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THE GEOLOGY AND GEOCHEMISTRY OF THE NELSHOOGTE SCHIST BELT AN ADJACENT STOLZBURG LAYERED ULTRAMAFIC COMPLEX, BARBERTON GREENSTONE BELT, SOUTH AFRICA

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by

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ABSTRACT

The southwestern portion of the Barberton greenstone belt is noteable for its varied and complex geology spanning at least 1360 Ma of earth history. A sequence dominated by metamorphosed Archaean komatiitic basalts and komatiites makes up most of the area occupied by the Nelshoogte Schist Belt. These rocks have, in the past, been correlated with the *c*. 3500 Ma lithologies in the lower division of the Barberton Supergroup (viz., the Tjakastad Subgroup of the Onverwacht Group in the Komati River type locality). Recent studies elsewhere in the Barberton region (including stratigraphic and geochronological investigations) have, however, introduced an alternative viewpoint suggesting that the Nelshoogte succession might be significantly younger (*c.* 3250 Ma). Views comparing the mafic and ultramafic rocks of the area to Phanerozoic-style ophiolites are discussed and found to be untenable. The term 'Jamestown Ophiolite Complex', which has been used to describe the rocks in the area, is therefore rejected. No direct ages are available for the Nelshoogte metavolcanics, but U-Pb dating of zircons from the adjacent trondhjemite-tonalite gneiss plutons (Kaap Valley and Nelshoogte plutons) have shown these intrusive bodies to be approximately 3213-3236 Ma old. Also adjacent to the metavolcanic rocks of the Nelshoogte Schist Belt is a sequence of metamorphosed ultramafic-mafic cumulate rocks that make up the Stolzburg Layered Ultramafic Complex. This Complex, which is fault bounded, has been subdivided into a Lower Division consisting of serpentinized dunites and orthopyroxenites and an Upper Division comprising altered dunites, harzburgites, lherzolites, wehrlites, websterites, gabbro-norites and anorthositic gabbros. A zone of Ca-metasomatised gabbros and associated rodingite dykes separates the rocks of the Upper and Lower Divisions. Estimates of the bulk composition of the Stolzburg Complex have shown that the layered body formed from a magma of komatiitic parent composition. By contrast, another igneous body intruded into the Nelshoogte Schist Belt in close proximity to the Stolzburg Complex (Sterkspruit Intrusion) consists almost exclusively of altered gabbroic-to-dioritic rocks and has a tholeiitic magma parentage. The Nelshoogte Schist Belt has an unusual, triangular, funnel-shaped structural form, which is considered to have developed as a result of the gravitational collapse of the metavolcanic succession between upwardly emplaced diapric granitoid plutons (Nelshoogte pluton in the west and Kaap Valley pluton in the north). The granitoid rocks in the Nelshoogte area display several intrusive and structural phases as well as augen-gneiss development adjacent to the granite-greenstone contact. A small, homogeneous, tonalitic-to-diotitic granitoid body containing numerous amphibolite inclusions (Goedehoop pluton), is embayed into the Nelshoogte Schist Belt near the intersection of the three fold axial traces of the triangular structure and may represent an anatectic product of the infolded metavolcanic rocks. Diabase dykes, believed to range in age from *c.* 3000-1876Ma, appear to represent the youngest magmatic events in the Nelshoogte region. They crosscut all the rocks in the area, are themselves unaffected either structurally or metamorphically, but do show deuteric alteration effects. Three chrysotile asbestos deposits were mined in the Stolzburg Complex, the mineralization being controlled by faulting and folding of the dunite host rocks and their associated, structurally more competent orthopyroxenite interlayers. Minor gold and copper-nickel occurrences are also present in the Nelshoogte Schist Belt and adjacent areas. Potential for platinum group mineralization is deemed favourable, particularly in the layered ultramafic complexes of the Stolzburg type, a number of which are present elsewhere in the Barberton region.

