The Agate Mountain Carbonatite Complex, Cape Fria, NW Namibia

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The 2.4-km diameter Agate Mountain Complex intrudes basalts and red quartz latites of the early Cretaceous Etendeka Formation on the inland extension of the Walvis Ridge. It appears to be a satellite vent located on the cauldron subsidence ring fracture of a slightly older and much larger alkaline volcano centred offshore. Reworking of pyroclastic deposits of this early volcano produced epiclastic conglomerates containing pebbles of quartz latite and fenitised basement rocks within the caldera structure. The quartz latites and conglomerates were intensely ferruginised adjacent to the ring fracture. All movement on the ring fracture ceased shortly thereafter. The Agate Mountain Carbonatite Complex was then emplaced. Fenitisation of the red quartz latites to a pervasive green colour preceded local ring fracturing, brecciation of the fenite and emplacement of early breccias, radial carbonatite dykes and the main sövitic carbonatite. Progressive alteration of the sövite to a bastnaesite-bearing beforsite was followed by explosive emplacement of a core breccia. This was followed by intrusion of three small basic plugs. Thirty-one satellite plugs and diatremes and a microgranite dyke were emplaced during or after formation of the central ring complex. Green phonolite dykes and plugs are late-stage intrusions. Tertiary erosion produced a silcrete duricrust, aragonite-filled solution cavities and oxidation of REE minerals.

Introduction

The post-Etendeka Agate Mountain Carbonatite Complex was discovered in October 1985 and mapped in January 1990. This paper presents the results of the field mapping and petrographic and mineralogical analysis. Geochemical analyses still remain to be carried out.

The complex appears to be a satellite vent to a slightly older and much larger alkaline volcano centred offshore. The complex itself is located in a range of hills 6.5 km ENE of Cape Fria on the coast of NW Namibia. It occurs directly inland of the Walvis Ridge in a coast-parallel graben down faulted to the west. This graben contains a succession of Karoo sedimentary rocks topped by flows of early Cretaceous basalt and overlying quartz latite of the Etendeka Group (Erlank *et al.*,1984; Milner *et al.*, 1994; Renne *et al.*, 1996; Marsh *et al.*, in press). Dolerite dykes intrude the volcanic rocks.

Evidence for the earlier volcano is provided by a local epiclastic conglomerate that overlies the quartz latite flows and is composed largely of pebbles of quartz latite. The conglomerate contains small fragments of fenitised basement granite and metasedimentary rocks in which aegirine is the only mafic mineral present. The conglomerate and the underlying quartz latite are intensely ferruginised near the complex.

The Agate Mountain Complex was emplaced in a NNW-trending fault down thrown to the west. Along this fault, quartz latite and the epiclastic conglomerate are juxtaposed against basalt. The fault may be the outer, broadly arcuate, cauldron subsidence ring fracture related to the earlier volcano. The quartz latites adjacent to the complex were fenitised then brecciated inside an almost circular ring fracture prior to intrusion of carbonatites, various breccias and radial carbonatite dykes of the complex. Satellite plugs, diatremes and dykes of breccia, carbonatite and phonolite were emplaced subsequently. The intense fenitisation of the red quartz latite to a pervasive green colour contrasts with the very limited and local fenitisation of the basalts and dolerites. In this paper, reference to inclusions of pink or Green Fenite in the satellite intrusive bodies refers to fragments of quartz latite that were fenitised prior to their incorporation as inclusions, whereas reference to pink and green quartz latite refers to inclusions of red quartz latite that were fenitised with the host satellite intrusive during or after its emplacement. The former is the situation in most cases. Samples from the complex were investigated petrographically, by X-ray diffraction and by staining for calcite, ferroan calcite and ferroan dolomite according to the method of Friedman (1959) and Dickinson (1965).

The name Agate Mountain is a misnomer. Its origin is uncertain but it could have been inspired either by the jasper duricrust or by white, colloform and banded aragonite filling an 8 m-diameter solution cavity in the carbonatite at the southern foot of the Camp Hill.

Regional Setting, Petrography and Alteration of the Country Rocks

Karoo sedimentary rocks

The Karoo sedimentary rocks outcrop to the north and east of the present area (Miller and Schalk, 1980) and consist of Permo-Carboniferous fluvioglacial conglomerates of the Dwyka Formation overlain by lower Permian multicoloured shales and minor interbedded gritty, marly, fluvial sandstones. In places, these deposits are overlain by Jurassic to early Cretaceous fine-grained, well sorted, feldspathic, aeolian sandstones of the Etjo Formation. Thin lenses of aeolian sandstone are interbedded with overlying basalt flows 3.5 km NW of the centre of the complex (Fig. 1) and further south at Terrace Bay (Erlank *et al.*, 1984). Some of these Karoo sedimentary rocks occur as xenoliths in several of the satellite plugs (Table 1), the commonest and largest (up to 80 m across on the southern side of the complex) being of the aeolian sandstone. In northwestern Namibia, the Karoo sedimentary rocks are often absent or only very thinly developed below the Etendeka basalts

Table 1: Composition and components of the satellite plugs

Plug number; colour, size	**Matrix**					**Inclusions**												**Late phase veins**	**Associated dykes**
	Calcite	Dolomite	Fe Dolomite	Chert fluorite	Aegirine	Red quartz latite	Green fenite	Pink fenite	Granite	Aegirine granite	Carbonatite	Breccia	Etjo sandstone	Basalt	Dolerite	White syenite	Other		
Sövitic plug with few country rock inclusions																			
18; white, 75m Ø	a					r	r		m								D	N,L	
Sövitic plug with abundant country rock inclusions																			
17; yellow, 1 kmx580m	a	a-m	m-r	m Ch	r		a	a			m s, b	m 2 types		m	m		Pyroxenite	N	
Beforsitic plugs with few country rock inclusions																			
20; yellow, 100 x 50m,		a												m					b
23; 80m Ø, light brown		?											m	m					
24; 50m Ø, light brown		?												m					
26; 30m Ø, light brown		?									m					m	Jasper ec-r		
16; yellow, 25m Ø	r	a	r				m	m			m			m			fss	Sr,Q	
Breccia plugs with both calcite and dolomite matrices																			
5; pinkish, 15m Ø	a c.gr.	a f.gr.	m			m	m	a			m b, s						bxg	Cc	
10; lt. green brown, 380 x 20-120 m	a	a	m		m		a		r	m	m s, b				m		BFB, qtt, fss		red, dykes of 11
12; brown, 420 x 40m	a	a	m				a				m s, b				m		BFB		
19; deep red, 75 m Ø	a	a	m	r F	r	a	r	r										Cc,dol, Fedol	s, b
Breccia plugs with dolomite matrix, abundant inclusions and late calcite filling of small cavities																			
1; greenish brown, 80 x 40 m		a	m			r	a	m	r	r								dol, Fedol, Cc, F	
7; lt. yellow–pink, 120 x 40m,		a	m	m Ch	m		m	a									ec	dol, Cc	
28; yellow brown, 280x200m		a	r		r		a			a	m s, b	a 6 types					D	dol, F, Fedol, RE, Cc	
31; yellow, 360 x 50 m		a					m	m		a	m - b		a, 80 m Ø	m	m		D, fss		br
2; lt. green, 80x20-40m	r	a				m	a	m		m	m - b						Jasper	dol, Cc	
11; brown, 50 m Ø		a	m				a		r	m	r – b, s	r, with pl			r		BFB, qtt, fss	dol, Cc	red
Breccia plugs with dolomite matrix, abundant inclusions and no late calcite filling of small cavities																			
3; pinkish, 80 m Ø		a	r		r	m		a	m	m	r - b				r		r - jasper	dol	
4; brown, 20m Ø		a?									r					a	r – ec, jasper		
8; deep red – green, 400x120m		a	a		a	a	a	a			r - s								
6; pink, 10 m Ø		a	r				a	a		r	r	r 2 types		r	r		bxg	Cc	
13; brown, 100x40m		a				a	a	m	a		m – s,b	r 2 types			r				
22; brown, 100m Ø		a, with pl	m				m		a	a	m - b	r 2 types	a	a				dol, z, F	
25; buff, 250x200m														a					
27; brown, 20 m Ø		a	r							r	r - b			a					
15; yellow, 400 x 30 - 80m		a					a			r	r - b						r –BFB, bxg		
Diatremes with matrix largely of very finegrained mass of aegirine																			
9; green, 500x320m	r				a		a												s
29; green, 30 x 10 m		r			a		a												
Diatremes with very minor carbonate matrix																			
30; reddish, 120x40m															a				
14;greenish–yellow, 25 m Ø		m	r	r -Ch			a	r		r	r	r					bxg	Cc	
Bleached circular structure in basalt																			
21; buff, 300 m Ø		m	r											a					

