*Communs geol. Surv. Namibia, **9** (1994), 63-78*

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

N.M. Steven[1*], F.P. Badenhorst[2] & V.F.W. Petzel[3]
[1]*Department of Geological Sciences, University of Cape Town, Rondebosch 7700, South Africa*
[2]*Navachab Gold Mine, Box 150, Karibib, Namibia*
[3]*Gold Fields Namibia, Box 3718, Windhoek, Namibia*
[*]*Present Address: 10 Evergreen Lane, Constantia 7800, South Africa*

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-Damaran 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-Damaran times, swarms of Karoo dolerite dykes, post-Karoo granites

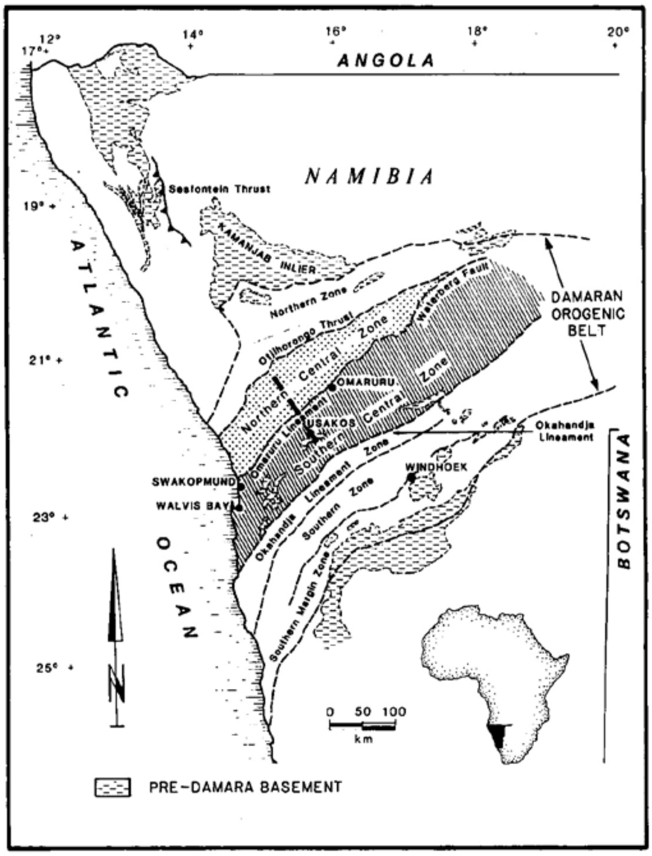

Figure 1: Tectonostratigraphic zones of the Damara Orogen with Northern Central Zone (stipple) and Southern Central Zone (shading) highlighted (after Miller, 1983a). Thick black line shows location of NW/SE cross-section shown in Fig. 3.