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INTRODUCTION

The southwestern portion of the Archaean Barberton greenstone belt (Fig. 1) is notable for its complex and varied geology. The central component of the area described in this paper is the Nelshoogte Schist Belt, which is buttressed by the Kaap Valley tonalite-gneiss pluton in the north and by the Nelshoogte trondhjemite-gneiss pluton in the west (Fig. 2). In the southeast is the Sterkspruit Gabbro Intrusion and the Stolzburg Layered Ultramafic Complex. The latter is, in turn, juxtaposed with, and separated from, the Stolzburg Syncline by a major, northeast-trending regional shear zone referred to as the Belvue Fault. The Stolzburg Syncline, which trends oblique to the Belvue Fault (Fig. 2), consists of Moodies Group sediments.

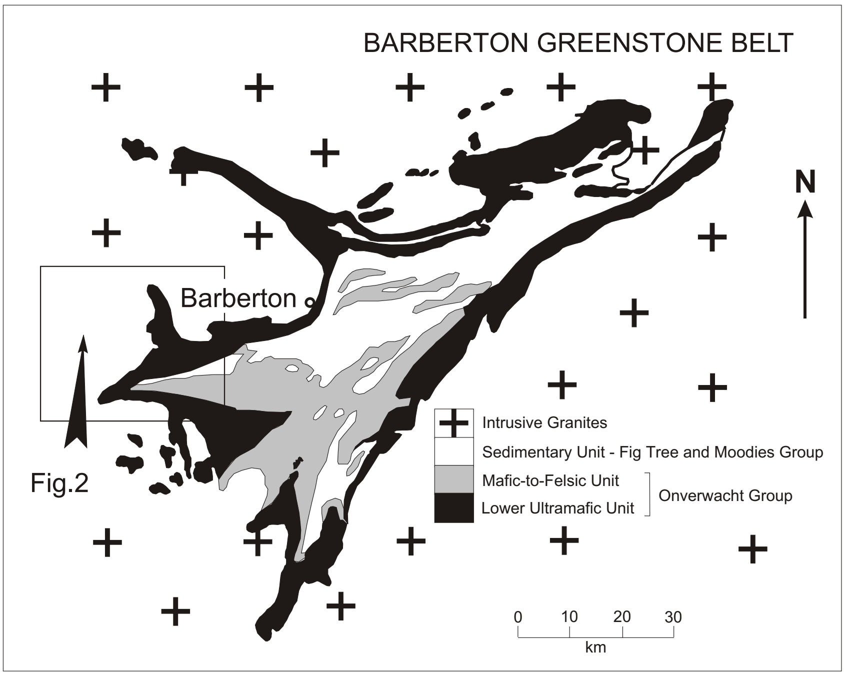

Figure 1: *General geological map of the Barberton greenstone belt showing the locality of the Nelshoogte Schist Belt and the area described in this paper (see also Figs. 2 and 3).*

In this study emphasis will be placed on the so-called Onverwacht Group metavolcanic rocks of the Nelshoogte Schist Belt as well as the plutonic rocks of the Stolzburg Ultramafic Complex. In addition, details of the granitoid and other rocks intruding the Schist Belt will be provided together with the structural and metamorphic history of the area.

Little previous work was carried out in the Nelshoogte Schist Belt prior to this study. Hall (1918), who first mapped the Barberton area, made only passing reference to the geology of the southwestern extremity of the Barberton greenstone belt. He grouped the various talc, chlorite, and amphibolite schists (as well as massive serpentinite bodies) into what he termed the Jamestown Series. Later, Visser et al. (1956) considered that the basic rocks of the triangular region displayed on their 1:50 000 geological map of the Barberton area (including the various serpentinite bodies found in the area), belonged to an igneous series of rocks they termed the Jamestown Plutonic Complex. The use of this term in the Barberton greenstone belt as a whole was later found to be untenable (Anhaeusser and Viljoen, 1965; Anhaeusser et al., 1966) and it was shown that these