a - abundant
b - beforsite
Ba - barite
BFB – Blocky Fenite Breccia
br – breccia
bxg – fragments of granite-derived quartz, microcline, plagioclase ± muscovite
Cc – calcite   Ch- chert

D – Damara metasediment, gneiss
dol – dolomite
ec – epiclastic conglomerate
F – fluorite
Fedol – ferroan dolomite
fss – fluviatile Karoo sandstone
i - inclusions

L - leucite
m – minor
N – nepheline
pl – pelletal lapilli
Q – quartz
qtt – quartzite
r – rare

RE – bastnaesite
s – sövite
Sr – celestite
x – present
z - zeolite
? – not sampled, assumed on basis of colour
Ø - diameter

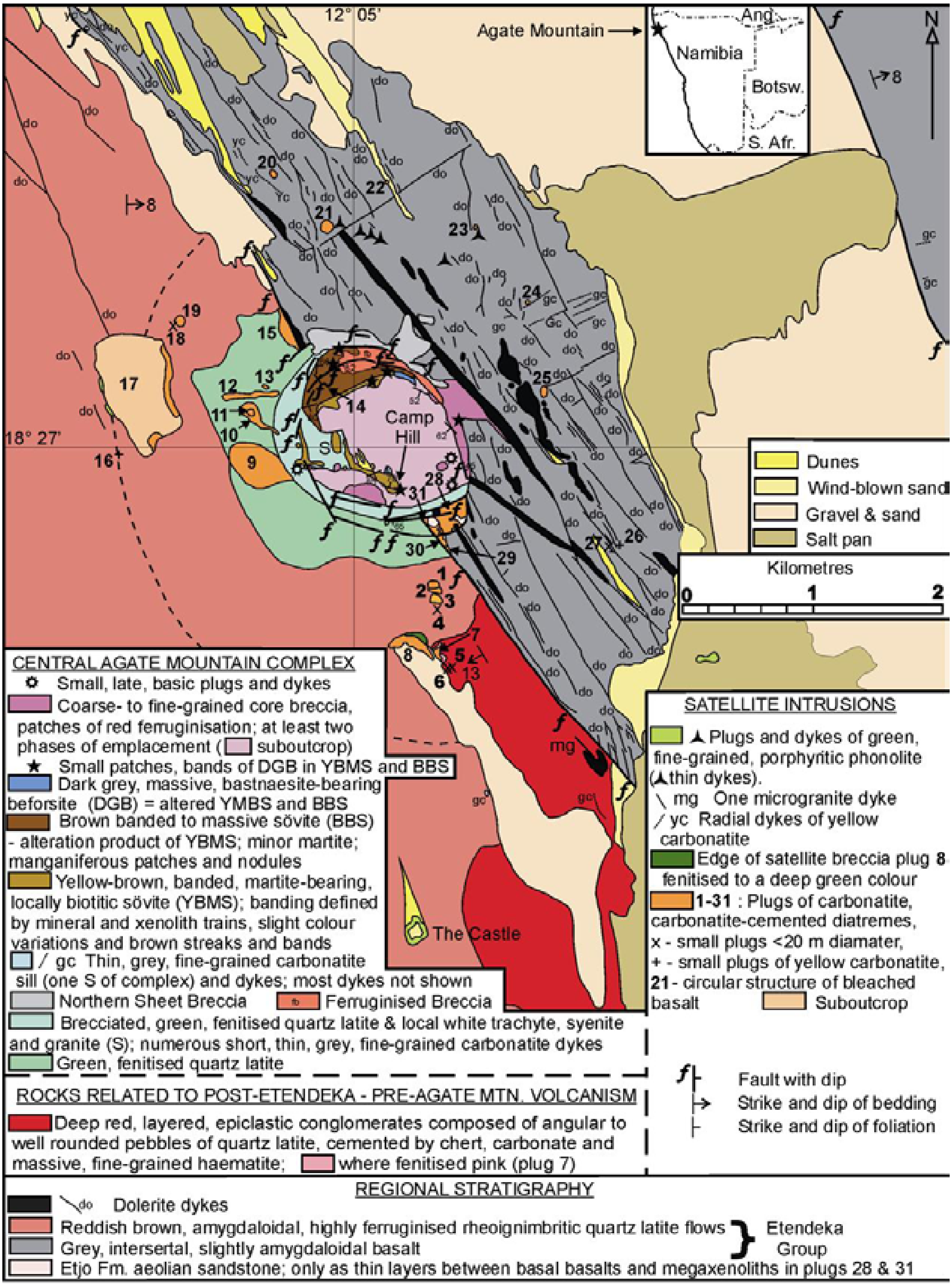

Figure 1: Geological map of the Agate Mountain Carbonatite Complex

(Miller and Schalk, 1980). This, together with the paucity of fragments of Karoo sedimentary rocks in most of the breccias, suggests that the Karoo sedimentary succession is not more than about 100 m thick in the Agate Mountain area.

Etendeka basalts

The basal part of the Etendeka volcanic succession in the area consists of a sequence of dark grey, intersertal, high-Ti (Ewart *et al.*, 1998), amygdaloidal basalts which dip gently south (Ewart *et al.*, in prep.). In the outcrop in the northeastern part of Figure 1 these are 250 m thick. The basalts are porphyritic, variously amygdaloidal and have a relatively coarse-grained intersertal texture. Phenocrysts of slender zoned plagioclase, olivine, rare augite and acicular ore are set in a turbid glassy groundmass containing plagioclase microlites and small crystals of augite, olivine and ore.

In the freshest specimens, plagioclase and augite are unaltered but olivine is completely replaced by carbonate, serpentine and haematite. In contrast to the quartz latites, the basalts have not undergone widespread fenitisation and it is only close to the central complex or to the satellite plugs that strong alteration and fenitisation becomes apparent. As alteration increases, augite becomes extensively replaced by carbonate and abundant haematite, plagioclase initially becomes progressively saussuritised and then sericitised and the glassy groundmass becomes turbid and opaque. Dolomite replacement become extensive with minor fine-grained highly ferroan dolomite scattered through the mafic minerals. In the most intensely altered samples, mafic minerals are replaced by serpentine and ore or aegirine and ore.