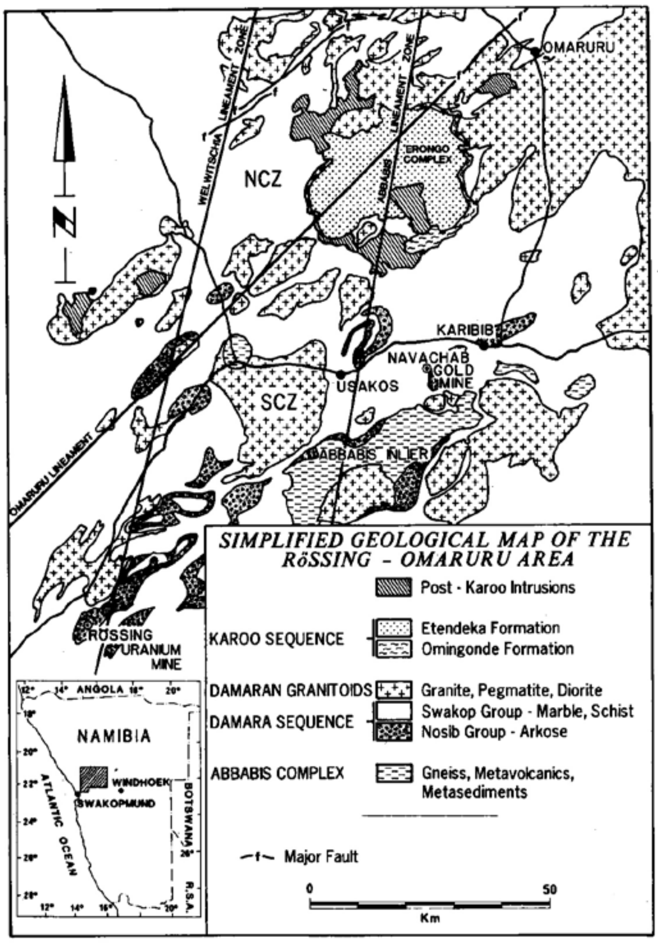

Figure 2: Simplified geological map of the Rössing-Omaruru area. Note location of Navachab Gold Mine.