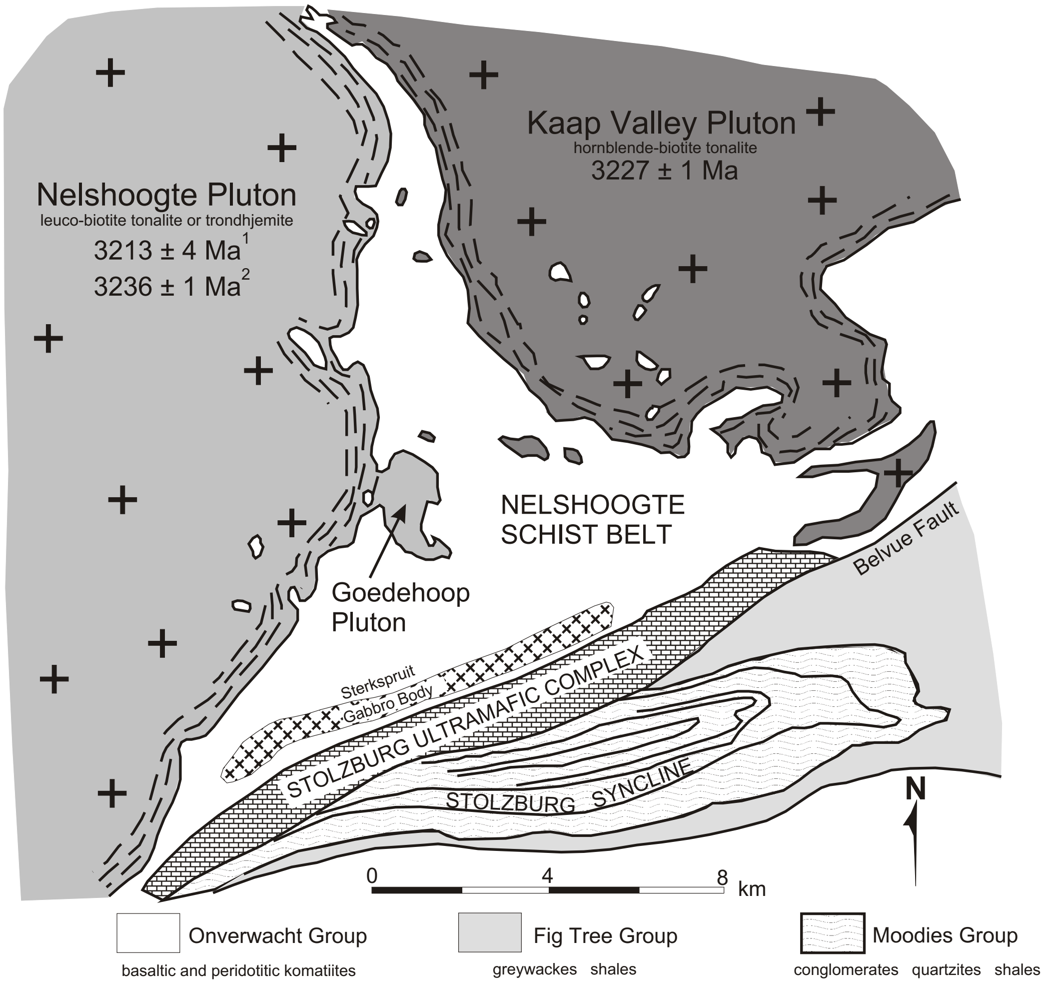

Figure 2: *General geological map of the Nelshoogte Schist Belt and surroundings. The age of the Kaap Valley pluton is after Kamo and Davis (1994) and the ages shown for the Nelshoogte pluton are after Layer et al. (1998)[1] and De Ronde and Kamo (2000)[2], respectively.*

rocks constituted part of the Onverwacht volcanic succession (Viljoen and Viljoen, 1967, 1969b; SACS, 1981).