Etendeka quartz latites

A sequence of dark reddish brown, rheoignimbritic quartz latite flows overlies the basalts and dips at an average of 8° SE. Individually between 5 and 100 m thick, these flows are best exposed on the northwestern side of the complex where each has a fine-grained, weather-resistant, almost amygdale-free, horizontally jointed base and a highly amygdaloidal, far less weather-resistant top. Often a well developed flow-top breccia up to 3 m thick is present. South of the complex, flows weather uniformly from top to bottom and distinguishing tops and bases beneath a thin scree of small fragments of quartz latite is difficult. The total measured thickness is 420 m. Close to the complex, pervasive haematitic alteration has turned the quartz latites a dark reddish brown. Quartz latites of this colour are not found anywhere else in the Etendeka succession.

The quartz latites are fine-grained, sparsely porphyritic rocks with scattered phenocrysts or glomeroporphyritic clusters of subhedral augite, subhedral plagioclase and alkali feldspar, euhedral apatite and anhedral to subhedral microphenocrysts of ore. The phenocrysts are set in a very fine-grained, holocrystalline matrix containing abundant unorientated slender laths of feldspar and minor acicular augite (ca. 30 %) and opaque ore. The reddish brown colour is due to unevenly distributed but pervasive haematite dust which is most intense along fractures. Augite phenocrysts are both fresh and altered to varying degrees to serpentine or carbonate and haematite. Plagioclase is slightly saussuritised.

Dolerite dykes

Most dykes occur in the basalt. Two occur in the quartz latites and one intrudes the epiclastic conglomerate (Fig. 1). Most dykes are less than 10 m wide but several reach widths of 120 m in places.

Textures are intergranular, coarse to fine grained. Major constituents are slightly subophitic augite and plagioclase. An opaque phase forms a variable minor constituent. The coarse-grained dykes contain a few small phenocrysts of augite and ore. Accessory amounts of micrographic intergrowths occur interstitially.

Fenitisation of the dolerites is only initiated within about 10 m of the central complex along fractures and bleaches the dark grey dolerite to white. Fenitisation manifests itself in several ways. Initially, intermittent hornblende rims form around augite crystals. Hornblende in its turn shows incipient alteration along fractures and grain boundaries to riebeckite. Further in, augite is either replaced by serpentine and dolomite or augite and hornblende are both strongly uralitised. Plagioclase is variably saussuritised and sericitised and extensively replaced by carbonate in the bleached zones. Approximately 2 m from the central complex, all the mafic minerals are either replaced by dolomite and ore and the plagioclase is very strongly saussuritised and sericitised, or the mafic minerals are replaced by serpentine and/or aegirine with plagioclase apparently scarcely altered.

Rocks and features related to a post-Etendeka – pre-Agate Mountain phase of volcanism

Epiclastic conglomerates

These conglomerates are unique to this area and occur nowhere else in the Etendeka volcanic succession. They form an outcrop 2 km wide that extends for 8 km SSE of the complex (Fig. 1).

The conglomerates are deep red to reddish brown, massively to thinly bedded, clast- and matrix-supported and are composed largely of pebbles of highly ferruginised quartz latite. Pebbles reach a maximum size of 10 cm. Rare pebbles of agate up to 5 cm across are present. Sorting varies significantly. Some beds are unsorted and contain pebbles of all sizes in a matrix of gritty, lithic sand. Other beds are well sorted and either largely unimodal, bimodal and even trimodal with large pebbles set in a matrix of small pebbles up to 1 cm across, themselves set in a gritty lithic sand matrix. Thin beds of gritty sand with a few small pebbles also occur. Beds are massive, normally graded or inversely to normally graded. Clasts are generally subangular to subrounded but many are conspicuously well rounded, particularly those in the 1 cm size range. Initial porosity was highly variable. The most porous layers were better sorted and coarser grained and are now cemented by a deep red, very fine-grained haematite or patchy, white calcite.

The pebbles are highly ferruginised by haematite dust. Small lithic fragments in the matrix of many layers are tightly packed and consist largely of highly ferruginised quartz latite, fine-grained dolerite, quartzite and sandstone. Of particular note are a few small pebbles of aegirine-bearing granite and fenitised Damara metasediments in which all the mafic minerals are replaced by aegirine. Several unevenly distributed cements are present in the matrix. In places, an early chert cement forms a rim to the rock fragments. The intense red colour of the conglomerates is enhanced by a deep red, massive, extremely fine-grained haematite cement that can completely fill the pore space between pebbles. In many cases this haematite cement is broken into fragments and granules by a later, pervasive carbonate cement consisting either of dolomite grains with small goethite-stained cores and wide iron-free or weakly ferroan rims or by coarse-grained calcite. Some of the thicker carbonate veins are zoned and have walls of small, zoned, euhedral dolomite crystals which predate the main filling of coarse-grained calcite. Some fractures and cavities contain colourless fluorite as a final filling.

Fenite zones surround the satellite plugs 5,6 and 7 which intrude the epiclastic conglomerate. These zones are small and irregular in the case of the small plugs but up to 50 m wide in the case of plug 7. In the outer part of the fenite zone the conglomerate is bleached pink. The fenitisation front is sharp and advances dyke-like through the matrix of the conglomerate in the form of ramifying green veins consisting of a dense mass of very fine-grained aegirine. The aegirine replaces the earlier chert and carbonate cements of the matrix but not the enclosed rock fragments which are highly turbid. As fenitisation of the epiclastic conglomerate progresses, the red quartz latite pebbles begin to bleach to a light red or pink. Further in, no red pebbles remain and most are bleached light pink. Some are very pale green. The fenite around plugs 5 and 6 does not develop beyond this stage. In the innermost part of the wide fenite around plug 7, all the quartz latite pebbles are green and the matrix is yellowish green. The original chert, dolomite and haematite cements of this matrix are replaced by fine-grained aegirine.

NW-trending regional fault

A NW-trending fault with downthrow to the west (centre of Fig. 1) juxtaposes the stratigraphically lower basalts and their intrusive dolerites in the east against the stratigraphically higher, almost dolerite-free quartz latites and epiclastic conglomerates in the west. Several stages of carbonatite injection, aragonite deposition and movement on the fault are recorded in the fault breccia which contains fragments of highly ferroan beforsite, goethite-stained beforsite, fine-grained ferroan dolomite, aragonite, sövite carbonatite and layered botryoidal pyrolusite-calcite-dolomite-chert. These fragments are set in a matrix of coarse-grained calcite. All movement on the fault ceased before the central ring structure of the Agate Mountain Complex formed.

Geology of the Agate Mountain Carbonatite Complex

The almost circular Agate Mountain Complex has a diameter of 1.5 km and straddles the NW-trending regional fault. It thus intrudes both the basalts and the quartz latites. It post-dates all movement on the fault and is totally unaffected by it.

The complex itself consists of fenites, intrusive carbonatites, various breccias and satellite plugs diatremes and dykes. The apparent succession of events is presented in the sections that follow, from oldest to youngest (see also Fig. 1).

Field relationships, petrography and mineralogy

The Green Fenite

Fenitisation of the reddish brown quartz latites first manifests itself along a roughly circular front 2.4 km from the centre of the complex (Fig. 1) as a patchy alteration of the more permeable zones in the flow-top breccias of the quartz latite layers. As fenitisation progresses, the quartz latites are progressively bleached to brown, light brown, light brown with uneven bands and patches of very light green, light greyish green and finally to pervasive green. The green zone forms a half ring about 500 m wide with an irregular outer margin (Fig. 1). Fracturing, marked by very thin, cross-cutting aegirine veinlets facilitated the advance of metasomatising solutions.

