

Report: The geological history of the Pre-Damara Gaub Valley Formation and Weener Igneous Complex in the vicinity of Gamsberg

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Volcanic rocks of the Gaub Valley Formation (GVF) and intrusive rocks of the Weener Igneous Complex (WIC) have been studied in an area south of the Gamsberg within the Southern Margin Zone of the Pan-African Damara Orogen. The emphasis of this study is placed on the facies and contact relationships of these rock types. The Gaub Valley volcanic rocks can be distinguished in domains distal and proximal to a volcanic centre. Distal domains are characterized by fine-grained, finely-banded sericitic schists of regional extent, here interpreted as meta-ash tuffites and intercalations of different types of meta-lapilli tuff. They are interpreted as outflow facies of a caldera. Proximal domains comprise a variety of rock types including meta-crystal tuffs, meta-pyroclastic breccia, accumulations of scoria and pumice, lava and feeder channels. They form chaotic deposits and are interpreted as caldera fill. The boundary between distal and proximal domains often coincides with a zone of granitic lensoid bodies inferred to be a ring structure related to the intrusion of the WIC. Both the concentric distribution of a caldera fill facies around the WIC and the development of a granitic ring structure, indicate that the WIC represents the subvolcanic source area from which magma has intruded the volcanic rocks of the GVF in a sheet-like fashion. A comagmatic evolution of the volcanic rocks of the GVF and the WIC is proposed. The tectonic history comprises two main deformation phases, both of Damaran age. No pre-Damara deformation has been recognized in the rocks of the GVF and WIC. D_1 is the dominant deformation and produced NW-trending and NE-facing folds and stretching lineations parallel to the fold axes. The main effect of the D_2 deformation was the rotation of D_1 structures into NW-dipping attitudes. The deformation acted heterogeneously on both the rocks of the WIC and GVF. Therefore, in domains of low deformation, primary pyroclastic structures have survived the tectonic overprint.

Introduction

This report presents results of a mapping project (at a scale of 1:25 000) in the Gamsberg area about 100 km southwest of Windhoek, Namibia. The study area is located on the farms Corona 223, Weener 193, Swartkrans 224 and Gamsberg 23 in the area indicated on Fig. 1.

The study area falls within the Southern Margin Zone (SMZ) of the Damara Orogen. The structural style in the northeast-trending, 25-55 km-wide SMZ is dominated by northwest-, and northeast-trending fold structures and low-angle thrust sheets (Hoffmann, 1983, Pfurr *et al.*, 1987). Both Damara metasediments and pre-Damara basement rocks have been affected by this deformation.

Four main lithologic units occur in the Gamsberg area. They belong to three different sequences known as the Rehoboth Sequence, the Sinclair Sequence and the Damara Sequence. According to SACS (1980), the oldest unit exposed in the area, is the volcanoclastic Gaub Valley Formation (GVF) of the Mesoproterozoic Rehoboth Sequence. To the south the GVF rests with a sedimentary contact upon the Mooirivier Complex (pre-Rehoboth Sequence) and, with a strongly sheared and thrust contact upon gneisses of the Billstein Formation (Rehoboth Sequence) (Schulze-Hulbe, 1979, SACS, 1980). To the north and east the Gaub Valley rocks have been repeatedly, intruded by granitoid rocks. The older granitoids belong to the WIC whose stratigraphic position is uncertain, but assumed to be of pre-Sinclair age. The younger granitoids belong to the Gamsberg Granite Suite and have been correlated with the Sinclair Sequence. To the west, the GVF is over-

lain unconformably by terrestrial and marine metasediments of the basal Damara Sequence.

Age determinations by various workers on the Gamsberg Granite Suite (GGS) using different methods (U/Pb, Rb/Sr) have yielded intrusion ages between 1050 Ma and 1200 Ma. For the WIC, Rb/Sr whole rock analyses from different localities yield a substantial range in age from about 1207 ± 170 Ma to 1871 ± 143 Ma (Table 1). A detailed discussion of these data is given in Reid *et al.*, 1988. One age determination on a zircon fraction from the type area on the farm Corona 223 yields 1723 Ma and is interpreted to represent a minimum age for the emplacement of the WIC (Ziegler and Stöbel, 1991, 1992, 1993). Since the WIC intrudes the GVF, this age is also regarded as the minimum age of the volcanic rocks.

The volcanic rocks of the GVF have been previously interpreted as pre-Damara basement older than 1500 Ma (Hill, 1975), representing initial rift volcanics of the Damara Sequence (Pfurr, 1990) or collision-induced rift volcanics related to the Kibaran orogeny (Pfurr *et al.*, 1991). However, little work has been carried out on this formation with respect to mapping, detailed petrography, geochemical analysis and geochronology. The same holds true for the Weener Intrusive Complex (WIC), which has only undergone reconnaissance mapping (De Kock, 1934; De Waal, 1966).

Lithostratigraphy

Figs. 2 and 3 show a simplified geological map of the study area and a rock relation diagram. Six major lithologic domains are distinguished. They are here referred