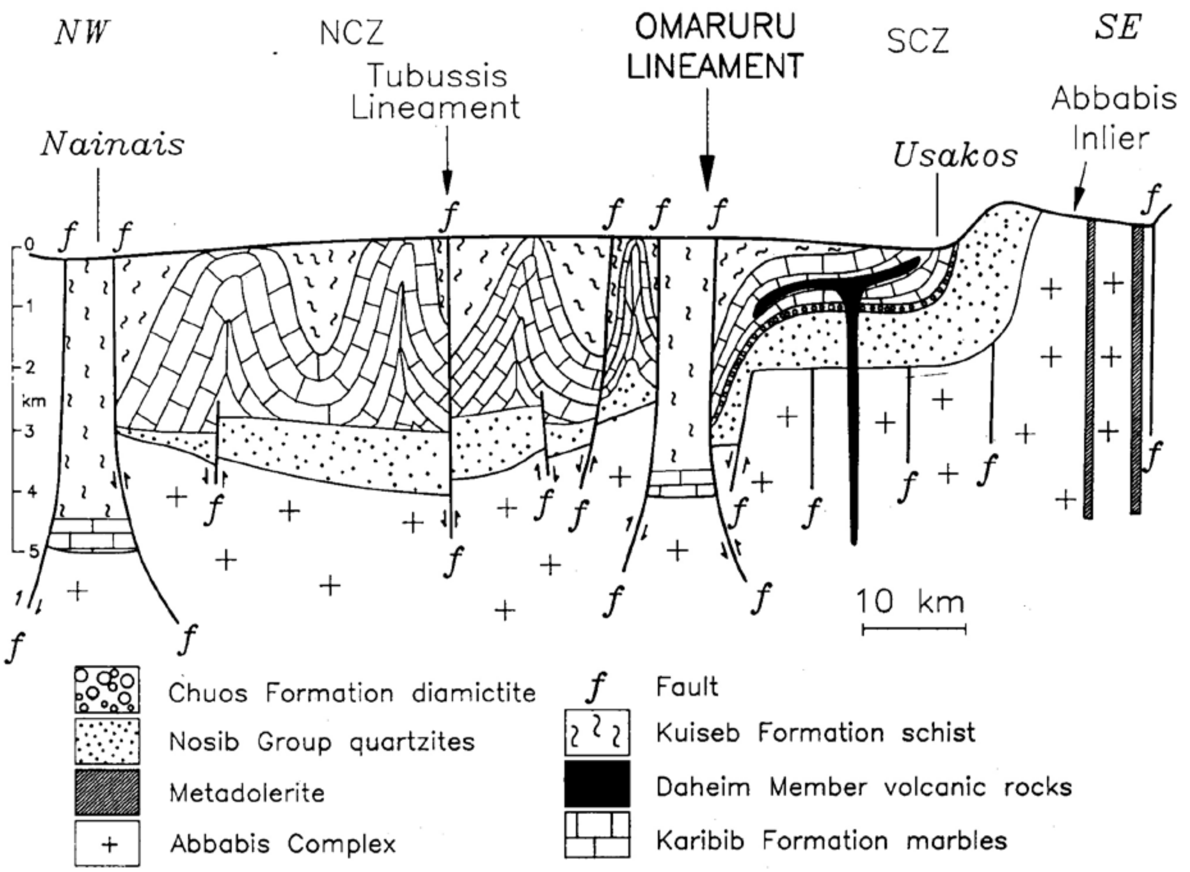

Figure 3: Schematic NW/SE cross-section through the Central Zone of the Damara Orogen to illustrate the distribution of the Damara Sequence across the Omaruru Lineament. Basement profile and thickness of Nosib Group in NCZ taken from Corner's (1983) computer-model section. Granitoids have been omitted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

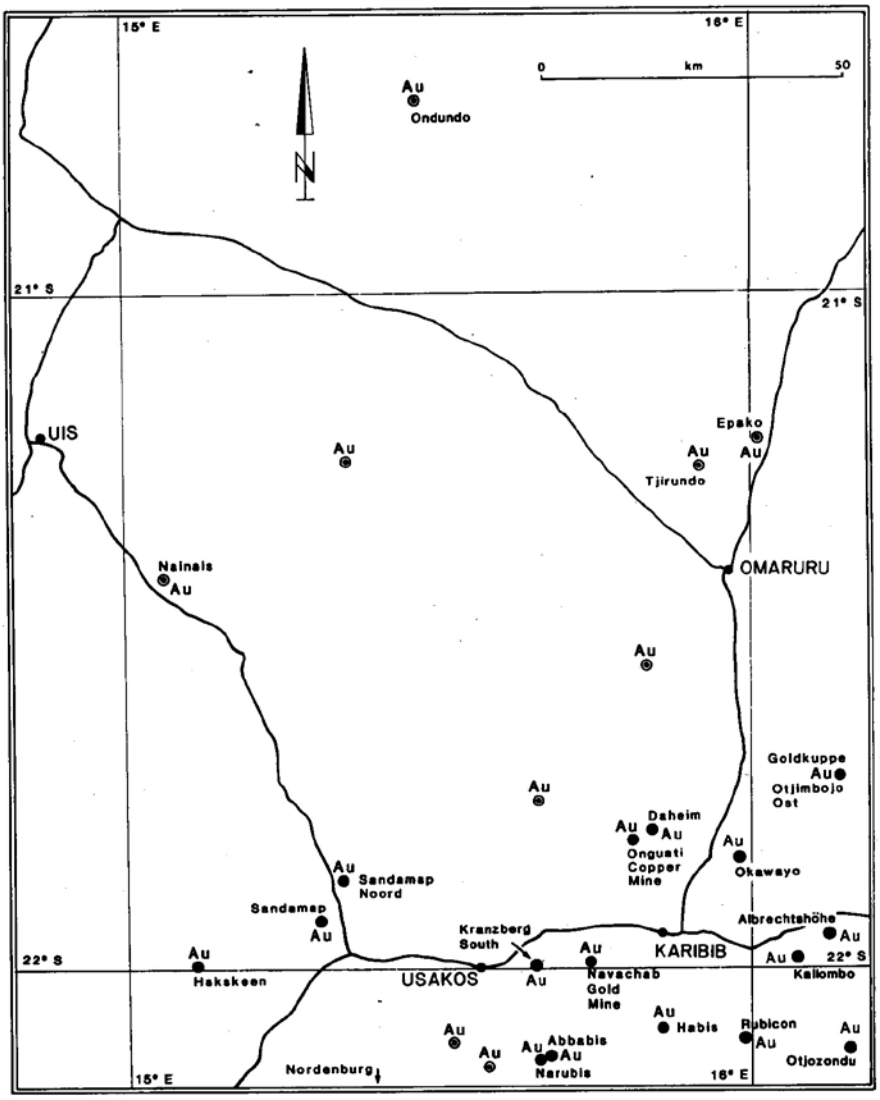

Figure 4: Gold occurrences in central Namibia (ringed occurrences after Martin, 1963).