With progressive fenitisation augite phenocrysts are replaced initially by serpentine or carbonate and haematite and then by fine-grained aegirine in the brown quartz latite. Plagioclase is initially saussuritised and then extensively replaced by carbonate. Alkali feldspar orders to microcline. Apatite microphenocrysts are no longer present once the quartz latite has become light brown in colour. The groundmass initially becomes turbid and the ore granules oxidise to haematite but where the rock is light brown in colour, the turbidity has cleared and most of the groundmass augite has been replaced by very fine-grained, acicular aegirine. Ore granules are no longer present in the Green Fenite.

The Blocky Fenite Breccia

This forms the outermost ring to the complex and was approximately 1.5 km in diameter. Only the western, southern and the northern parts are still preserved, the latter two extending across the early NW-trending fault and into the basalts (Fig. 1). It is made up of tightly packed angular blocks and fragments of the Green Fenite. Blocks average 30 to 50 cm in length but some up to 2 m across are not uncommon as are patches of finely brecciated Green Fenite. Quartz blobs up to 10 cm across in the western part of the breccia represent the recrystallised filling of amygdales in the original quartz latite. That part of the breccia closest to the centre of the complex and marked on Fig. 1 with an "S" also contains abundant white fragments of fine-grained trachyte, medium- to coarse-grained syenite and biotite granite. The matrix between the breccia fragments consists of very finely granulated Green Fenite set in a cement of chert or very fine-grained aegirine stained yellow by goethite. The Blocky Fenite Breccia is cut by a network of thin, irregular, fine-grained, brownish grey to dark brown beforsitic veinlets and dykes up to 10 cm wide, most of which lack country rock inclusions.

The trachyte fragments consists of a few phenocrysts of twinned K-feldspar set in a trachytic groundmass of twinned K-feldspar laths. The grain size of the syenite is variable. It consists of a few slightly sericitised, anhedral K-feldspar phenocrysts set in a granitic textured groundmass of largely untwinned, anhedral to subhedral, slightly sericitised K-feldspar, some grains of which have very thin, clear, unaltered albitic rims. In some fragments, small, thin, bladed K-feldspar crystals are abundant. Highly sericitised plagioclase is a minor component. Quartz, as an intergranular filling, makes up about 5 % of the rock. Felspars have euhedral faces or terminations protruding into the quartz-filled interstitial spaces. Aegirine is generally accessory but can make up 30 % of the syenite. The granite rock fragments are largely biotite granite but some are partially fenitised and contain accessory perovskite and aegirine either as separate crystals or as a fine-grained rim to biotite.

The syenite and trachyte are fragmented and hydraulically brecciated. Fragments are cemented by chert or fanning growths of acicular quartz. Thin, cross-cutting calcite veins contain up to 20 % skeletal ore, minor zoned rhombs of goethite-stained dolomite and accessory aegirine, fine-grained perovskite and, locally, acicular bastnaesite and fluorite. A minor, late, barite cement is present in places.

The beforsitic veins and dykes between the breccia blocks are often foliated. They have no preferred orientation and consist primarily of fine-grained, clear, anhedral dolomite. Small amounts of calcite are scattered through the dolomite. Most dolomite and calcite grains are separated from each other by a thin film of chert which often has a thin core of haematite running down its centre. Foliation-parallel ferruginous bands up to 3 mm wide impregnate the carbonate grains with haematite, goethite and an opaque phase and have central bands of pure haematite and goethite.

The Northern Sheet Breccia

This is a massive, brownish grey, fragment-filled, carbonate-cemented breccia sheet overlying basalt and a sliver of the Green Fenite on the northern edge of the central ring structure. It dips in towards the centre of the complex at an angle of 5°. The most abundant rock fragments are Green Fenite and fenitised granite and gneiss. Less abundant are unaltered granite, breccia fragments which are mainly quartz latite breccias, brown quartz latite, carbonatite, altered dolerite, feldspathic sandstone and fragments of a highly ferruginised, fine-grained breccia. The matrix consists of a fine-grained quartzo-feldspathic groundmass cemented by abundant, fine-grained, intensely goethite-stained dolomite with local, clear, ferroan dolomite rims. A few grains of calcite are scattered through the matrix. Broken crystals of aegirine are an accessory component in the matrix. Small cavities in the matix are either filled with calcite and chert or barite or are lined with fine-grained, euhedral, goethite-coated dolomite without any later fill.

Regional carbonatite dyke swarms

There are two main swarms of thin, fine-grained, grey, brownish grey or very light brown carbonatite dykes generally between 10 and 40 cm wide. A few red dykes cut the epiclastic conglomerate. One swarm predates and one post-dates the Northern Sheet Breccia (Fig. 2). The dykes intrude the Northern Sheet Breccia and all rocks older then the Northern Sheet Breccia. Where the Northern Sheet Breccia is absent, dykes from the two swarms cannot be distinguished from each other. Most are approximately radial in strike but have variable dips. A few concentric, inward-dipping dykes are present close to the complex. Several dykes occur up to 4.5 km from the complex (Fig. 1) and one occurs on the coast near False Cape Fria, 7 km to the southwest. They are most abundant close to the complex in the Green Fenite, the Blocky Fenite Breccia and, to a lesser extent, in the Northern Sheet Breccia. Figure 2 compares the orientation of relatively abundant dykes in the Green Fenite immediately west of the Northern Sheet Breccia and of less abundant dykes in the adjoining western edge of the Northern Sheet Breccia. Of these, most dip westwards. The orientation of those in the Green Fenite is more variable than those in the Northern Sheet Breccia. The few clearly concentric dykes are more steeply dipping in the Green Fenite (two sets on poorly defined great circles that dip 40 and 80° inwards) than in the Northern Sheet Breccia (average 26°). Most of the westerly dipping radial dykes do not fall on these great circles and were thus emplaced into fracture systems that are unrelated to those filled by the

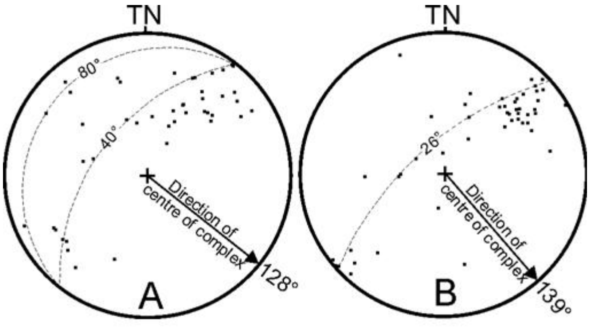

Figure 2:. Lower hemisphere Schmidt net projection of poles to thin, regional carbonatite dykes in: A – the Blocky Fenite Breccia just east of the Northern Sheet Breccia; B – the western end of the Northern Sheet Breccia.

concentric dykes.

The dykes have variable textures, grain sizes and mineralogical compositions. They include dykes with: (a) euhedral rhombs and doughnut-like globules of calcite with small cores of goethite-stained dolomite set in an intergranular chert matrix that makes up 40 % of the dyke; (b) calcite with very fine-grained, intergranular dolomite; (c) calcite, dolomite, ferroan dolomite and intergranular chert; and (d) fine-grained dolomite. Opaque ore dust is unevenly disseminated through most dykes.

