic pegmatites (two phases)
Daheim	late- to post-tectonic lepidolite-bearing pegmatite
Epako	late-tectonic pegmatite and minor granite intrusions
Kranzberg South Navachab Gold Mine	late- to post-tectonic pegmatite minor fluorine-bearing leucogranite, pegmatites and aplite
Navachab (Eastern Zones)	minor fluorine-bearing leucogranite, pegmatites and aplite
Nordenburg	late- to post-tectonic pegmatite
Rubicon Mine Abbabis/Narubis	Li-Bi-pegmatite intrudes quartz-diorite and pegmatitic granite widespread pre-Damara and Damara granite and pegmatite intrusions

Locality	9. Suspected age of mineralisation
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	late Damara mid-late Damara late Damara early Damaran tectonism late Damara (D <sub>4</sub> ): Galena in gold zone has a Pb-Pb model age of 469-464 Ma
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	late Damara (D <sub>4</sub> ) late Damara late Damara late Damara (D <sub>4</sub> ) late Damara (D <sub>4</sub> )
Daheim	early Damara
Epako	late Damara (syn-D <sub>3</sub> ): Galena in gold vein has a Pb-Pb model age of 473 Ma
Kranzberg South Navachab Gold Mine	late Damara 490 Ma (biotite from skarn vein - cooling age?)
Navachab (Eastern Zones)	490 Ma (biotite from skarn vein - cooling age?)
Nordenburg	late Damara?
Rubicon Mine Abbabis/Narubis	515 Ma (various minerals; Haack and Gohn, 1988): late Damara pre-Damara and Damara (dolerite dykes maybe of Gannakouriep age, ~900 Ma)

Locality	10. Highest fire assay value (g/t Au)
East of Messum	0.58
Hakskeen	0.52
Okawayo	10
Ondundo	> 14.0
Sandamap Nd.	45.8
Albrechtshöhe	> 50
Habis	0.4
Navachab (Grid A)	> 50
Onguati Cu Mine	> 50
Otjimbojo Ost	native gold recorded from panning
Daheim	0.95
Epako	79.0
Kranzberg South	11
Navachab Gold Mine	50
Navachab (Eastern Zones)	> 50
Nordenburg	0.35
Rubicon Mine	11.2
Abbabis/Narubis	1.0

Locality	11. Geochemical association*
East of Messum	Au-B-Bi-W
Hakskeen	Au-B-As-Bi-W-Cu-F(-Zn-Sn)
Okawayo	Au-As-Bi
Ondundo	Au-As(-Cu)
Sandamap Nd.	Au-As-W-Pb-F(-B-Cu-Bi-Ag-Te)
Albrechtshöhe	Au-Bi-Cu
Habis	Au-As-W-Bi(-Cu-Zn)
Navachab (Grid A)	Au-Bi-W(-Cu)-(As?)
Onguati Cu Mine	Au-Cu-Zn-As-W-Bi-Ag-Te-Se-Co(-Sb-Sn)
Otjimbojo Ost	Au-Bi-As-Cu-W-Zn(-Pb)
Daheim	no information available
Epako	Au-As-Pb-W(-Bi-Cu)
Kranzberg South	Au-Cu-As
Navachab Gold Mine	Au-Ag-Bi-W(-Cu)
Navachab (Eastern Zones)	Au-Cu
Nordenburg	Au-Cu(-Bi)
Rubicon Mine	Au-Bi
Abbabis/Narubis	Au-Cu(-Pb-Zn) [As, Bi, W only very locally anomalous]

\*elements, except Au, in approx. order of importance (i.e. concentration relative to crustal abundance not absolute concentration)