The massive occurrences of serpentinite, which served as host rocks to a number of chrysotile asbestos deposits in the Barberton greenstone belt, were recognized as having been derived from altered dunites, peridotites and pyroxenites, all of which were intruded into a variety of mafic and ultramafic schists. The serpentinite bodies were, furthermore, regarded as components of either the Jamestown Series (Hall, 1930) or the Jamestown Igneous Complex (Visser et al., 1956; Van Biljon, 1964). By contrast, Anhaeusser (1969, 1972a, 1976, 1982, 1985, 1986), Viljoen and Viljoen (1969d, 1970), Wuth (1980) and Rodel (1993) considered the layered ultramafic complexes to be intrusive subvolcanic sill-like bodies emplaced into, and constituting part of, the Lower Ultramafic Unit of the Swaziland Supergroup. Rodel (1993) also suggested an alternative “lava river” model which envisaged the ultramafic complexes to be integral components of the volcanic stratigraphy (cp., Hill et al., 1989, 1995).

Investigations by De Wit and Stern (1980) and De Wit et al. (1987) led these authors to the conclusion that the mafic and ultramafic rocks of the Barberton greenstone belt “form a pseudostratigraphy comparable to that of Phanerozoic ophiolites”. They referred to this mafic-ultramafic assemblage as the Jamestown Ophiolite Complex in deference to the name 'Jamestown' used earlier by Hall (1918) and again later by Visser et al. (1956). De Wit et al. (1987) further advocated the revival and re-establishment of the term Jamestown Complex (as defined by Visser et al., 1956), claiming that "this complex can be regarded as both igneous and metamorphic, because it adheres to the original Steinmann Trinity and because it closely resembles the more detailed Penrose Conference definition for ophiolites (Anonymous, 1972)." A series of papers followed perpetuating the notion of an ophiolitic pseudo-stratigraphy for the 3.5Ga mafic-ultramafic rocks of the Barberton greenstone belt (De Wit, 1983, 1986, 1991; De Wit and Tredoux, 1988; De Wit and Hart, 1993). The ophiolitic concept has, however, remained contentious and is dependant on interpreting a vertically rotated volcanic sequence as a right-way-up sheeted-dyke complex, a concept initially refuted by Anhaeusser (1983) and Viljoen et al. (1983). Follow-up studies in the type locality of the Onverwacht volcanic succession (Van der Heyde, 1985; Cloete, 1991, 1999; Lowe, 1999; Dann, 2000) have also cast doubt on the ophiolitic model.

The difficulties associated with evaluating and correlating stratigraphy within the Barberton greenstone belt are daunting in the face of its complex structure and the paucity of regional marker beds. The availability of some high-precision, single-crystal zircon geochronology (Armstrong et al., 1990; Kröner et al., 1991, 1996; Kamo and Davis, 1994; Byerly et al., 1996) has provided a possible solution to this vexing problem. Using the available age data Lowe (1994, 1999), Lowe and Byerly (1999) and Lowe et al. (1999) have subdivided the Barberton greenstone belt into four principal structural/ stratigraphic blocks termed the (1) Southern, (2) West-Central, (3) East-Central and (4) Northern Domains. In the view of these authors the Northern Domain, which is portrayed as including the area occupied by the Nelshoogte Schist Belt, is made up of rocks of the uppermost Onverwacht Group and succeeding clastic units of the Fig Tree and Moodies Groups. Lowe and Byerly (1999) assigned the various mafic and ultramafic volcanic rocks, as well as the intrusive layered ultramafic complexes in the Northern Domain, to a newly defined formation, the Weltevreden Formation, which they included in the uppermost Onverwacht Group. The Weltevreden Formation, it was claimed, bears a strong lithologic resemblance to the upper cycles of the Mendon Formation. Hence, a correlation with the upper part of the Mendon Formation was preferred rather than one with the lower komatiitic parts of the Onverwacht Group as suggested by previous investigators (e.g.,Viljoen and Viljoen, 1969b; Anhaeusser et al., 1981).