The Ferruginised Breccia

This is a massive, deep rust red, intensely haematite-stained, very coarse-grained breccia. Ferruginisation by powdery haematite is so intense that the original rock type of the fragments can often not be recognisable. However, some of the large blocks in the breccia are themselves breccias with fragments up to 1 m across of a rock not unlike the Green Fenite set in a network of carbonatite veins and dykes up to 1.5 m wide. In thin section fragments of quartz latite and aegirine granite could be recognised in a highly ferrruginised matrix of smaller fragments and fine-grained dolomite with accessory amounts of broken aegirine crystals. A few patches of clear, coarser grained calcite occur in the matrix. The Ferruginised Breccia is considered to have been emplaced after the Northern Sheet Breccia but prior to intrusion of the main sövitic carbonatite because it appears to consist mainly of quartz latite rock fragments, lacks the large variety of rock types contained in later breccias and is not cut to any great extent by the radial dyke swarms.

The Yellow Banded Martite Sövite

The Yellow Banded Martite Sövite is the main carbonatite intrusion in the complex. It forms a partial, discontinuous ring of variable width which intruded the central Blocky Fenite Breccia. Banding in the sövite is defined by colour changes in yellow and darker and lighter brown, by bands of differing grain size and composition, by trains of minor and accessory minerals and, in places, by trains of inclusions up to 20 cm in diameter of Green Fenite and white trachyte and syenite. Bands vary from a few mm to several cm in width and although sinuous, broadly conform to the circular outline of the ring structure.

Clear, anhedral to euhedral, medium-grained calcite is the main constituent. Dolomite makes up about 20 % of the rock and occurs as very pale brown grains similar in size to the calcite and as very fine-grained, colourless, interstitial grains with which some ferroan dolomite is also associated. The abundance of dolomite varies from band to band with some bands consisting almost entirely of dolomite. An opaque phase is the next most abundant constituent. Much of it is in the form of anhedral to octahedral pseudomorphs of martite (Ford, 1963) after magnetite which vary in size from minute granules up to crystals 5 mm across. The octahedra are generally disseminated in the carbonatite but they also concentrate into trains and almost pure clusters up to 1 m across. The opaque phase occurs both as solid and skeletal grains enclosed in carbonate or concentrated along carbonate grain boundaries. Accessory minerals are acicular aegirine with local pink terminations, euhedral perovskite, anhedral to euhedral, colourless fluorite and dark brown, strongly pleochroic biotite.

Characteristically, the carbonate grains in the sövite are enclosed in an intergranular cement of chert, sheaf-like quartz with wavy extinction or quartz with plain extinction which can make up 30 % of the rock. Locally, radiating clusters of tiny bastnaesite needles grow outward from the margins of carbonate grains and are enclosed in the quartz cement. Elongate, foliation-parallel cavities up to 3 mm wide and 10 mm long in the sövite have a thin lining of chert or ferroan dolomite and a final filling of quartz. Locally, aegirine prisms with pink terminations, bastnaesite sheaves or clusters and anhedral to euhedral fluorite also occur in the cavities.

Very few dykes cut the main carbonatite. These are limited to rare, short, dark brown or black, very fine-grained carbonatite dykes up to 2 cm wide.

Dark Brown Sövite

In the northern part of the complex, the Yellow Banded Martite Sövite grades into and appears to be replaced by banded to massive carbonatite which is a relatively uniform dark brown sövite. Banding in this carbonatite is less common, less distinct and thicker than in the Yellow Banded Martite Sövite. Country rock fragments are also less common. Highly ferruginous fragments of the Ferruginised Breccia occur in the Dark Brown Sövite close to its contact with the Ferruginised Breccia. In the northern and western parts of the Dark Brown Sövite, black, round or irregularly shaped manganiferous nodules are present. These reach 10 cm in diameter and occur singly or in stringers along short, randomly orientated joints.

Fine- to coarse-grained, anhedral to euhedral calcite is the main component. Many grains are slightly elongate. Some with euhedral terminations look like pseudomorphs after olivine. Dolomite is usually very minor (<5 %) and similar in grain size to calcite but in places it makes up 40 % of the rock. Ferroan dolomite occurs as clear rims to some calcite grains, near cavities and in patches of scattered grains. Martite pseudomorphs after magnetite are considerably less abundant in this rock than in the Yellow Banded Martite Sövite. In most samples of the Dark Brown Sövite, very fine-grained goethite and haematite are abundant and are concentrated around pseudomorphs of martite, along cleavage planes in the carbonate grains and along carbonate grain boundaries. In the manganiferous nodules there is a dense concentration of fine-grained needles of ore along cleavage planes and grain boundaries. Accessory minerals in the Dark Brown Sövite are aegirine, biotite, sheaves of yellow, fine-grained bastnaesite needles, unzoned and well zoned perovskite, fluorite and rare melilite, the latter enclosed in carbonate. An interstitial cement of radiating clusters of quartz needles constitutes up to 20 % of this rock in places but is not universally present. The filling of small, narrow, elongate cavities in this carbonatite is variable. Some cavities have a lining of anhedral or octahedral grains of ore, others are lined by euhedral ferroan dolomite. The final fill can be calcite or sheaf-like clusters of quartz. Aegirine with pink rims occurs in some cavities and rare sheaf-like clusters of bastnaesite needles in the quartz in others.

Dark Grey Beforsite

The Dark Grey Beforsite is the product of replacement of both the Yellow Banded Martite Sövite and the Dark Brown Sövite. The replacement front is either patchy, irregular and gradational (e.g. eastern edge of Camp Hill) or advances as sharp-edged bands that cut diagonally across the banding in the host carbonatite (e.g. northernmost outcrops of the Yellow Banded Martite Sövite). Although the Dark Grey Beforsite is generally structureless, the growth and concentration of yellow to straw coloured bastnaesite in small, scattered, elongate, foliation-parallel cavities that were present in the host carbonatite produces a lineation which follows the extension of the banding in the unaltered host.

Although not obvious in outcrop, thin sections reveal very variable textures and mineral compositions. Dolomite is the main constituent. In some samples, an early, anhedral, fine-grained, intensely goethite-stained dolomite is post-dated by two generations of fine-grained, euhedral, zoned dolomite rhombs. In one generation, different intensities of goethite staining define the different zones with the intensity increasing towards the outer margins of grains. The second generation consists of slightly larger rhombs with large clear cores and thin, intensely goethite-stained margins. Other samples are composed almost entirely of euhedral rhombs of weakly ferroan dolomite with goethite-stained cores enclosed in five alternating clear and goethite-stained zones. The outermost zone is usually clear. A few grains of highly ferroan dolomite are usually present. Isolated stringers of very fine-grained, weakly ferroan dolomite occur along the margins of the larger dolomite grains. Remnant, relatively coarse-grained, primary calcite generally constitutes up to 10 % of the above rocks. It is either disseminated or forms clusters of anhedral, slightly elongate grains up to 0.8 mm long. In these clusters there are a few grains of very pale brown dolomite of the same size as the calcite as well as very fine-grained, clear dolomite along the margins of the larger grains or in small clusters. Opaque phases form 3 - 40 % of the rock, mainly as fine granules in the carbonate grains and along grain boundaries. A few martite octahedra are present. X-ray diffraction analysis detected only haematite and goethite, although accessory, very fine-grained, radial, black needles in the groundmass could be a manganese oxide. In places, patches of colourless, anhedral fluorite form up to 20 % of the rock. Fluorite also occurs as very fine-grained cubes in the dolomite rhombs. Sheaves and radiating clusters of fine-grained, pale yellow bastnaesite form up to 10 % of the rock and even 40 % in small patches. It occurs along grain boundaries but is most abundant in cavities. Aegirine is accessory.