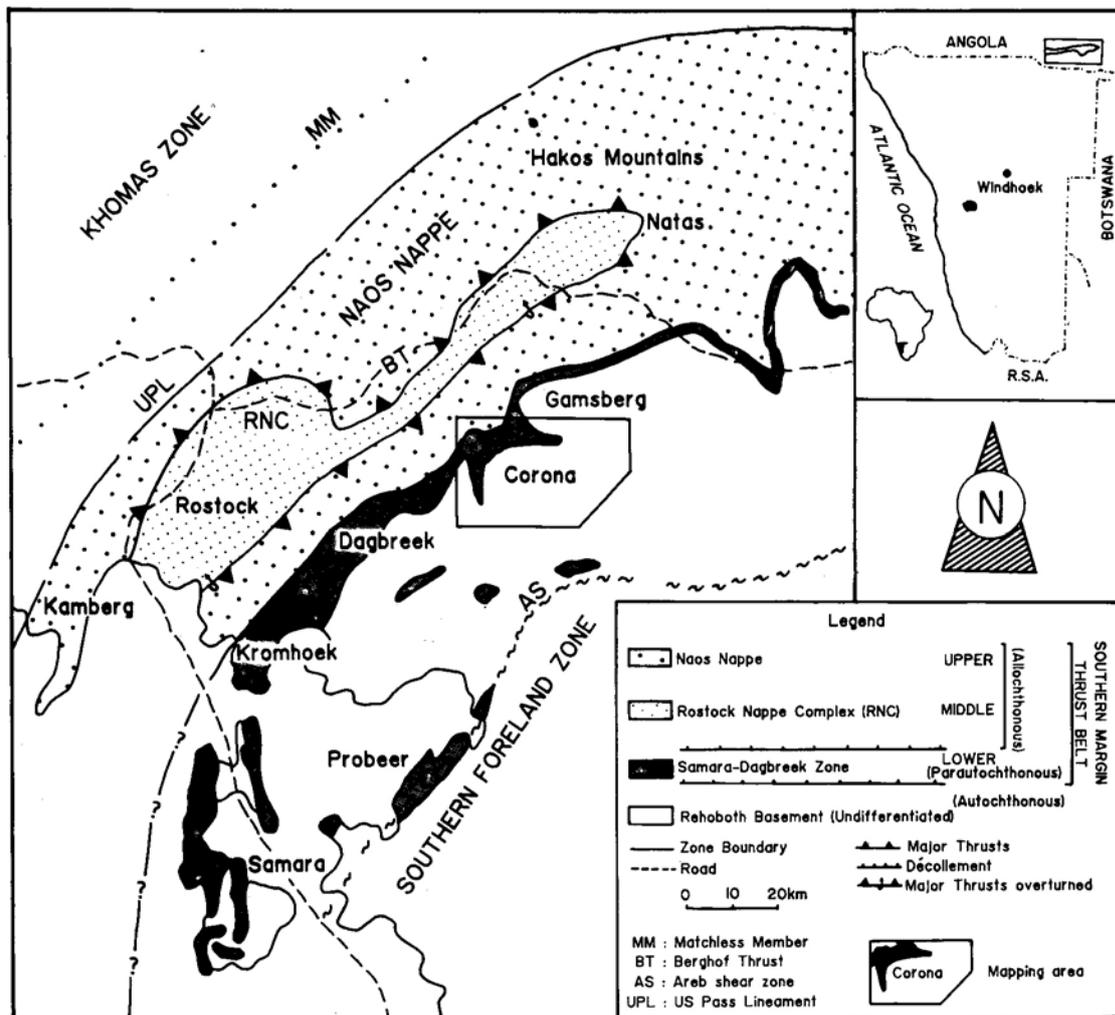


Figure 1: Structural zones of the southern Damaran Belt and location of the study area within the SMZ (from Hoffmann, 1983)

to as Distal Gaub Valley Formation. (DGVF), Proximal Gaub Valley Formation (PGVF), Weener Igneous Complex (WIC), Gamsberg Granite Suite (GGS), and meta-sediments of the basal Damara Sequence (DMS).

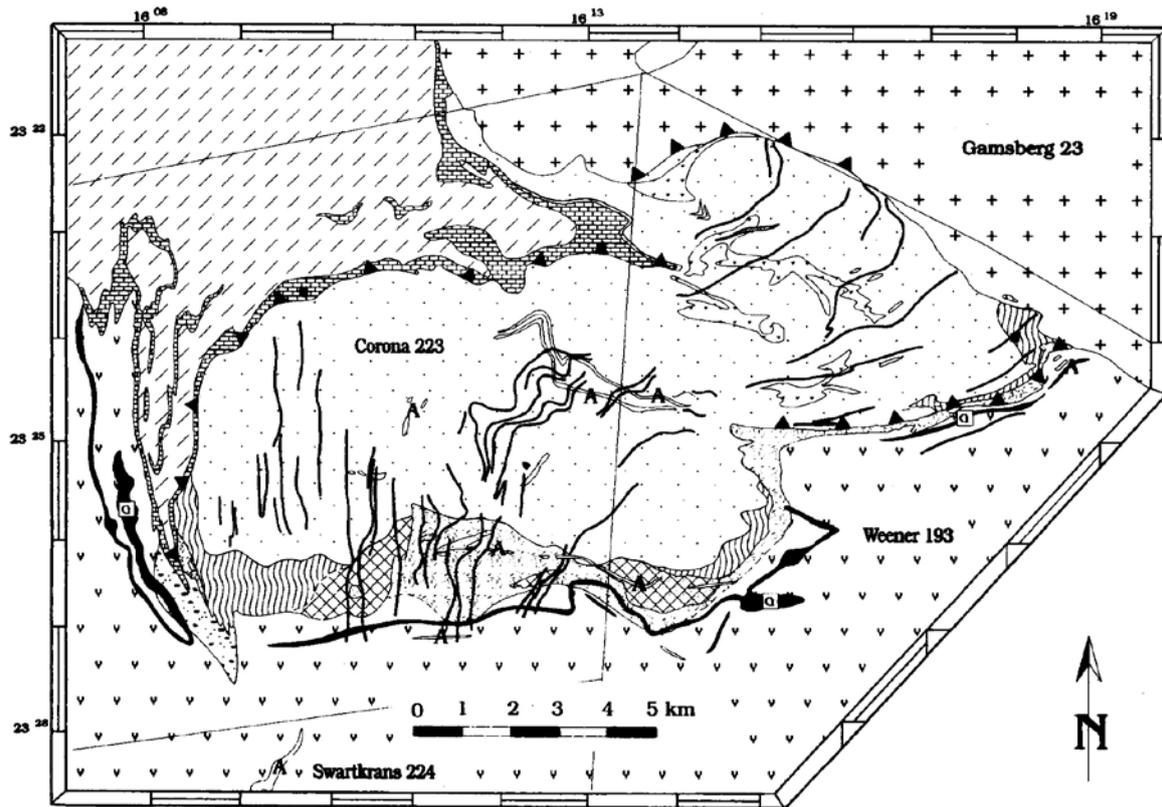
Gaub Valley Formation

The GVF consists of meta-sedimentary and meta-volcanic rocks, however, with a distinct abundance of meta-volcanic rocks in the study area. The meta-sedimentary units, exposed mainly outside the area, are believed to represent the basal part of the GVF. The lower portion of the succession is made up of coarse conglomerate intercalated with micaceous quartzite. The conglomerate consists of poorly sorted pebbles and boulders, up to 50 cm in size, of granite, gneiss, quartzite, vein quartz and quartz porphyry (De Waal, 1966; Brewer, 1989). The clasts are set in a fine-grained quartzose sericitic matrix and generally display elongation and flattening. However, on the farm Swartkrans 224 the clasts are often virtually undeformed. The conglomerate grades into and is overlain by a sericite schist with discontinu-

ous bands of small monomictic pebbly conglomerates. Fine-grained, grey, massive meta-quartzites without internal structures are developed in places.

The volcanoclastic GVF has been subdivided into proximal and distal domains with respect to the major body of the WIC. The distal facies is widespread and present in virtually all occurrences of this formation. It is almost exclusively represented by felsic pyroclastic rocks. Deposits of the proximal facies (PGVF) partly overlap with those of the distal facies (DGVF). The boundary between the PGVF and DGVF is defined where PGVF deposits become absent in the DGVF facies domain. However, it is important to note that the PGVF facies which is generally ascribed to being distal (lapilli tuff and ash tuff), may still be common and in some places dominant. The boundary often coincides with a zone of granitic intrusions.