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 (Onguati). 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 locating 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 ofhessite 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_3 and D_4 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
	Chuos	Glaciogenic mixtite, Banded Iron Formation
	Rössing	Dolomitic marble, minor calc-silicate rocks and calcitic marble
Nosib	Khan	Pyribole 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_4 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/calcitic marble dolomitic marble dolomitic and calcitic marble dolomitic and calcitic 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 calcitic 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 overlying basement high	(meta)arkose/grit
Abbabis Inlier	Rubicon Mine, Okongava Ost Narubis 67 Abbabis 70	granitic basement inlier granitic basement inlier granitic basement inlier	Damaran 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_1, 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_3/D_4 doming runs parallel to NNE D_4 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 monoclinal downfold (?over basement fault), vein swarm dips SE mineralis. in N/S fractures axial planar to F_2 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	late- to post-tectonic granites and pegmatites
Hakskeen	late- to post-tectonic pegmatites
Okawayo	syntectonic granite and late-/post-tectonic cassiterite-bearing pegmatites
Ondundo	nearest exposed/outcropping intrusions >20km away, south of Otjihorongo Thrust
Sandamap Nd.	syntectonic granite and late-/post-tectonic cassiterite-bearing pegmatites
Albrechtshöhe	late- to post-tectonic lepidolite-bearing pegmatite
Habis	red gneissic granite in core of dome, small andesite plug and lithium pegmatites
Navachab (Grid A)	none
Onguati Cu Mine	late- to post-tectonic lepidolite-bearing pegmatite
Otjimbojo Ost	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	late- to post-tectonic pegmatite
Navachab Gold Mine	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	Li-Bi-pegmatite intrudes quartz-diorite and pegmatitic granite
Abbabis/Narubis	widespread pre-Damara and Damara granite and pegmatite intrusions

Locality	9. Suspected age of mineralisation
East of Messum	late Damara
Hakskeen	mid-late Damara
Okawayo	late Damara
Ondundo	early Damaran tectonism
Sandamap Nd.	late Damara (D_4): Galena in gold zone has a Pb-Pb model age of 469-464 Ma
Albrechtshöhe	late Damara (D_4)
Habis	late Damara
Navachab (Grid A)	late Damara
Onguati Cu Mine	late Damara (D_4)
Otjimbojo Ost	late Damara (D_4)
Daheim	early Damara
Epako	late Damara (syn-D_3): Galena in gold vein has a Pb-Pb model age of 473 Ma
Kranzberg South	late Damara
Navachab Gold Mine	490 Ma (biotite from skarn vein - cooling age?)
Navachab (Eastern Zones)	490 Ma (biotite from skarn vein - cooling age?)
Nordenburg	late Damara?
Rubicon Mine	515 Ma (various minerals; Haack and Gohn, 1988): late Damara
Abbabis/Narubis	pre-Damara and Damara (dolerite dykes maybe of Gannakouriep age, ~900 Ma)