Elongate and irregularly shaped cavities are lined either by very fine-grained dolomite or by small anhedral crystals of weakly ferroan dolomite with clear and goethite-stained zones, or by bastnaesite or by ore granules. The final filling of the cavities is relatively coarse-grained quartz and/or calcite, a platy zeolite or layers and crystals of colourless to purple fluorite. Basnaesite needles and skeletal needles of opaque ore grow into the quartz or calcite fill.

Core Breccia

The Core Breccia was emplaced explosively into the Yellow Banded Martite sövite and its replacement products. It occupies a broad, shallow depression in the centre of the complex and extends beyond the eastern margin of the complex into the basalts. Near the southern edge of the main complex, a broad arm of the Core Breccia extends westwards into the Blocky Fenite Breccia. Outcrops are poor and confined largely to the eastern and southern parts of this intrusive body. Greyish brown in the west, the Core Breccia becomes redder eastwards and is dark red and intensely ferruginised by powdery haematite in the east.

The Core Breccia is a fine-grained dolomitic carbonatite with abundant inclusions of country rock comprising essentially two components. The first, and slightly coarser grained, contains fragments that are generally less than 1 cm in diameter but range up to 10 cm. The later and finer grained component forms intrusive veins in the first and contains fragments that are all less than 1 cm in diameter. Fragments present are Green Fenite, abundant calcite carbonatite which includes recognisable Yellow Banded Martite Sövite with martite octahedra, Dark Brown Sövite with manganiferous nodules, granite, dolerite, quartzite, other breccias of which some are highly ferruginised, and rare fragments of coarse-grained Damara dolomitic marble. Fragmented grains of calcite, quartz, microcline, plagioclase and aegirine are common. The proportion of carbonatite fragments varies considerably from place to place in the breccia.

Textures and the distribution of the various constituent minerals of the matrix are very variable. Finely comminuted rock fragments are a ubiquitous constituent. Subhedral to euhedral, goethite-stained grains of dolomite are the primary matrix carbonate but small fragments of calcite from the main sövite make up the bulk of the matrix carbonate in places. Weakly ferroan dolomite occurs in patches, in thin streaks of disseminated grains and as isolated grains. The coarse-grained breccia contains abundant colourless to purple, euhedral to anhedral and vermicular fluorite. Rare aegirine-rich rock fragments contain up to 40 % apatite. Accessory apatite also occurs in some carbonatite fragments and in the matrix. Martite octahedra and perovskite are accessory constituents. Chert and haematite form an abundant cement in places.

Numerous thin, short dykes of grey, brown and dark brown carbonatite up to 10 cm wide intrude the Core Breccia along microfractures in the southernmost outcrops. Some of the dykes are themselves displaced by microfractures. The dark brown dykes consist of fine-grained, zoned, anhedral to euhedral grains of dolomite with dark brown, goethite-stained cores and clear rims.

Late basic plugs and dykes

Of only three occurrences, one forms a series of intermittent outcrops up to 22 m wide over a N-S distance of 150 m in the Blocky Fenite Breccia on the southwestern edge of the westermost occurrence of the main sövite. It has a fine-grained intergranular texture with slightly subophitic augite. Twinned plagioclase laths, zoned from labradorite to andesine, range from fresh to completely altered to carbonate. An opaque phase makes up about 5 % of the rock. The augite is either fresh, uralitised in patches or is marginally altered to aegirine with pink rims. Patches consisting clusters of aegirine needles, carbonate and opaque ore may be replacement products of olivine.

The second occurrence is a 6 m-diameter plug of fine-grained nepheline-bearing dolerite which intrudes the Core Breccia near its eastern margin. Two dykes extend from the plug into the Core Breccia, one 1.5 m wide and 50 m long, the other 0.5 m wide and 40 m long. The plug and dykes have baked the adjoining Core Breccia to a hard olive brown rock in which some of the carbonatite rock fragments have become orange in colour. The dolerite contains microphenocrysts of anhedral to euhedral magnetite, augite and nepheline in that order of abundance set in a groundmass of strongly zoned but untwinned plagioclase that poikilitically encloses fine-grained, acicular augite.

The third occurrence is a dolerite dyke 4 m wide and 100 m long that occurs south of the nepheline-bearing dolerite at the southeastern edge of the Core Breccia. The dyke has a porphyritic intersertal to intergranular texture. Phenocrysts of labradorite, pale green augite and altered olivine are set in a fine-grained matrix of plagioclase, augite, serpentine and glass. Small magnetite octahedra are accessory. Riebeckite replaces augite and olivine.

Microgranite dyke

A microgranite dyke between 0.5 and 5 m wide and 900 m long occurs west of, and parallel to, the main regional fault to the south of the central ring structure. The dyke is composed of approximately equal amounts of stumpy, sericitised alkali feldspar and partly saussuritised, twinned oligoclase. The remaining constituents are interstitial granophyric intergrowths (20 %), separate grains of interstitial quartz (5 %), opaque ore (3 %) and accessory carbonate.

Satellite intrusions

Thirty out of a total of 31 satellite diatremes and plugs (Table 1) were emplaced into the fenites and country rocks outside the main ring structure (Fig. 1) and up to a distance of 2 km away. One plug intrudes the Dark Brown Sövite. Most are circular but some are dyke like, others broad and elongate. They vary in size from 1 km x 580 m to 10 m in diameter. Most are fragment-choked breccias, particularly the large diatremes to the west and south of the central ring structure, but a few consist largely of carbonatite. Feature 21 is a circular, bleached zone in the basalts that is only slightly brecciated. Many contain fragments of both green and pink fenite and clearly post-date the Green Fenite. Some, such as 31, contain fragments of several different types of breccia. Of particular interest are dark brown breccia fragments in diatreme 11 which contain pelletal lapilli (see Table 1) that are almost identical to features described and illustrated by Le Bas (1977) as accretionary lapilli (Plate XXd). Plug 22 contains pelletal lapilli in the matrix. Diatreme 11 is younger than and intrusive into diatreme 10. Diatreme 31 contains the largest of all inclusions, a block of aeolian Etjo Formation sandstone 80 m across. This diatreme appears to include fragments of diatreme 28 and is therefore the younger. Diatreme 14 post-dates the Dark Brown Sövite. For the rest, the ages of the diatremes and plugs relative to each other and relative to events in the central ring structure are unknown. Since the general sequence of intrusion of carbonatite is calcite carbonatite followed by dolomite then ferroan dolomite or ankerite carbonatite (Barker, 1989), it has been assumed that the composition of the primary carbonate of the plug or the diatreme matrix gives an indication of the relative age of the host body. Thus, in Table 1, plugs and diatremes are listed according to the composition of the primary carbonate of the plug or the matrix. Those with primary calcite are listed first, those with both calcite and dolomite are listed next followed by those with a dolomite matrix. Those with other matrices or very little or no carbonate are listed last. This sequence may in part give an indication of relative age. Those satellite intrusions containing fragments of aegirine-bearing granite and Damara metasedimentary rocks (Table 1) have clearly been emplaced from depths below the base of the Karoo sedimentary succession, i.e. from at least 800 m below present erosion levels. Those lacking such fragments appear to have been emplaced from shallower depths.

Other carbonatite dykes

Thin fine-grained, yellow, brown and white carbonatite dykes less than 30 cm wide occur in the basalt north and northeast of the main ring structure. Some are radially orientated and appear to be related to the main structure but others have various orientations, are similar to and may be part of the late dykes system associated with the satellite plugs in this area. The matrix of the dykes consists largely of dolomite with minor amounts of ferroan dolomite. Fluorite, melilite and barite are accessory minerals. Various rock and breccia fragments are present in variable amounts.