In contrast to the more stratiform emplacement pattern of the DGVF the geometry of the PGVF deposits is rather chaotic. Individual beds may attain thicknesses of 40 m, but generally pinch out laterally within 30 to 100 m. Most of the lithotypes interfinger. Because of this



Legend

	Carbonaceous phyllite	Corona Formation	SWAKOP GROUP	DAMARA SEQUENCE
	Dolomitic marble			
	Conglomerate/Quartzite/Biotite schist			
	Granitic gneiss	GAMSBURG GRANITE SUITE	SINCLAIR SEQUENCE	
	Mafic dyke	uncertain correlation		
	Aplittic dyke	WEENER IGNEOUS COMPLEX	REHOBOTH SEQUENCE	
	Granitic ring dyke			
	Granodioritic gneiss			
	Biotite depleted granodioritic gneiss			
	Biotite enriched granodioritic gneiss			
	Highly gneissic granodiorite			
	Proximal facies (PGVF)	Gaub Valley Formation		
	Distal facies (DGVF)			

Map symbols

	thrust		farmhouse
	inferred or poorly defined lithologic boundary		farmborder

Figure 2: Simplified geological map of the study area

depositional style and distinct facies, such as coarse-grained ash tuffs, collapse breccias, volcanic breccias, high temperature deposits, and its local occurrence, the PGVF has been interpreted as caldera fill.

Distal Facies

The distal facies forms a monotonous succession. The dominant lithotype consists of finely banded, fine-grained schist, with the banding distinguished by changes in colour from grey to white (Fig. 4). Individual layers are millimetres to metres thick with lateral continuity. The schist consists of quartz, plagioclase, sericite, biotite, and epidote, with minor garnet and amphibole. The well-sorted appearance and widespread occurrence of the schist, which additionally contains intercalations of meta-lapilli, suggests a possible interpretation as meta-ash tuff. Mafic rocks (amphibolites) are dominantly of intrusive origin (sills or dykes). To the south of the study area the basal portion of the volcanic unit grades into the sedimentary rocks of the GVF and interfinger with small pebbly conglomerates.

Structures interpreted as meta-lapilli form lensoid intercalations and discrete horizons within the meta-ash tuff. The lapilli exhibits a sharp contact with the country rock. The intercalations attain thicknesses of up to 1 m and the abundance of meta-lapilli varies from layer to layer. Internal layering or gradation in size is not recognizable. Two different types of meta-lapilli are distinguished. The common type, shown in Figs. 5 and 6, is characterized by micro-crystalline, tectonically flattened domains set in a fine-grained matrix of quartz, plagioclase, biotite, and muscovite. The new formation of microcrystalline plagioclase and quartz with diffuse grain boundaries indicates devitrification processes within the lapilli. The other type is represented by lapilli with a dense grey sericitic core, surrounded by a concentric darker shell with lobate rims. These bodies are inferred to be accretionary lapilli implying subaerial transport by plinian activity (Fisher and Schmincke, 1984). Since the delicate fabric has been preserved, there has been no transport after deposition (Figs. 6 and 7). An interpretation as gneiss seems unlikely, since the structures are confined to discrete horizons and due to the low metamorphic grade. However, primary differences in composition may have been enhanced by metamorphic diffusion processes.

Rarely, fine-grained, massive felsic rocks occur which are marked by amygdaloidal structures with quartz epidote fills. The abundance of amygdaloids decreases from bottom to top of the deposits whose tectonic position, however, is uncertain (Fig. 8). These structures are interpreted as vesicles. Vesicular tuffs are commonly more indurated than overlying and underlying vesicle free beds. This primary difference may explain the comparatively weaker deformation and, hence selective preservation of pyroclastic structures.

Proximal Facies

Coarse-grained muscovite schist forms a major part of the PGVF. Massive, non-graded and well-sorted beds predominate. The rock is composed of abundant muscovite with quartz, biotite and minor plagioclase. Post-tectonic metamorphism has caused the growth of unoriented muscovite flakes (up to 5 mm in size). Some intercalated fine-grained layers show, however, that despite metamorphism, primary grain size differences have been preserved. Accessory lithic fragments rarely occur within the beds. Due to the massive appearance and the pyroclastic environment, these units are genetically interpreted as coarse-grained ash-fall or -flow deposits.

The second major rock type of the PGVF possibly represents a caldera wall or collapse breccia. Numerous poorly sorted fragments of different origins set in a fine-grained matrix of dacitic to rhyodacitic composition are a significant feature. The fragments are either derived from the country rock or seem to be of cognate origin. Angular and rounded clasts of igneous and sedimentary provenance occur with variable sizes, generally in a range of up to 1 m. None of the clasts display any fabric of pre-Damaran metamorphic origin (Fig. 9). Besides schistosity, no other internal structure is visible in the matrix.

At one locality a volcanic breccia displaying reaction rims around mafic fragments and some flow-structures is indicative of higher temperatures during deposition. There are also local accumulations of dark, vesicle-rich angular or subrounded, relatively undeformed scoriaeous blocks and lapilli in a medium- to coarse-grained felsic matrix (Fig. 10). Layering is restricted to the top of these deposits.

Another common facies is interpreted as crystal tuff. It is characterized by an abundance of fine- to medium-grained euhedral to anhedral and non-oriented plagioclase crystals embedded in a fine-grained sericite-biotite-quartz-plagioclase matrix. The crystals are generally surrounded by a white fine-grained feldspar rim. An intriguing feature is feldspar-rich, flattened accretions which may represent compressed pumice. Volcanic and sedimentary fragments of various sizes are typical (Fig. 11). The facies is typically poorly sorted.

A distinct feature of the PGVF is finely-banded rocks of migmatite appearance. The felsic domains of these rocks essentially consist of fine- to medium-grained quartz, feldspar and minor muscovite, whereas in the mafic domains fine-grained plagioclase, biotite, muscovite, and quartz are the main constituents. The origin of the banding is indeterminate, yet various processes seem possible. Close to apophyses of the WIC an origin as injection migmatite is proposed. Such migmatites are characterized by a stromatic layering. They presumably resulted from devolatilization of the underlying granodioritic magma (Fig. 12). Finely-banded and strongly folded migmatitic rocks in contact with virtually un-