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

Locality	11. Geochemical association*
East of Messum Hakskeen Okawayo Ondundo Sandamap Nd.	Au-B-Bi-W Au-B-As-Bi-W-Cu-F(-Zn-Sn) Au-As-Bi Au-As(-Cu) Au-As-W-Pb-F(-B-Cu-Bi-Ag-Te)
Albrechtshöhe Habis Navachab (Grid A) Onguati Cu Mine Otjimbojo Ost	Au-Bi-Cu Au-As-W-Bi(-Cu-Zn) Au-Bi-W(-Cu)-(As?) Au-Cu-Zn-As-W-Bi-Ag-Te-Se-Co(-Sb-Sn) Au-Bi-As-Cu-W-Zn(-Pb)
Daheim	no information available
Epako	Au-As-Pb-W(-Bi-Cu)
Kranzberg South Navachab Gold Mine	Au-Cu-As Au-Ag-Bi-W(-Cu)
Navachab (Eastern Zones)	Au-Cu
Nordenburg	Au-Cu(-Bi)
Rubicon Mine Abbabis/Narubis	Au-Bi 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	Pyrite, scheelite, bismuth sulphides
Hakskeen	pyrite
Okawayo	gold, arsenopyrite
Ondundo	gold, arsenopyrite (chalcopyrite)
Sandamap Nd.	gold, loellingite, arsenopyrite, pyrrhotite, galena, pyrite
Albrechtshöhe	gold, chalcopyrite, pyrite
Habis	none identified in gossan
Navachab (Grid A)	gold, maldonite, bismuthinite, pyrrhotite, pyrite
Onguati Cu Mine	chalcopyrite, pyrrhotite, sphalerite, bismuth, hessite, pyrite, marcasite, costibite
Otjimbojo Ost	gold
Daheim	pyrite
Epako	gold, pyrite, galena (coarse-grained loe, po, cp, aspy in enclosing schists)
Kranzberg South	gold, silver, chalcopyrite
Navachab Gold Mine	gold, maldonite, pyrrhotite, chalcopyrite, scheelite, bismuth, silver
Navachab (Eastern Zones)	gold, pyrite, pyrrhotite
Nordenburg	none identified
Rubicon Mine	native bismuth
Abbabis/Narubis	chalcopyrite, pyrite

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

Locality	13. Gangue and secondary minerals
East of Messum	quartz, tourmaline, bismite
Hakskeen	tourmaline, conichalcite, natrojarosite, chrysocolla, malachite
Okawayo	tourmaline, graphite, quartz
Ondundo	quartz, sericite, feldspar, graphite, ankerite
Sandamap Nd.	garnet, grunerite, graphite, calcite, tourmaline, jarosite, alunite, limonite, opal, scorodite, mimetite
Albrechtshöhe	tremolite, quartz
Habis	tremolite, scapolite
Navachab (Grid A)	quartz, garnet, pyroxene, biotite, tremolite, quartz
Onguati Cu Mine	quartz, biotite, chlorite, goethite, malachite (vesuvianite, Frommurze et al., 1942)
Otjimbojo Ost	not investigated
Daheim	no information available
Epako	quartz, tourmaline, biotite
Kranzberg South	quartz, biotite
Navachab Gold Mine	quartz, garnet, diopside, hornblende, biotite
Navachab (Eastern Zones)	quartz, goethite, malachite
Nordenburg	unidentified yellow-green mineral
Rubicon Mine	bismuthite
Abbabis/Narubis	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	Tourmalinisation related to intrusion of Damaran granites and pegmatites
Hakskeen	Tourmalinisation of metasediments (at the apex of a pegmatite system?)
Okawayo	
Ondundo	Prospect has similarities with Bendigo-Ballarat, Australia (Keppie et al., 1986)
Sandamap Nd.	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	Gold concentrated with chalcophile minerals in pegmatite
Abbabis/Narubis	Shears and dykes channelled hydrothermal fluids into overlying carbonates