Of particular interest is a 10 cm-wide, yellowish brown dyke in the isolated, northeastern patch of the Northern Sheet Breccia. This dyke contains abundant small fragments of quartz latite, aegirine-bearing granite and several spherical pelletal lapilli set in a fine-grained, quartzo-feldspathic matrix with abundant blebs, patches and crystals of fine-grained, goethite-stained dolomite and accessory calcite. The pelletal lapilli have cores of either zoned or clear dolomite rhombs or euhedral alkali feldspar with a relatively thick, brown, fine-grained, optically unresolvable mantle containing primatic microphenocrysts (feldspar?) arranged concentrically relative to the core. They are similar to pelletal lapilli described by Lorenz (1979), Mitchell (1986) and Clement and Skinner (1985). Plug 22 contains somewhat similar lapilli and may be the source for this dyke.

Green phonolite plugs and dykes

Green, fine-grained, porphyritic to microporphyritic, markedly weather-resistant phonolite plugs and dykes occur in the basalts and quartz latite between 1.4 and 3.7 km from the centre of the main ring structure. At least eight dykes up to 3 m wide and 100 m long intrude the basalts in the area between Plugs 21 and 24. Two similar dykes 120 m long and up to 40 m wide occur on the western edge of Plug 17. One plug occurs in the salt pan southeast of the complex and another, “The Castle,” is due south. The Castle forms a thick-walled square with a hollow, sand-filled centre. The square is 160 m across and the phonolite walls up to 50 m thick.

The phenocryst suite varies. In the least variable dykes, platey laths of plagioclase with only Carlsbad twinning and small, blocky euhedral microphenocrysts of nepheline, together making up about 1 % of the rock, are set in a fine-grained groundmass of felted feldspar laths with abundant single crystals and radiating and bowtie aggregates of dark green acicular aegirine. In other dykes, euhedral phenocrysts of sanidine and microphenocrysts of green anhedral to euhedral aegirine with rare cores of pink titanaugite, euhedral, clear nepheline, biotite, carbonate euhedra and ore are set in an almost cryptocrystalline feldspathic groundmass containing clusters of very fine-grained, acicular aegirine needles which make up about 20 % of this groundmass. Rounded single crystals of carbonate up to 2 mm across may represent filled vesicles. The sanidine is partly replaced by a zeolite forming a fine-grained mosaic of unevenly extincting crystals. Biotite and ore microphenocrysts are enclosed in a broad rim of very fine-grained aegirine. The aegirine phenocrysts have a similar but narrow rim of very fine-grained aegirine.

The Castle phonolite contains a few small fragments of aegirine-bearing granite. Foliation parallel to the margins of the phonolite is defined by a faint grain size and colour banding and by orientation of the feldspar phenocrysts. The largest phenocrysts are clear, euhedral to well rounded sanidine with Carlsbad twins. The rounded phenocrysts have a thin rim of nepheline. Hexagonal pseudomorphs of carbonate and zeolite may initially have been nepheline. Smaller phyric minerals are highly altered sodalite, anhedral phlogopite and augite which is extensively replaced by serpentine and ore and, along grain margins, by aegirine. The phlogopite grains are enclosed in a dense mass of fine-grained aegirine. The fine-grained, felted to trachytic groundmass consists of abundant plagioclase laths and aegirine needles containing about 30 % microphenocrysts of highly altered sodalite and about 5 to 10 % clear, euhedral nepheline with a few very fine-grained inclusions of aegirine needles orientated parallel to crystal margins.

The phonolite plug in the salt pan is very similar to The Castle phonolite. However, dark brown, strongly pleochroic biotite phenocrysts occur in this rock instead of phlogopite.

The Ring Faults

The ring faults shown on Figure 1 are all between 10 and 40 cm wide and are largely filled with brown, structureless jasper. However, parts of the northernmost faults and that on the southeastern edge of the Core Breccia are filled with layered white aragonite with a few local layers of botryoidal pyrolusite up to 4 cm thick or layers of nodular dendritic pyrolusite growths up to 8 cm long. Some of the faults appear to be early in age as they form the boundary between rock types formed early in the history of the complex such as between the Northern Sheet Breccia and the Ferruginised Breccia and between the Green Fenite and the Blocky Fenite Breccia. The same faults also displace the fine-grained, grey, radial sövite dykes and Plugs 28 and 31 and therefore appear to have been active throughout most of the evolution of the complex. It is believed that the jasper, aragonite and pyrolusite are late-stage, epithermal deposits in the faults. Adjoining the ring faults, the above radial sovitic dykes are replaced by chert for a distance of up to 1 m from the faults, the amount of the replacement decreasing away from the fault.

Tertiary to Recent surface and near-surface modification of the carbonatite

The Yellow Banded Martite Sövite and the Dark Brown Sövite contain a few solution cavities ranging from 5 cm to 8 m across. All are completely filled with massive white aragoniteor banded white and grey aragonite. Erosion remnants of a brown jasperoidal silcrete duricrust cover the highest hills of Yellow Banded Martite Sövite and Ferruginised Breccia. Thin over the Ferruginised Breccia, the jasper is up to 3 m thick over the Yellow Banded Martite Sövite and becomes even thicker where it penetrates down into the sövite along vertical joints. No other rock types are covered by this duricrust and it is clear that the bedrock composition played an important role during precipitation of the silcrete.

Discussion

Nowhere else in the Etendeka succession has a conglomerate similar to the epiclastic conglomerate been found. Furthermore, the pebbles in the epiclastic conglomerate are all deep red. There are no pebbles of Green Fenite. However, the clast suite in the conglomerate includes small pebbles of fenitised granite and metasediments from the underlying Damara basement in which all the mafic minerals have been replaced by aegirine. Except where fenitised by late carbonatite and breccia plugs, there is no other aegirine in the epiclastic conglomerate. The intense ferruginisation of the conglomerate, its contained pebbles and the underlying quartz latite is also a feature that is unique to this small area of the Etendeka succession. The massive haematite cement in the matrix of parts of the conglomerate points to a very intense ferruginisation process.

All the above rocks and features are suggestive of a large-scale explosive volcanic event that produced pyroclastic ejecta composed largely of fragmented quartz latite and caused deep-seated fenitisation of the pre-Karoo basement. Reworking of the ejecta into epiclastic deposits was followed by faulting and intense late-stage oxidation and ferruginisation of the down-faulted quartz latite and epiclastic conglomerate. No vent to which this volcanism and fenitisation could be ascribed has been found but mapping by Ewart *et al.* (in prep.) of the Etendeka volcanic succession in this area has revealed a set of faults, including the fault in Figure 1 separating basalt and quartz latite, that is slightly concave to the west and towards the epiclastic conglomerate. The fault set may be the result of cauldron subsidence associated with a large volcanic feature located just offshore. High levels of Fe_2O_3 are typically the result of late-stage processes in carbonatite complexes (Woolley and Kempe, 1989). This suggests that the Agate Mountain Complex might be a satellite vent to a much larger and slightly older alkaline volcano and that its emplacement took place on the main bounding ring fracture of this older volcano after late-stage ferruginisation had affected down-faulted rocks within the main caldera. This conclusion is supported by the late-stage brecciation of carbonatite veins and aragonite in the main fault in Figure 1 but the lack of propagation of the fault into the central ring structure of the Agate Mountain Complex.