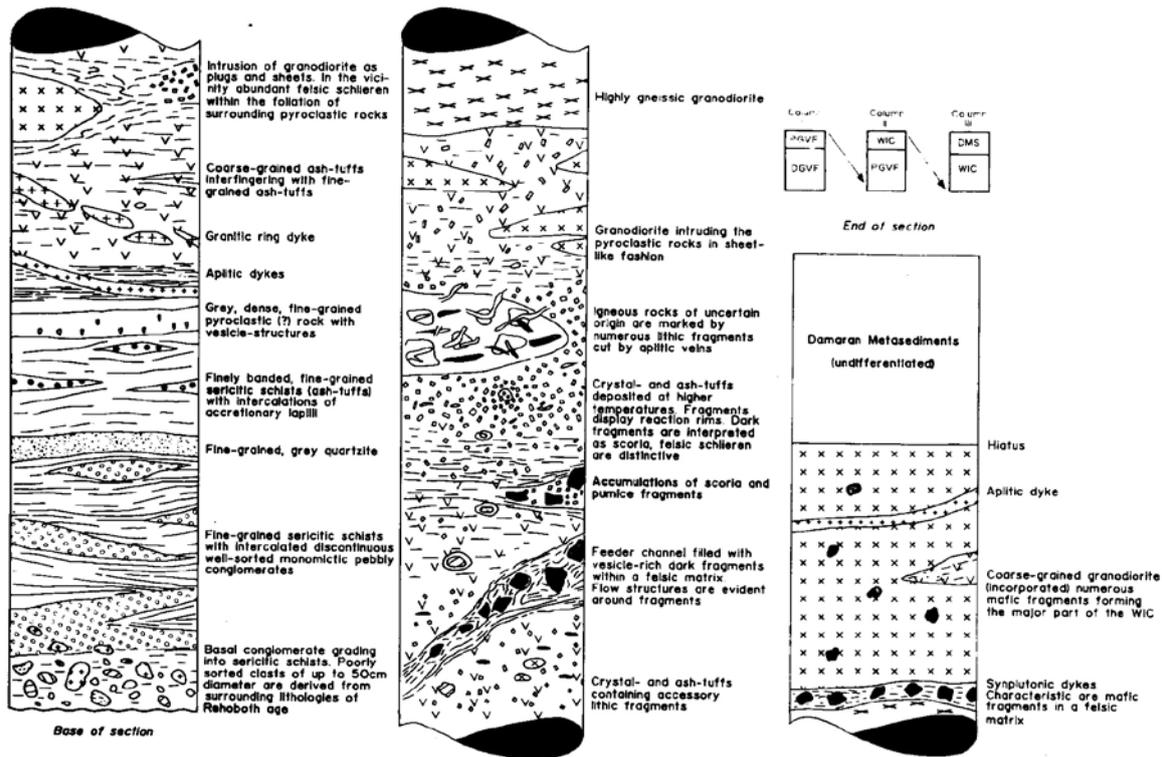


Figure 3: Rock relation diagram from the basal Gaub Valley Formation into the basal Damara Sequence (intrusion of Gamsberg granite is not shown)

deformed country rock are in contrast interpreted as meta-rhyolites with contorted flow banding structures, has rheo-ignimbrites (Fig. 13). Fragments within the rocks show reaction rims, while flow structures are significant in the matrix close to the fragments. Due to the regional lower amphibolite facies metamorphism and the absence of contact aureoles an origin by anatexis of country rocks is excluded.

Another igneous rock type of indeterminate origin has been found close to the WIC. A conspicuous feature is the abundance of mafic and felsic fragments in a coarse-grained matrix of granodioritic composition. Both clasts and matrix are crosscut by numerous aplitic veins. Whereas the mafic clasts are often flattened, the veins seem to be rather undeformed. The flattening is inferred to be a primary feature of the mafic fragments and these are interpreted as scoria.

Small degassing pipes, characterized by up to 40 cm-wide fill zones of felsic lapilli breccia with the absence of fine-grained particles are sometimes encountered in the PGVF (Fig. 14). The walls display alteration rims caused by rock-volatile interaction. Such pipes commonly occur in pyroclastic flows and develop due to degassing of the hot flow after emplacement.

A much larger pipe has been found in the PGVF and occurs as a linear structure of about 200 m in length and up to 10 m in width. It has been interpreted as a feeder channel (Fig. 15). This particular pipe is filled with angular lapilli- and block-sized mafic and felsic fragments

in a medium-grained, feldspar-quartz matrix. Reaction rims are developed around the fragments. Flow structures are conspicuous close to the wall rock.

Weener Intrusive Complex

Most of the mapping area is occupied by the medium- to coarse-grained, foliated tonalitic to granodioritic body of the WIC (Fig. 2). Plagioclase, quartz, biotite, hornblende and some K-feldspar are the main mineral components, with post-tectonic epidote and amphibole sometimes evident. Numerous angular or rounded, and often corroded mafic enclaves (up to 1 m in size) occur within the WIC. Some of them are rich in biotite. Locally, the mafic enclaves form accumulations. In the marginal areas of the WIC, single rounded clasts of the country rock are encountered.

Large enclaves (up to 3 km long and 1 km wide) of meta-volcanic and meta-sedimentary rocks from the GVF occur on the farm Weener 193. These units are generally intruded by sheet-like bodies of the WIC resulting in *lit-par-lit* layering (best seen at the hill north of kraal "die Hoek"). Magnetite quartzite marker horizons within these units have not been encountered elsewhere in the mapping area, but are reported as massive deposits within the GVF on the farm Dagbreek 394, and as intercalations in granulite of the Marienhof Formation on farms Nauams 177 and Alberta 175 (Blecher, 1990; De Waal, 1966).

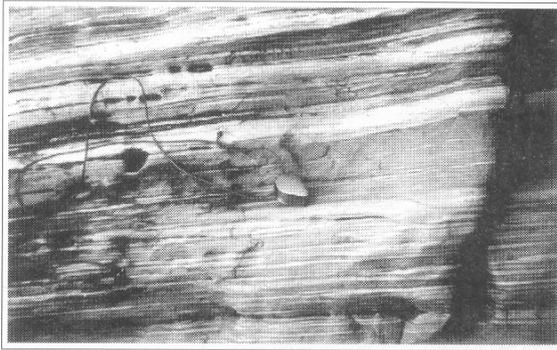


Figure 4: Finely-banded, fine-grained ash tuffs; farm Weener 193

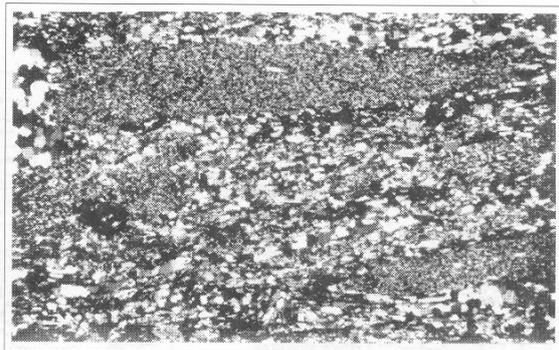


Figure 5: Photomicrograph showing small lapilli (micro crystalline domains) in a fine-grained quartzplagioclase matrix (lower side 0.78cm)

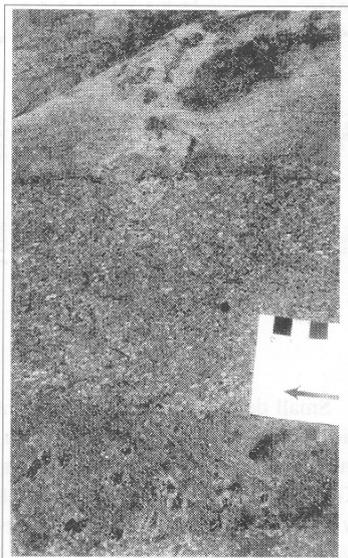


Figure 6: Accretionary lapilli (bottom) normal lapilli (centre), and ash tuff (top) deposits with sharp contact to the surrounding layers; farm Corona 223