Locality	17. General References
East of Messum	
Hakskeen	Steven (1993a)
Okawayo	
Ondundo	Reuning (1937), Miller (1980)
Sandamap Nd.	Frommurze et al. (1942), Steven (1991, 1992, 1993a, 1993b)
Albrechtshöhe	
Habis	Steven (1993a)
Navachab (Grid A)	Navachab Mine Field Guide (1989), Badenhorst (1993a, 1993b)
Onguati Cu Mine	Pirajno et al. (1990a, 1991), Pirajno and Jacob (1991), Steven (1993a)
Otjimbojo Ost	
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	Haack and Gohn (1988)
Abbabis/Narubis	Brandt (1987), Steven (1993c)

that was sponsored by Gold Fields South Africa and Gold Fields Namibia. N.M.S wishes to thank both companies for generous financial and logistical support. N.M.S. also acknowledges support from the Council for Scientific and Industrial Research (CSIR) of South Africa. The consulting geologists Richard Viljoen (Gold Fields) and Roger Attridge (Erongo Mining and Exploration Company, managers of the Navachab Gold Mine) are thanked for allowing the release of unpublished data. Dick Rickard (Department of Geological Sciences, University of Cape Town) is thanked for considerable assistance with electron microprobe analysis. James Willis, Andy Duncan and Dave Reid (University of Cape Town) are thanked for answering numerous analytical questions which assisted in the compilation of the geochemical data base. John Moore (Rhodes University), Roger Jacob (Rhodes University) and Marcus Tomkinson (Anglovaal Namibia) are thanked for reviewing earlier versions of this paper. Move Steven is thanked for her assistance with the diagrams.

References

Badenhorst, F.P. 1986. ‘n Voorlopige petrografiese studie van die granitiese gesteentes van Gebied 2115B in die noordelike Sentrale Sone van die Damaraorogeen. *Communications of the Geological Survey of S.W.A./Namibia*, **2**, 13-26.

Badenhorst, F.P. 1987. Lithostratigraphy of the Damara Sequence in the Omaruru area of the northern Central Zone of the Damara Orogen and a proposed correlation across the Omaruru Lineament. *Communications of the Geological Survey of S.W.A./Namibia*, **3**, 3-8.

Badenhorst, F.P. 1988. A note on stratiform tourmalinites in the Late Precambrian Kuiseb Formation, Damara Sequence. *Communications of the Geological Survey S.W.A./Namibia*, **4**, 67-70.

Badenhorst, F.P. 1993a. The Navachab Gold Mine in central Namibia, *Conference on Mining Investment in Namibia*, Windhoek, 17th -19th March, Ministry of Mines and Energy publication, 1993, 33-34

Badenhorst, F.P. 1993b. The Navachab skarn gold deposit in central Namibia. *Mineral Exploration ‘93 conference*, Cape Town, 18th-20th August, 1993.

Brandt, R. 1987. A revised stratigraphy for the Abbabis Complex in the Abbabis inlier, Namibia. *South African Journal of Geology*, **90** (3), 314-323.

Colvine, A.C., Fyon, J.A., Heather, K., Marmont, S., Smith, P.M. and Troop, D.G. 1988. Archean lode gold deposits in Ontario. *Ontario Geological Survey, Miscellaneous Paper*, **139**, 136 pp.

Corner, B. 1983. An interpretation of the aeromagnetic data covering the western portion of the Damara Orogen in S.W.A./Namibia. *Special Puhlication of the Geological Society of South Africa*, **11**, 339-354.

De Greef, R. 1988. Final prospecting report on grant M46/3/1652 Kanona Ost, Anglo American Prospecting Services Namibia (Pty.) Ltd.

Foster, R.P. 1993. Gold metallogeny and exploration. Chapman and Hall, London, 448 pp.

Frommurze, H.F., Gevers, T.W. and Rossouw, P.J. 1942. The geology and mineral deposits of the Karibib area, South West Africa. *Explanation to Sheet 79, Geological Survey of South Africa*, 172 pp.

Groves, D.I., Barley, M.E., Cassidy, K.F., Fare, R.J., Hagemann, S.G., Ho, S.E., Hronsky, J.M.A, Mikucki, E.J., Mueller, A.G., McNaughton, N.J., Ridley, J.R. and Vearncombe, J.R. 1990. *Subgreenschist to granulite-hosted Archean lodegold deposits: a depositional continuum from deep-sourced hydrothermal fluids in crustal-scale plumhing systems*?, 357-359. Third Archean Symposium, Perth, Australia.