The lithologic similarities of the various mafic and ultramafic rocks in the Nelshoogte Schist Belt with counterparts in the Onverwacht type locality are, in the view of the author, equally convincing; hence the former attempts at correlating the rocks from both these localities. However, in this study, and that carried out by Philpot (1979), difficulties were experienced in directly correlating the Nelshoogte metavolcanic assemblages with existing formations of the Onverwacht Group as defined by either Viljoen and Viljoen (1969b,c) in the type locality, or by Lowe and Byerly (1999) in the Weltevreden Formation. Rather than siding with any one of the correlation possiblities mentioned above the mafic-ultramafic assemblages found in the Nelshoogte region will, for the purposes of this paper, be assigned to the so-called Lower Ultramafic Unit. This term has been in general use to categorize the essentially basaltic and komatiitic volcanic assemblages of the Onverwacht Group occurring around the fringes of the Barberton greenstone belt (Anhaeusser et al., 1981; Fig.1). These rocks are also regarded as being located at, or close to, the stratigraphic base of the Barberton Supergroup.

As mentioned earlier recent geochronological studies undertaken in various parts of the Barberton Mountain Land have yielded a wide range of ages which have cast doubts on past correlation attempts within the Barberton region as a whole. No direct age dating has yet been attempted in the Nelshoogte Schist Belt, but a number of studies have been carried out in the granitoid rocks flanking the schist belt (Oosthuyzen, 1970; Robb et al., 1986; Barton et al., 1983; Tegtmeyer and Kröner, 1987; Armstrong et al., 1990; Kamo and Davis, 1994; Layer et al., 1998). More recent age studies place the Kaap Valley pluton at *c*.3227 Ma (Tegtmeyer and Kröner, 1987; Kamo and Davis, 1994) and the Nelshoogte pluton at between 3213 and 3236 Ma (Tegtmeyer and Kröner, 1987; Armstrong et al., 1990; Layer et al., 1998; De Ronde and Kamo, 2000).

The Nelshoogte Schist Belt and flanking granitoid rocks were later intruded by a mafic dyke swarm, believed to be mainly Late Archaean to Proterozoic in age (Hall, 1917; Visser et al., 1956; Hunter and Halls, 1992). In addition, a massive and, in places, layered body of gabbroic- to-dioritic composition, known as the Sterkspruit Intrusion, occurs northwest of, and sub-parallel to, the Stolzburg Layered Ultramafic Complex (Visser et al., 1956; Anhaeusser, 1972b; 1985; Pospisek, 1991; Conway, 1997; Figs. 2, 3 and 14). The Sterkspruit gabbro body was regarded by Visser et al. (1956) as a sheet-like intrusion of pre-Godwan Formation age (i.e., *c*. 3000 Ma old). Although the precise age of the mafic dykes in the Barberton region is not known, Hunter and Halls (1992) suggested that most of them were probably emplaced between *c*. 3000 and 2700 Ma.

GEOLOGY OF THE NELSHOOGTE SCHIST BELT

Geological Setting

The Nelshoogte Schist Belt occupies the southwestern part of the Barberton greenstone belt, which consists of mountainous terrain interspersed with incised valleys. The highest point in the area mapped is the Nelshoogte trigonometrical beacon (~5405 ft or 1649 m, Fig. 3, F1) and the lowest is on the Komati River (~3000 ft or 915 m, Fig. 3, C7). The physiography of the region is illustrated in Figure 4 (A-H), which provides views of the mountainous regions and the lower-lying granitic terrane. The variability of the geology in the area is responsible for the topographic diversity. In the Nelshoogte Schist Belt prominent ridges usually consist of komatiite flow units, which occur interlayered with less prominent komatiitic basalts (Fig. 4A-C). In places, resistant ridges are formed of cherty banded iron formation layers (Fig. 4D).

The mafic dykes in the area also generally produce prominent exposures. Examples include the Nelshoogte dyke intruded into the schist belt (Fig. 3, F1) as well as the Swartrand dyke, which is prominent in the Nelshoogte pluton (Fig. 4H), but is also a resistant feature cross-cutting the southwestern part of the Nelshoogte Schist Belt (Fig. 3, B5). Most of the mafic dykes produce ridge-like exposures, but in places they are less resistant than the surrounding host rocks and may weather negatively producing depressions. This is particularly evident where dykes cut across the Stolzburg Layered Ultramafic Complex. Massive orthopyroxenite layers, which themselves form prominent ridges (Fig. 4E-G), are in places, crosscut by mafic dykes, which are not as resistant to weathering as the surrounding orthopyroxenites. This relationship is evident northeast of the Sterkspruit asbestos mine (Fig. 3, B6).