A distinction between the Agate Mountain Complex and most other carbonatites (Barker, 1989) is the absence of early undersaturated silicate rocks in the former. Although none of the green phonolites occur in the main ring structure, the two dykes on the western edge of Plug 9 and the apparent absence of green phonolite fragments in the numerous diatremes and fragment-filled dykes suggest that the phonolites post-date the satellite plugs. As with many carbonatites (Barker, 1989), the main fenitising event preceded emplacement of the first carbonatites, the thin, irregular dykes in the Blocky Fenite Breccia and the Yellow Banded Martite Sövite. Plugs 5, 6 and 7 are associated with a front of fenitisation advancing into the enclosing conglomerates ahead of their central carbonatitic intrusions. However, some of the early and late regional carbonatite dykes, although by no means all, have fenitised the rocks they have intruded for distances of 1 to 3 cm. Intense, post-emplacement fenitisation has altered the northeastern edge of Plug 8 and the adjoining quartz latite.

An early phase of ferruginisation followed emplacement of the early Ferruginised Breccia, but preceded emplacement of the main carbonatite. Emplacement/replacement of the carbonatites followed the normal sequence of calciocarbonatite first followed by magnesiocarbonatite then ferrocarbonatite with fluorite, REE minerals, chert, quartz, zeolites and minor barite and celestite being late-stage intergranular or cavity fillings (Le Bas, 1981; Kapustin, 1987; Barker, 1989). A final oxidation phase caused fairly intense ferruginisation of the Core Breccia and is commensurate with the late-stage increase in Fe_2O_3 in carbonatites (Woolley and Kempe, 1989). The only REE mineral that the author has been able to detect in the several samples analysed is bastnaesite but parisite and cerianite have been identified in samples studied by A.N. Mariano (P. Siegried, pers. comm., 1999).

There is clearly a very strong bedrock control on the distribution of the silcrete duricrusts Watson and Nash (1997). A similar bedrock control is evident around the foot of the Rössing Mountain 50 km ENE of Swakopmund where dolomites of the Karibib Formation are capped by similar silcrete (Schneider and Seeger, 1992). The massive nature of the silcrete duricrusts at Agate Mountain, the aragonite-filled solution cavities and the occurrence of cerianite (CeO) which is the product of weathering of Ce from REE-bearing minerals (Mariano, 1989) suggest that the duricrusts could be related to deep weathering during a much wetter period in the past, possibly the mid-Miocene when the high-level Orange River gravels were deposited (Ward *et al.*, 1983).

As yet undated, the Agate Mountain Complex is clearly post Etendeka. It may well be the same age as complexes further south, namely 132 Ma (Renne *et al.*, 1996). However, it could also be approximately 90 Ma and the same age as the Phoenix High, a large Cenomanian volcano centred on the southern edge of the Walvis Ridge at 18° 51' S 11° 19' E some 90 km to the southwest (Light *et al.*, 1993; Holtar and Forsberg, 1997).

The concentrations of martite in the Yellow Banded Martite Sövite and pyrolusite in the ring fractures are too low to be of economic interest. Although bastnaesite constitutes up to about 20 % of the Dark Grey Beforsite and the Core Breccia in places, tonnages appear to be too low for this mineral to be of economic interest.

Summary

The Agate Mountain Carbonatite Complex is located just onshore of the Walvis Ridge and intrudes earliest Cretaceous quartz latites and basalts of the Etendeka Group. These are underlain by Karoo sediments, primarily aeolian and fluviatile sandstone and shale. The pre-Karoo basement consists of Pan-African metasediments and granites of the Damara Orogen. The complex appears to be a satellite vent to a slightly older and much larger alkaline volcano centred offshore. The following is believed to be the sequence of events that took place prior to and during emplacement of the Agate Mountain Carbonatite Complex:

1. Large offshore volcano:
a) Fenitisation of Damara basement;
b) Explosive volcanism creating a pyroclastic deposit composed largely of fragments of quartz latite with very minor aegirine-bearing granite and metasediment;
c) Reworking of the pyroclastic deposits to form epiclastic conglomerates;
d) Ring faulting, cauldron subsidence, juxtaposition of basalt and quartz latite;
e) Intense ferruginisation by haematite of the downfaulted quartz latite and epiclastic conglomerate close to the ring fracture within the caldera;
f) Intrusion of different carbonatite veinlets and deposition of aragonite in the ring fracture; periodic movement on the ring fracture and brecciation of the carbonatitic and aragonitic filling;
g) Cessation of movement on the ring fracture.

2. The Agate Mountain Carbonatite Complex
a) Extensive and intense fenitisation of the red, ferruginised quartz latite to Green Fenite in a semicircular zone roughly 4 km in diameter adjoining the earlier ring fracture; fenitisation decreasing in intensity and becoming patchy outwards for another 1 to 1.5 km;
b) Formation of an almost circular ring fracture 2 km in diameter in the centre of the Green Fenite semicircle. This straddled the older ring fault, half being in the Green Fenite and half in the basalts. Concomitant coarse blocky brecciation of the Green Fenite to form a Blocky Fenite Breccia inside the ring fracture and apparent displacement of the corresponding basalts such that the brecciated Green Fenite completely filled the area inside the ring fracture. Possible concomitant emplacement of thin, grey to brownish grey, radial sövite dykes in the country rocks for a distance of up to 7 km from the complex;
c) Emplacement of numerous, thin, brown carbonatite veinlets along the margins of the blocks in the Blocky Fenite Breccia;
d) Emplacement of a low-angle sheet of breccia, the Northern Sheet Breccia, into the fenite and basalt on the northern edge of the complex;
e) Emplacement of a second set of thin, grey to brownish grey, radial sövite dykes into the country rock and the Northern Sheet Breccia;
f) Emplacement of a coarse-grained breccia into the northeastern edge of the Blocky Fenite Breccia and intense ferruginisation thereof to form the Ferruginised Breccia;
g) Emplacement of the main Yellow Banded Martite Sövite as thick, incomplete rings and plugs in the central Blocky Fenite Breccia;
h) Two-stage alteration of the Yellow Banded Martite Sövite to (a) a Dark Brown Sövite with nebulous and nodular patches of black, manganiferous staining and (b) ultimately to a Dark Grey Beforsite that carries bastnaesite;
i) Formation of local, fragment-filled, carbonatitic breccias (only seen as inclusions in the next unit);
j) Two-stage, explosive emplacement of the carbonatitic Core Breccia, an earlier slightly coarser grained phase preceding a finer grained phase; possible concomitant emplacement of dolomitic regional dykes, some radially, some randomly orientated;
k) Emplacement of numerous, thin, dark brown carbonatite veinlets in the Core Breccia;
l) Local ferruginisation of the Core Breccia;
m) Emplacement of 31 carbonatitic and fragment-filled

satellite plugs; emplacement of local dolomitic carbonatite dykes in and around some of the plugs. Because some of the plugs have calcite matrices and others dolomite and ferroan dolomite matrices, emplacement of the satellite plugs is likely to have occurred over a considerable period of time during evolution of the rest of the complex. In addition, many of the plugs carry fragments of earlier breccias, some as many as five different breccia types. Pelletal lapilli occur in some of the plugs;

n) Local intense fenitisation of matrix, fragments and xenoliths in Plug 8;

o) Discontinuous ring fractures in the central part of the complex are likely to have formed at various stages but were active until a very late stage;

p) Deposition of silica, botryoidal pyrolusite and white aragonite in the radial fractures;

q) Erosion of the complex, formation of a brown jasperoidal silcrete duricrust on the Yellow Banded Martite Sövite and the Ferruginised Breccia, possibly during the mid Miocene. Concomitant formation of karst-like cavities in the main sövites and the filling thereof with aragonite. Growth of cerianite as a result of weathering of primary REE-bearing minerals;

r) Continued erosion of the complex and the silcrete duricrust.

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