Haack, U. and Gohn, E. 1988. Rb-Sr Data on some pegmatites in the Damara Orogen. *Communications of the Geological Survey of Namibia*, **4**, 13-18.

Haack, U., Hoefs, J. and Gohn, E. 1983. Genesis of Damaran granites in the light of Rb/Sr and ^{18}O data, 847-872. *In*: Martin, H. and Eder, F.W., Eds., I*ntracontinental Fold Belts*. Springer Verlag, Berlin, Heidelberg, 945 pp.

Haughton, S.H., Frommurze, H.F., Gevers, T.W., Schwellnus, C.M. and Rossouw, P.J. 1939. The geology and mineralogy of the Omaruru area, South West Africa. *Explanation to Sheet 71, Geological Survey South Africa*, 151 pp.

Hirsch, M.F.H. and Genis, G. 1992. The Mineral Resources of Namibia - Gold, 18. Section 4.1. *Publication of the Geological Survey of Namibia*.

Jacob, R.E., Kröner, A. and Burger, A.J. 1978. Areal extent and first U-Pb age of the pre-Damaran Abbabis complex in the central Damara belt of South West Africa. *Geologische Rundschau*, **67**(2), 706-718.

Kasch, K.W. 1983. Continental collision, suture progradation and thermal relaxation: A plate tectonic model for the Damara Orogen in central Namibia. *Special Publication of the Geological Society of South Africa*, **11**, 423-429.

Keppie, J.D., Boyle, R.W. and Haynes, S.J. Eds. 1986. Turbidite-hosted gold deposits. *Geological Association of Canada Special Paper*, **32**, 186 pp.

Kröner, A. 1982. Rb-Sr geochronology and tectonic evolution of the Pan-African Damara Belt of Namibia, southwestern Africa. *American Journal of Science*, **282**, 1471-1507.

Martin, H. 1963. Geological map of South West Africa (1:1,000,000).

Martin, H. 1983. Alternative geodynamic models for the Damara Orogeny: A critical discussion, 913-945. *In*: Martin, H. and Eder, F.W., Eds., *Intracontinental Fold Belts*. Springer Verlag, Berlin, Heidelberg, 945 pp.

Martin, H. and Porada, H. 1977. The intracratonic branch of the Damara Orogen in South West Africa.

I. Discussion of geodynamic models. *Precambrian Research*, **5**, 311-338.

Masberg, H.P., Hoffer, E. and Hoernes, S. 1992. Microfabrics indicating granulite-facies metamorphism in the low-pressure central Damara Orogen, Namibia. *Precambrian Research*, **55**, 243-257.

Miller, R.McG. 1980. Geology of a portion of Central Damaraland. *Memoir of the Geological Survey of South Africa, South West Africa Series*, **6**, 78 pp.

Miller, R.McG. 1983a. The Pan-African Damara Orogen of S.W.A./Namibia. *Special Puhlication of the Geological Society of South Africa*, **11**, 431-515.

Miller, R.McG. 1983b. Economic implications of plate tectonic models of the Damara Orogen. *Special Puhlication of the Geological Society of South Africa*, **11**, 385-395.

Navachab Gold Mine Field Guide. 1989. Prepared for the Geological Society of Namibia by Erongo Mining and Exploration Company.

Phillips, G.N. and Powell, R. 1993. Link between gold provinces. *Economic Geology*, **88**, 1084-1098.

Pirajno, F. and Jacob, R.E. 1991. Gold mineralisation in the intracontinental branch of the Damara Orogen, Namibia: a preliminary survey. *Journal of African Earth Sciences*, **13**, 305-311.

Pirajno, F., Jacob, R.E. and Petzel, V.F.W. 1990a. Marble-hosted sulphide and gold mineralisation at Onguati-Brown Mountain, southern central zone of the Damara Orogen, Namibia, 443-446. *23rd Earth Science Congress of the Geological Society of South Africa*.