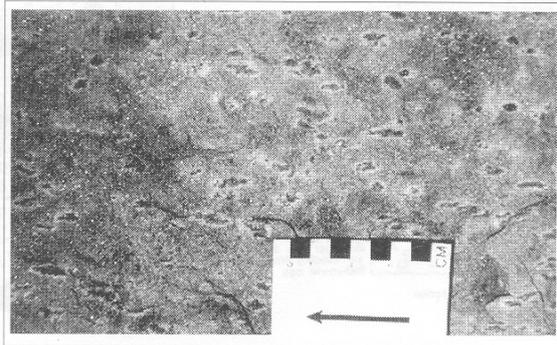


Figure 7: Accretionary lapilli (fine-grained white rim, dark core) in a sericitic matrix; farm Corona 223

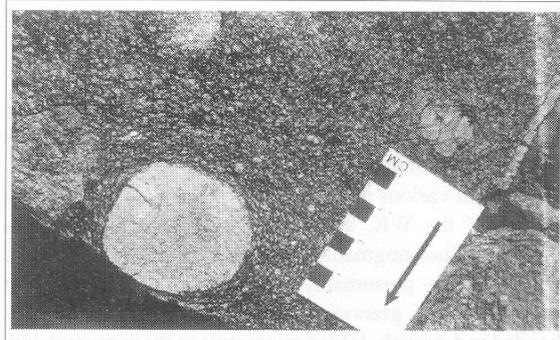


Figure 9: Unwelded plagioclase crystal-tuff containing rounded accessory fragments. Note concentric alignment of crystals around larger fragments; farm Weener 193

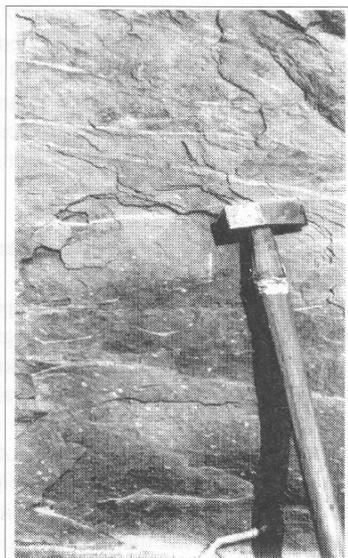


Figure 8: Vesicle structures in massive fine-grained rock. Abundance of vesicles decreases from bottom to top; farm Corona 223

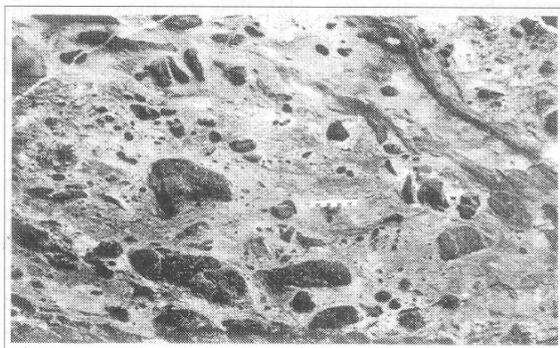


Figure 10: Dark vesicle-rich rock fragments in a lapilli-block tuff; farm Corona 223

Table 1: Radiometric age data from the igneous rocks of the Weener complex, Piksteel Suite and the Gamsberg Suite displaying the wide range in the ages for the Weener complex and the Piksteel suite

Lithological unit	Locality	Method	Age (Ma)	Sr87/86-Initial	MSUM (N)	Reference
Gamsberg Granite Suite	Uitdraai Oos 296	U/Pb	932 ± 50			1,2
	Hohenheim 24	U/Pb	1078 ± 30			1,2
	Hohenheim 24/ Gamsberg 23	Rb/Sr	984 ± 55	0.7123 + 39	21.0 (5)	4
	Gamsberg 23/ Picadilly 221	Rb/Sr	1190 ± 23	0.7026 + 12		5
	Ganeib 61	U/Pb	1150 ± 30			2
Gamsberg Granite Suite	Kanaus South 336	U/Pb	1064 ± 20			2
	Kangas 336	U/Pb	1104 ± 20			2
	Nauchas 14	U/Pb	1178 ± 20			2
	Nauchas 14	Rb/Sr	1073 ± 20	0.7082 + 16	3.48 (4)	4
	Namibgrens 154	Rb/Sr	1096 ± 62	0.7075 + 25	6.87 (5)	4
Post-Gamsberg mafic dykes	Namibgrens 154	Rb/Sr	1079 ± 25	0.7081 + 12	4.39 (9)	4
	Namibgrens 154	Rb/Sr	1030 ± 185	0.7064 + 4	0.71 (4)	4
Post-Gamsberg aplites	Gamsberg 23/ Weener 193	Rb/Sr	926 ± 21	0.7215 + 54	(3)	5
Marienhof Formation (acid lava)	Rehoboth Townlands	U/Pb	1232 ± 30			3
	Piksteel 209	U/Pb	1076 ± 25			3
Piksteel Suite	Rehoboth Townlands	U/Pb	1476 ± 30			2
		Rb/Sr	1170 ± 20	0.7095 + 7	2.21 (5)	4
	Namibgrens 154	Rb/Sr	1207 ± 170	0.7041 + 6	0.16 (5)	4
Weener Intrusive complex	Weener 193	Rb/Sr	1560 ± 100 (1871 ± 143)	0.7051 + 14 (0.7009 + 19)		5 (5)
	Weener 193	U/Pb	1723			6
Namibgrens 15	Biesiepoort 275/ Weener 193	Rb/Sr	1238 ± 13	0.7041 + 1	2.16 (7)	4

Data: 1 Hugo & Schalk 1972, 2 Burger & Coertze 1975, 3 Burger & Coertze 1977, 4 Reid, Malling & Allsopp 1988, 5 Seifert 1986, 6 Ziegler & Stöbel 1991, 1992, 1993

Besides the coarse-grained granodiorite, three other magmatic varieties have been distinguished in the marginal areas of the WIC which differ from the common WIC granodiorite in grain-size, mineral composition and schistosity (Fig. 2).

Felsic dykes and plugs

Synplutonic dykes

Remnants of structures which are interpreted as synplutonic dykes (Castro, 1991) have been encountered at two localities within the WIC on the farm Weener 193. The dykes are up to 20 m wide and filled with strongly corroded, angular and rounded scoria and mafic rocks. The matrix is composed of coarse-grained, amphibole-rich granodiorite.

The pegmatite often invades the fragments. The contact between these dykes and the country rock is often diffuse. Fragments of other rock types are not found within these dykes. On the farm Weener 193, a synplutonic dyke coincides with the boundary between a strong foliated variety of the WIC and coarse-grained granodiorite.

Granitic dyke

A granite emplaced in a ring structure around the WIC is important in our interpretation of both the WIC and the GVF. It is developed in a zone, up to 150 m wide and forms streaks, lensoid bodies or thick sheets at various angles to the bedding of the surrounding volcanics. Numerous apophyses invade the volcanics. Xenoliths are rarely encountered. Since the ring dyke is still recognizable, folding and thrusting must have been of minor importance in this area.