Locality	12. Ore minerals (minor minerals in brackets)
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	Pyrite, scheelite, bismuth sulphides pyrite gold, arsenopyrite gold, arsenopyrite (chalcopyrite) gold, loellingite, arsenopyrite, pyrrhotite, galena, pyrite
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	gold, chalcopyrite, pyrite none identified in gossan gold, maldonite, bismuthinite, pyrrhotite, pyrite chalcopyrite, pyrrhotite, sphalerite, bismuth, hessite, pyrite, marcasite, costibite gold
Daheim	pyrite
Epako	gold, pyrite, galena (coarse-grained loe, po, cp, aspy in enclosing schists)
Kranzberg South Navachab Gold Mine	gold, silver, chalcopyrite gold, maldonite, pyrrhotite, chalcopyrite, scheelite, bismuth, silver
Navachab (Eastern Zones)	gold, pyrite, pyrrhotite
Nordenburg	none identified
Rubicon Mine Abbabis/Narubis	native bismuth chalcopyrite, pyrite

loe = loellingite, po = pyrrhotite, cp = chalcopyrite, aspy = arsenopyrite

Locality	13. Gangue and secondary minerals
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	quartz, tourmaline, bismite tourmaline, conicalcrite, natrojarosite, chrysocolla, malachite tourmaline, graphite, quartz quartz, sericite, feldspar, graphite, ankerite garnet, grunerite, graphite, calcite, tourmaline, jarosite, alunite, limonite, opal, scorodite, mimetite
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	tremolite, quartz tremolite, scapolite quartz, garnet, pyroxene, biotite, tremolite, quartz quartz, biotite, chlorite, goethite, malachite (vesuvianite, Frommurze et al., 1942) not investigated
Daheim	no information available
Epako	quartz, tourmaline, biotite
Kranzberg South Navachab Gold Mine	quartz, biotite quartz, garnet, diopside, hornblende, biotite
Navachab (Eastern Zones)	quartz, goethite, malachite
Nordenburg	unidentified yellow-green mineral
Rubicon Mine Abbabis/Narubis	bismuthite none identified

Locality	14. Associated alteration (minor alteration in brackets)
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	quartz veins (tourmalinisation) tourmalinites (silicification, pyritisation and jasperoids)  arsenopyrite in enclosing sediments, tourmalinites and tourmaline rocks ferruginisation (tourmalinisation, calcite-graphite rocks)
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	massive tremolite alteration, quartz-tremolite veins, gossan skarn minerals developed on edge of quartz veins none noted quartz-tremolite veins, iron staining, (tourmalinisation of Kuiseb Fmn.)
Daheim	sericitisation and pyritisation of tuff units
Epako	none identified except very minor chlorite schist and local bleaching of schist
Kranzberg South Navachab Gold Mine	skarn minerals developed on edge of quartz veins skarn minerals developed on edge of quartz veins
Navachab (Eastern Zones)	
Nordenburg	minor epidotisation (propylitic alteration ?) of quartzite
Rubicon Mine Abbabis/Narubis	not applicable chlorite-magnetite-amphibole rocks

Locality	15. Provisional classification
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	turbidite-hosted gold of magmatic origin auriferous tourmaline replacement body hosted by turbidites turbidite-hosted gold of magmatic origin metamorphogenic turbidite-hosted gold turbidite-hosted gold of magmatic origin
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	gold skarn (sensu lato) gold skarn (sensu lato) gold skarn (sensu lato) gold skarn (sensu lato) gold skarn (sensu lato)
Daheim	pyroclastic volcanic-hosted gold
Epako	auriferous veins in schist
Kranzberg South Navachab Gold Mine	gold-copper skarn gold skarn
Navachab (Eastern Zones)	auriferous veins in schist
Nordenburg	quartz vein
Rubicon Mine Abbabis/Narubis	gold concentrations in bismuth pocket in pegmatite gold concentrations in shear zones and altered dolerite dykes