Pirajno, F., Roesener, H., and Petzel, V.F.W. 1990b. The volcanic history of the Paresis igneous complex, 447-450. *23rd Earth Science Congress of the Geological Society of South Africa, Cape Town, 2nd-6th July 1990*.

Pirajno, F., Jacob, R.E. and Petzel, V.F.W. 1991. Distal skarn-type mineralisation in the Central Zone of the Damara Orogen, Namibia, 95-100. *In*: Ladeira, E.A., Ed., P*roceedings of Brazil Gold '91, An International Symposium on the Geology of Gold. Belo Horizonte*, 1991. Balkema, Rotterdam, Holland 823 pp.

Reuning, E. 1937. Die Goldfelder von Ondundo, Südwestafrika. *Geologische Rundschau*, **28** (34), 229-239.

Roesener, H. 1988. Progress report on exploration conducted in the Erongo Caldera prospecting grant **M46/3/1611**. Unpublished report of Gold Fields South Africa, 40 pp.

Rossouw, P.J. 1937. *Alluvial gold occurrences at Epako 38, Omaruru District*. Unpublished Report.

Sandiford, M. and Keays, R.R. 1986. Structural and tectonic constraints on the origin of gold deposits in the Ballarat Slate Belt, Victoria, 15-24. *In*: Keppie, J.D., Boyle, R.W. and Haynes, S.J., Eds., *Turhidite-hosted gold deposits*. Geological Association of Canada Special Paper **32**, 186 pp.

Smith, D.A.M. 1965. The geology of the area around the Khan and Swakop Rivers in S.W.A. *Memoir of the Geological Survey of South Africa, South West Africa Series*, **3**, 113 pp.

Stanistreet, I.G., Kukla, P.A. and Henry, G. 1991. Sedimentary basinal responses to a Late Precambrian Wilson Cycle: the Damara Orogen and Nama Foreland, Namibia. *Journal of African Earth Sciences*, **13**, 141-156.

Steven, N.M. 1991. Turbidite-hosted gold mineralisation at the Sandamap Noord prospect, central Namibia, 567-574. *In*: Ladeira, E.A., Ed., *Proceedings of Brazil Gold '91, An International Symposium on the Geology of Gold: Belo Horizonte*, 1991. Balkema, Rotterdam, Holland 823 pp.

Steven, N.M. 1992. A *study of epigenetic mineralisation in the Central Zone of the Damara Orogen, Namibia with special ref'erence to gold, tungsten, tin and rare earth elements*. Unpublished Ph.D. thesis, University of Cape Town, 221 pp.

Steven, N.M. 1993a. A study of epigenetic mineralisation in the Central Zone of the Damara Orogen, Namibia with special reference to gold, tungsten, tin and rare earth elements. *Memoir of the Geological Survey of Namibia*, **16**, 166 pp.

Steven, N.M. 1993b. The Sandamap Noord gold prospect, central Namibia: Discovery of anew style of turbidite-hosted gold mineralisation. *International Geology Review*, **35**, 840-854.

Steven, N.M. Mafic dykes in the pre-Damara basement, south-east of Usakos, central Namibia. *Communications of the Geological Survey of Namibia*, **9** (this volume).

Steven, N.M. and Hartnady, C.J. 1993. Early Palaeozoic gold metallogeny in the Damara Orogen, A-100. *Joint Annual Meeting of the Geological Association of Canada/Mineralogical Association of Canada, Edmonton, Alberta*, May 1993.

Tomkinson, M.J. 1988. Gold mineralisation in phyllonites at the Haile Mine, South Carolina. *Economic Geology*, **83**, 1392-1400.

Van Loon, 1984, Accurate determination of the noble metals I: Sample decomposition and methods ofseparation. *Trends in Analytical Chemistry*, **3**, 272-275.

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).