Aplitic dykes

Aplites are developed within the WIC as well as in the GVF. Two generations of aplitic intrusions are distinguishable: Those related to the intrusion of the WIC form dykes up to 4 km long and 10 m wide. A larger body, measuring some 200 m by 3 km, is exposed on the farm Swartkrans 224. The younger age of the aplites relative to the granitic ring dyke is evident from off-set relationships. Aplites of a younger generation intrude both the WIC and the GGS and are attributed to late-stage magmatism of the GGS. No fragments of country rocks are present in either type.

Table 2: Igneous rocks and their age relationships in the study area

				younger
Gamsberg Granit Suite	post-Gamsberg mafic dykes (undifferentiated)			
	post-Gamsberg aplite			
	Gamsberg intrusion			
Mafic Dyke swarm	medium-grained amphibolite with chilled margins	fine-grained amphibolite with spheroidal weathering		
	medium-grained glomerophyric amphibolite	intrusion of quartz porphyry		
	coarse-grained amphibole fels			
Weener Igneous Complex (WIC)	post-WIC aplites	post-WIC microdiorite	post-WIC granite (ring dyke)	
	central body	gneissic margin	biotite-poor and hbl-biotite-rich fine-grained granodiorite	
proximal Gaub Valley volcanic rocks		intracaldera facies		
distal Gaub Valley volcanic rocks		outflow facies		
				older

Microgranodiorite

Microgranodiorite occurs within the WIC and the PGVF as dykes and as plugs, the latter up to 50 m in diameter. Angular fragments of country rock are often incorporated within this rock. Chilled margins in contact with the WIC are common. The microgranodiorite is possibly representative of the last magmatic stage in the evolution of the WIC.

Mafic dykes

Mafic dykes post-date all the Weener-related intrusives and Gaub Valley pyroclastic rocks, but predate Gamsberg related intrusives, with few exceptions. The abundance of mafic dykes is nearly equal in the GVF and the WIC (De Kock, 1934). The dykes are aligned subparallel to each other and, on a regional scale, parallel to the foliation of the surrounding GVF. The different stress regimes prevailing during emplacement of the mafic dykes and the felsic WIC dykes respectively is evident from high-angle intersections of the two dyke types. Five different varieties have been distinguished according to the presence and grain-size of plagioclase, crystal forms and grain-size of amphibole, chilled margins and offset relationships.

Gamsberg Granite Suite (GGS)

The GGS occupies the northernmost part of the study area. The contacts to the WIC and the GVF are in general intrusive, but partly tectonically overprinted. Near the homestead of the farm Weener 193, contacts to the WIC and the GVF are intrusive and sharp. The exocontact is marked by an increase of small aplitic veins towards the GGS. In the endocontact, a wealth of xenoliths of the WIC and GVF is significant within an approximately 5 m-wide zone. An intriguing feature is the foliated fabric of the xenoliths which is at variance with the weak foliation of the host rock (Fig. 16). Contact metamorphism is not evident within the WIC. The volcanic rocks of the GVF, however, are silicified, possibly by hydrothermal activity.

In its western part, the GGS is highly sheared and foliated. A fine-grained, weakly folded granitic mylonite with a thickness of about 10 m is developed at the contact with the WIC. The sense of shear indicates overthrusting of the GGS to southeast. Crenulated chlorite-biotite schist (up to 30 cm thick), derived from altered amphibolites, form intercalations in the granitic mylonite and in the WIC.

Two varieties of Gamsberg-type granites have been

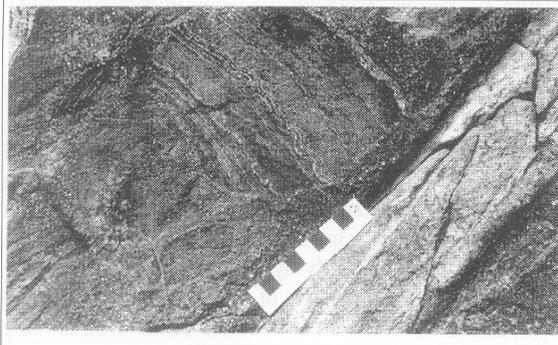


Figure 11: Unsorted pyroclastic fragments displaying internal layering in a fine-grained, muscovitebiotite-plagioclase matrix; farm Corona 223

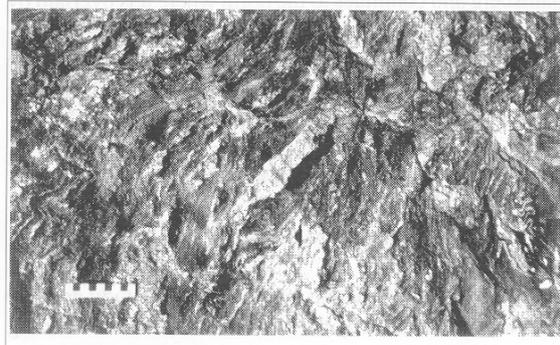


Figure 12: Migmatic structures, possibly due to magma injections, farm Corona 223

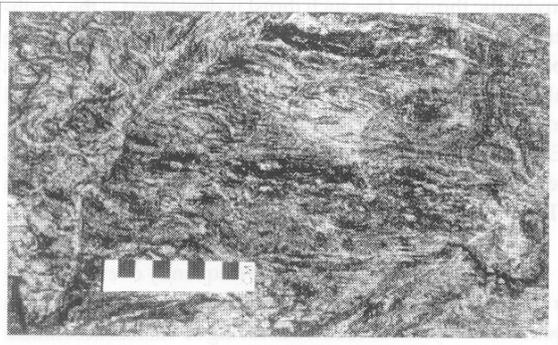


Figure 13: Contorted flow banding in lava or rheoignimbrite; farm Corona 223

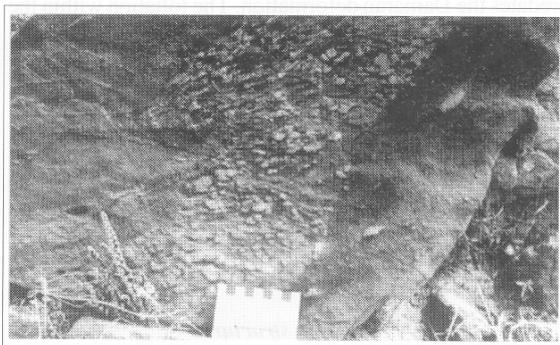


Figure 14: Degassing pipe marked by depletion of fine-grained particles in the matrix; farm Weener 193

Figure 15: Feeder channel filled with angular mafic clasts in a felsic matrix. Note flow structures and reaction rims around fragments (scale 1m); farm Corona 223