Locality	16. Comments
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	Tourmalinisation related to intrusion of Damaran granites and pegmatites Tourmalinisation of metasediments (at the apex of a pegmatite system?)  Prospect has similarities with Bendigo-Ballararat, Australia (Keppie et al., 1986) Concentration of auriferous fluids in high strain zone
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	This epigenetic carbonate-hosted gold mineralisation is possibly related to hidden, late-tectonic, felsic intrusions emplaced during the latter stages of the Damaran Orogeny. The close proximity of underlying auriferous basement rocks (i.e. a large gold reservoir) is considered to be significant.
Daheim	Volcanic rocks erupted along (auriferous?) ENE-trending deep-seated fracture
Epako	Mineralisation related to intrusion of late Damaran granites and pegmatites
Kranzberg South Navachab Gold Mine	see above comments on the five occurrences in the Karibib Formation
Navachab (Eastern Zones)	Eastern Zones 1 and 3 at Navachab GM contain one tonne of gold each
Nordenburg	Hydrothermal fluids derived from basement (?) during Damaran Orogeny
Rubicon Mine Abbabis/Narubis	Gold concentrated with chalcophile minerals in pegmatite Shears and dykes channelled hydrothermal fluids into overlying carbonates

Locality	17. General References
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	Steven (1993a)  Reuning (1937), Miller (1980) Frommurze et al. (1942), Steven (1991, 1992, 1993a, 1993b)
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	Steven (1993a) Navachab Mine Field Guide (1989), Badenhorst (1993a, 1993b) Pirajno et al. (1990a, 1991), Pirajno and Jacob (1991), Steven (1993a)
Daheim	
Epako	Rossouw (1937), Haughton et al. (1939, p.113), Steven (1993a)
Kranzberg South Navachab Gold Mine	Navachab Mine Field Guide (1989), Badenhorst (1993a, 1993b)
Navachab (Eastern Zones)	
Nordenburg	Smith (1965)
Rubicon Mine Abbabis/Narubis	Haack and Gohn (1988) Brandt (1987), Steven (1993c)

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#### Appendix: Analytical methods

##### *The analysis of gold in whole rock samples*

The geochemical information presented in this paper is mainly taken from a data base compiled by N.M.S. and V.F.W.P. for Gold Fields Namibia. In 1987 and 1988 the gold contents of approximately 1300 (thirteen hundred), 5-10 kg pre-Damaran and Damaran rock samples were determined by atomic absorption spectrometry (AAS) by Scientific Services Pty., Cape Town (referred to as AAS scan analysis). The technique employed was a modification of the one described by van Loon (1984).



Rocks were crushed and milled to finer than 100 mesh and pre-leached with HCl. A second leach with Aqua Regia was followed by stripping of the gold into DIBK and Aliquot 336. Gold contents were then determined by AAS. Numerous duplicates were analysed. Scientific Services Pty. claimed a lower limit of detection of 30 ppb Au for this technique. The gold contents of those samples containing in excess of 300 ppb Au were then determined by fire assay by Scientific Services and McLachlan and Lazar CC, Johannesburg. Both companies indicated lower limits of detection (LLD) of approximately 50 ppb for their fire assay analyses.

*The analysis of 'pathfinder elements' in whole rock samples*

Copper, lead, zinc and silver concentrations were determined by AAS by the aforementioned commercial laboratories, Sn, W, Mo, As, Sb, Bi, Se and Te contents

were obtained by XRF analysis. Readers interested in the concentrations of pathfinder elements in unaltered Damaran metasediments and metavolcanic rocks (i.e. background levels) in the Usakos-Karibib-Omaruru area are referred to a geochemical data base presented by Steven (1993a, chapter 2).

*Mineralogy*

The minerals described in Table 2 were optically identified where possible with a Nikon polarising microscope in transmitted and reflected light in the Department of Geological Sciences, University of Cape Town. Many of the secondary minerals, such as the carbonates, sulphates, arsenates and oxides were identified by x-ray diffraction (XRD). Sulphide phases were identified using a Cameca Camebax microbeam electron microprobe. Operating conditions for the electron microprobe analysis were detailed by Steven (1993a).