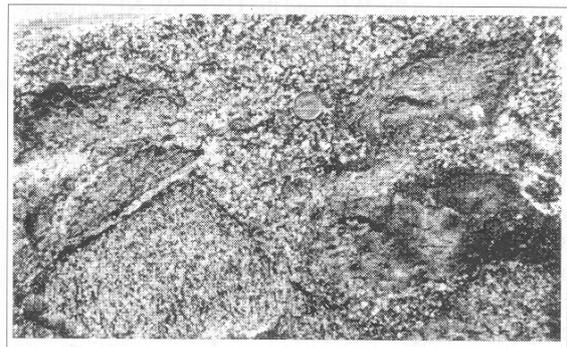
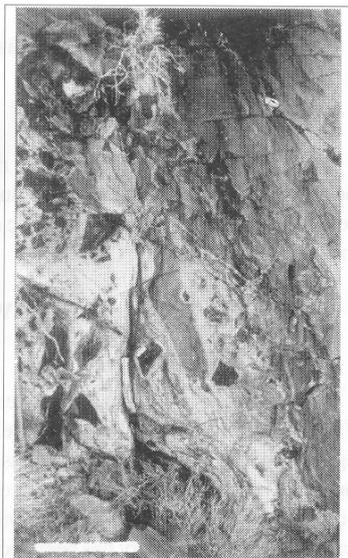


Figure 16: Unoriented foliated fragments of the Weener Intrusive Complex within the granitic matrix of the Gamsberg Suite; farm Weener 193

found in the study area. The main type is a medium- to coarse-grained, reddish to greyish rock with a hypidiomorphic granular texture. The other type is a fine-grained equigranular variety which is encountered in the area of the little

Gamsberg and continues to the north where it is overlain by Damaran metasediments. Contacts between the two varieties are indistinct. The intrusion of the GGS terminates the magmatic history of the study area. Table 2 shows the relative age relationships of most of the igneous rocks.

Structural history

Intrusion-related structures

The oldest deformation structures in the study area are assumed to be caused by the intrusion of the WIC. A strong foliation coinciding with the regional metamorphic fabric is often developed in the marginal zone of the WIC. Boundaries to less foliated domains are relatively sharp. Xenoliths of the WIC and volcanic rocks of the GVF, encountered in the GGS along its intrusive contact on the farm Weener 193, show a weak foliation without stretching halos around feldspar clasts (Fig. 16). The deformation of these xenoliths predates the Damaran deformation. The foliation within the xenoliths is interpreted to result from diapiric ballooning during the intrusion of the Gamsberg granite or earlier WIC related intrusions. Ballooning may also be responsible for a strong foliation developed in pyroclastic rocks close to weakly-foliated granodiorite intrusions. Such features are observed at the margins of the WIC, particularly where the presumed ballooning-foliation became homotactically overprinted by a Damaran foliation.

Tectonic structures

The structural development of the study area comprises two main phases of deformation, D_1 and D_2 , which are present in both pre-Damaran rocks of the WIC and GVF and Damaran metasediments. Both phases are related to the Damaran orogeny and readily correlated with the structural development of the surrounding region (Pfurr *et al.* 1987; Weber, 1992). There is no indication of a pre-Damaran orogenic event in the WIC and the GVF. SW-NE compression during D_1 produced high strain and the main foliation, while NW-SE compression during D_2 created the present outcrop geometry. The regional trend of the D_1 -foliation is influenced by the shape of the WIC so that the degree of deformation is highly variable throughout the study area. In the west and north-west the rocks are thus strongly folded and sheared, whereas south of the WIC, the rocks of the PGVF and DGVF are locally virtually unaffected by folding, while shearing is concentrated to narrow zones. In low strain areas pyroclastic structures of the volcanic rocks are recognizable despite the tectonic overprint.

The first compressional phase D_1 is characterized by a NW-trending mineral and stretching lineation parallel to the axes of NW-trending and NE-facing folds (Figs. 17 a,b). Two finite increments of $D_{1,1}$ and $D_{1,2}$ deformation can be distinguished. $D_{1,1}$ produced narrow internal folds ($F_{1,1}$) and the first axial plane parallel foliation. Major detachments are observed in the lower part of the Corona Formation. $D_{1,1}$ mylonites occur near the base of the Corona marble and outline NE-facing low-angle thrusts of unknown displacement. Contrary to this, sedimentary contacts of the DMS with rocks of the WIC and the GVF are frequently preserved. Low- to moderate-angle thrusting within the WIC and GVF was of little influence since the lithostratigraphic succession appears undisturbed. $F_{1,2}$ folds reveal the same strike and the same facing as $F_{1,1}$, however, $F_{1,2}$ folds are more open and concentric, indicating changes in rheology and possibly higher crustal levels. The two large structures of the Picadilly syncline in the west and the Corona syncline in the north of the WIC are NW-striking $D_{1,2}$ structures. The internal structure of the WIC and the GVF is dominated by D_1 .

The D_2 compression produced NE- to ENE-trending, SE-facing structures. During D_2 , the D_1 structures were rotated into dominantly NW-dipping attitudes. Along the southern margin of the WIC, the GVF was rotated into a steeply dipping and overturned position along SE-facing mylonitic thrusts. One such thrust is developed at the southern rim of the eastern part of the WIC. Mafic rocks have been transformed into chlorite- and chlorite/biotite-schists along the thrusts. Inside the WIC, steeply dipping sinistral mylonitic shear zones are developed. One prominent D_2 EW-striking shear zone in the central part of the WIC was refolded in the course of a late D_2 sinistral transpression (Fig. 17c).

$F_{2,1}$ -folds are rather tight and frequently overprinted by a NE- to ENE-striking crenulation cleavage, particularly in pelitic and mylonitic rocks. SE-facing *sc*-fabrics accentuate the polarity of tectonic transport during $D_{2,2}$. Local collapse structures and an accompanying NE-striking shallow dipping crenulation cleavage are the youngest tectonic structures (Fig. 17d). They are developed in steeply dipping schists and are related to late-orogenic or younger crustal extension.

Summary and discussion

Igneous history

Field observations indicate three major magmatic episodes, viz. the contemporaneous evolution of the GVF and the WIC, the later intrusion of a mafic dyke swarm, and the final emplacement of the GGS.

Gaub Valley Formation and the Weener Intrusive Complex

The complex relationships between the GVF and

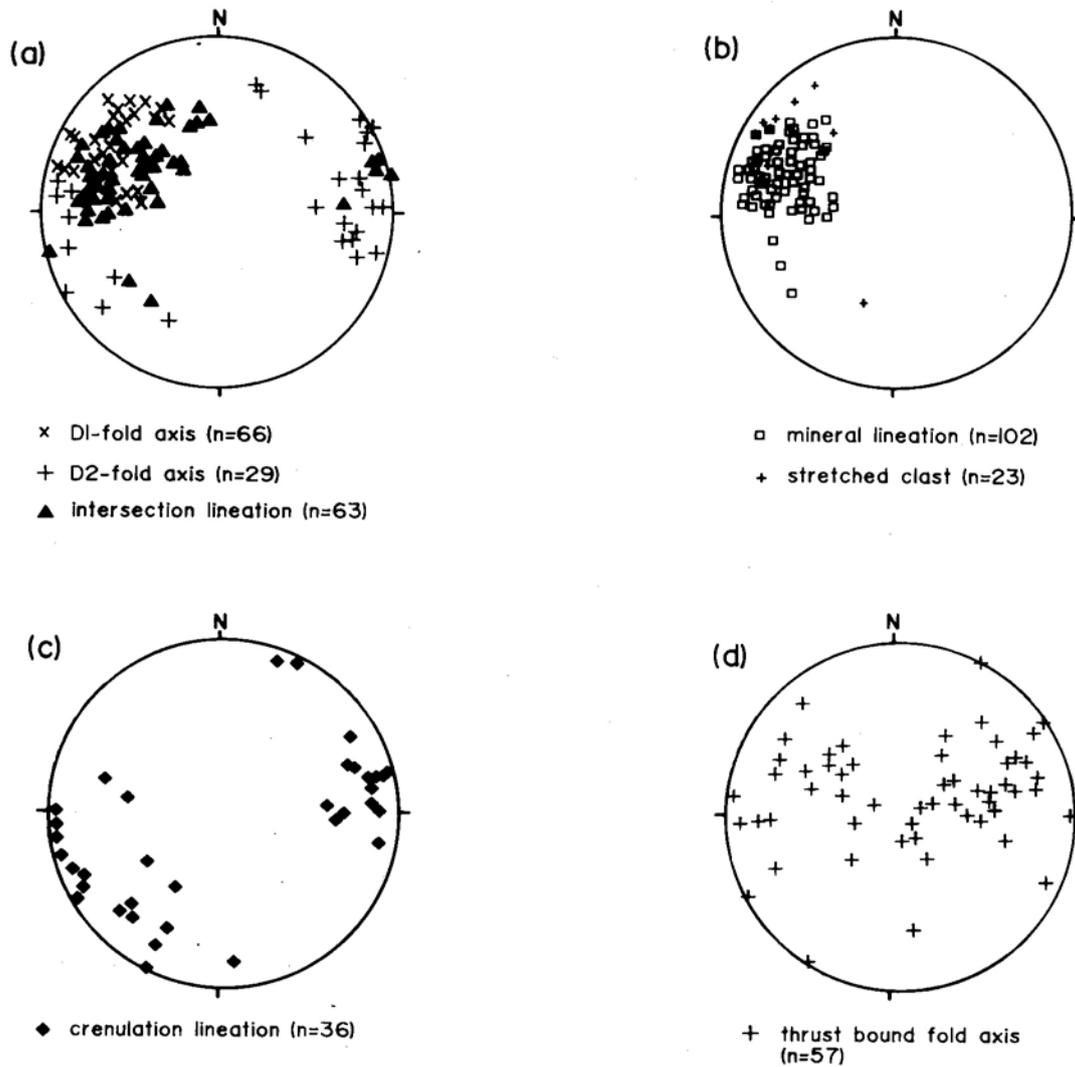


Figure 17: Plots of a) fold axes and intersection lineations b) mineral and clast stretching lineations c) crenulation lineations and d) thrust bound fold axes within the study area

the WIC have been demonstrated above. Field observations suggest an evolution of the igneous rocks in a caldera complex. Following the general concept for caldera cycles (Smith and Bailey, 1968; Lipman, 1984), a threefold magmatic-sedimentary history has been reconstructed comprising the stages of premonitory activity, culminating eruptions and caldera collapse, and post-collapse activity (resurgence).

Stage 1

The premonitory activity includes the development of tectonic grabens and pre-caldera volcanism. The distal parts of the GVF are dominated by coarse, poorly sorted fluvial conglomerates with clasts derived from igneous and sedimentary rocks situated to the south (De Waal, 1966). Subordinate quartzites and rare intercalated limestone as well as magnetite quartzite are interpreted as limnic-fluvial sediments. The extensional environment causing the graben subsidence was possibly associated with the rise of a shallow crustal

batholith and the development of volcanos. Eruptions of silicic pyroclastic material formed ash fall and lapilli fall deposits (DGVF). These deposits interfinger in distal parts of the volcano with clastic rocks of the GVF. Subaerial plinian activity is indicated by lapilli horizons and the large extent of the ash-fall deposits throughout the whole of the Gaub Valley Formation and intercalated accretionary lapilli deposits.

Stage 2

The main caldera-forming events were triggered by emptying of the magma chamber. The roof of the magma chamber collapsed along ring fractures causing an initial caldera depression with unstable steep scarps. The deposits that accumulated in the caldera include thick ash and crystal flow tuffs, intercalated collapse breccias slumped from the caldera walls, and post-collapse volcanic rocks. The intracaldera fill differs markedly from its outflow counterparts in respect of thickness, size and abundance of phenocrysts and lithic fragments, deposi-

tion temperatures and associated breccias. The collapse facies forms the PGVF that is distributed concentrically around the WIC. The WIC is therefore considered to be the subvolcanic source area of the volcanic rocks of the GVF.

Stage 3

During caldera resurgence, the WIC intruded the caldera floor. A multi-stage intrusion history is indicated by the development of at least three different magma types distinguished in the field and by geochemical analyses (Stoessel *et al.*, 1988). More evolved granitic magmas were emplaced along structural margins either during collapse or during resurgent uplift and form a ring dyke. Post-collapse volcanism is indicated by pipes cutting through the caldera fill.

Migmatitic fabrics neighboring granodioritic intrusions possibly originated from melt injections and metasomatic processes, caused by devolatilization of the underlying magma chamber. However, similar structures are also interpreted as contorted flow banding in rhyolitic flows.

At least 11 intrusive bodies of the Weener Suite occur in the Rehoboth-Nauchas area. They indicate the regional extent of magmatism with several eruption centers and hypabyssal intrusions.

Mafic dyke swarm

The main first GVF- WIC magmatic event was followed by an episode of mafic magmatism. All the observed dykes intrude both GVF and WIC, and many are affected by the intrusion of the GGS. A major hiatus between the emplacement of the WIC and the intrusion of the mafic dyke swarm is therefore proposed. So far no geochemical analyses have been carried out on these rocks.

Gamsberg Granite Suite

The third episode is dominated by the large-scale emplacement of granitic bodies of the GGS. They form part of the Sinclair Sequence which is believed to have evolved in continental rifts (Borg, 1988) or in a subduction environment (Hoal, 1990). Subordinate mafic magmatism during or after this episode is indicated by several mafic dykes in the GGS.

Tectonic history

No pre-Damara deformation has been recognized in the rocks of the GVF and WIC. The Damara deformation comprises two major deformation phases. The dominant deformation D_1 produced NW trending and NE-facing folds and stretching lineations parallel to the fold axes. The main effect of the D_2 deformation was the rotation of D_1 structures into NW-dipping attitudes. Local collapse structures and a shallow dipping crenulation cleavage are the youngest tectonic structures. The deformation acted very heterogeneously on the rocks of the WIC and GVF. The rigid body of the WIC may have

protected the areas immediately south of it from intense deformation. Therefore primary pyroclastic structures have been preserved in this domain.

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