Komatiitic Basalts and Komatiites

Dominating the geology of the Nelshoogte Schist Belt is an extensively developed mafic and ultramafic volcanic sequence made up of lavas and, in places, pyroclastic rocks. Komatiitic basalts are estimated to account for upwards of 80 per cent of the succession the remainder consisting of mafic tuffs and agglomerates. Approximately 5 per cent or less comprises komatiite flow units and subordinate interlayered metasediments, the latter forming useful marker beds.

Komatiitic pillow basalts are common throughout and some exceptional exposures were encountered along forestry roads cut into the hillsides on the farms Groenvaly 701 JT and Doyershoek 702 JT (Fig. 5A,B). Regrettably, these exposures are weathered and are not expected to survive very long. Other good exposures may be found in many of the small streams draining the region. Most of the pillow structures have been deformed to a greater or lesser extent, the most intense flattening occurring closest to the contact with the Nelshoogte pluton (see Fig. 16A-D) where the rocks have an intense schistose character. Massive exposures of pillow breccia, vesiculated lava with open cavities or cavities filled with quartz and carbonate, massive jointed basalt, mafic agglomerate or leharic debris, mafic lapilli tuff and finely laminated ash beds and spherulitic or ocelli-bearing lavas were encountered in many areas (Figs.5C-F; 6C,D,G; 17A-H), some of the best localities being shown on Figure 3.

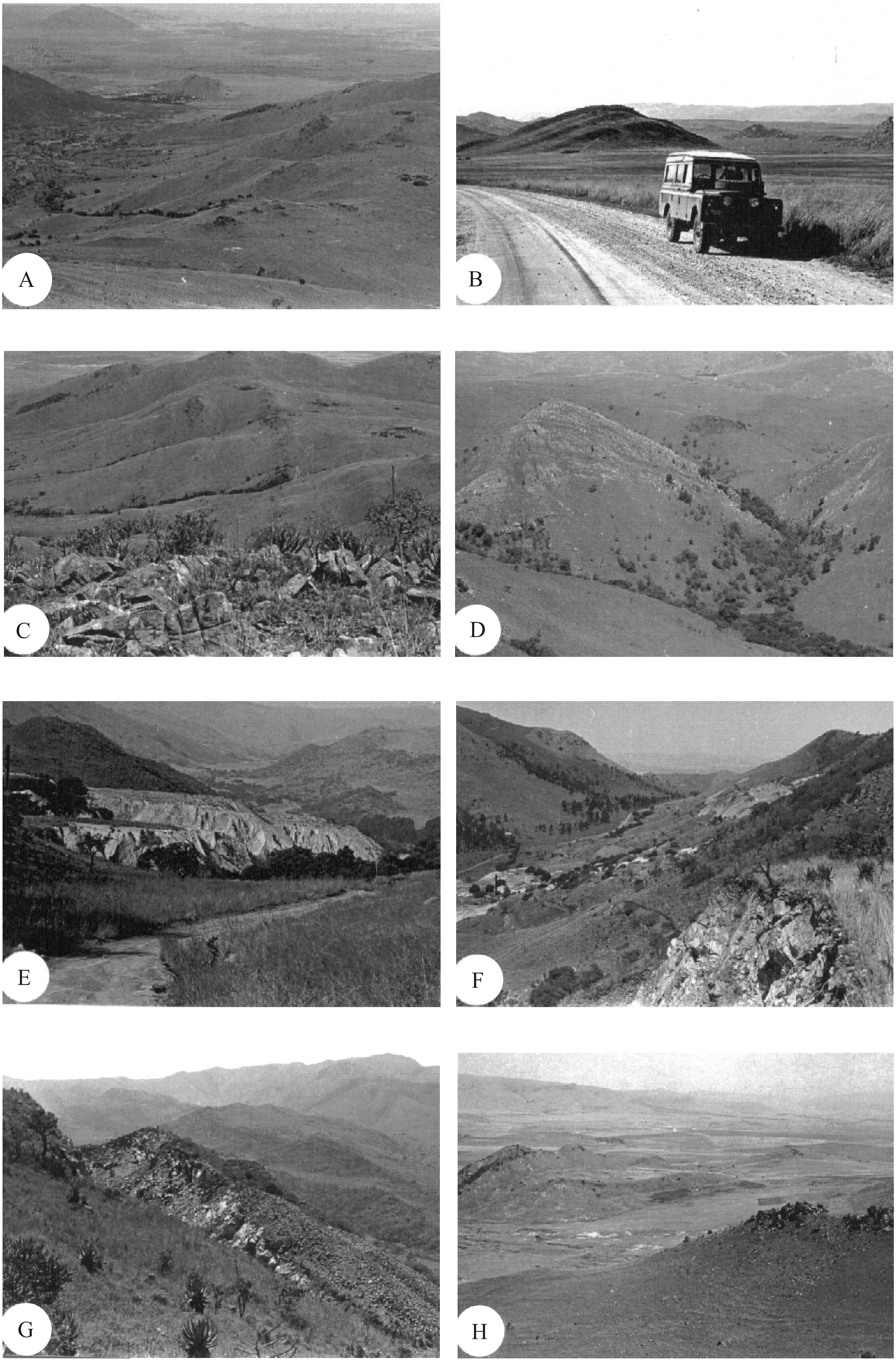
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Figure 4:

A. View of the southwestern sector of the Barberton greenstone belt showing part of the Nelshoogte Schist Belt in the vicinity of the Sterkspruit chrysotile asbestos mine (middle distance, left of centre). The southern extension of the Stolzburg Layered Ultramafic Complex is on the far left and the volcanic sequence is in the centre foreground and to the right. In the far distance is the granitic terrane described by Anhaeusser and Robb (1980), which is exposed in the Komati River valley east of Badplaas.

B. View, looking southeast, of layered komatiitic basalts and komatiites (dark and light ridges left of the vehicle) forming part of the southwestern extension of the Nelshoogte Schist Belt. The road leads to the Sterkspruit Mine, which is located behind the layered hill. In the middle distance, to the right of the vehicle, are exposures of trondhjemitic gneisses of the ~ 3460 Ma Stolzburg pluton (Kamo and Davis, 1994).

C. View, looking south, of komatiite volcanic rocks (ridges and foreground exposures with enhanced vegetation) interlayered with pillowed and massive komatiitic basalts in the Nelshoogte Schist Belt on the farm Stolzburg 710 JT (Fig.3, D 5).

D. View, looking southeast, showing a prominent banded chert succession on the far-eastern part of the farm Groenvaly 701 JT (Fig.3, I 3). Beyond the chert ridge, in the middle distance, is the northeastern extension of the Stolzburg Layered Ultramafic Complex. The high ground in the far distance consists of sediments of the Fig Tree Group (shale, banded chert, banded iron formation) and the Moodies Group (quartzite, conglomerate, shale). The old workings of the Bellevue Gold Mine are also situated in this area.

E. View, looking northeast, along the Mawelawela river valley. The Nelshoogte Schist Belt is on the left and the dunite and orthopyroxenite ridges of the Stolzburg Layered Ultramafic Complex occur on the right. In the foreground is the waste dump of the old Stolzburg chrysotile asbestos mine (locality: Fig.3, D, E, F, 5).

F. View, looking southwest, of the old Stolzburg Mine workings. The road in the valley marks the approximate position of a major fault (Stolzburg Fault), which separates Moodies Group quartzites and shales, on the left, from the layered ultramafic rocks of the Stolzburg Complex (foreground and right).

G. View, looking northeast, showing the layering in the Stolzburg Complex on the eastern parts of the farms Stolzburg 710 JT, Doyershoek 702 JT and Groenvaly 701 JT. The open pit in the foreground is part of the Stolzburg asbestos mine (locality: Fig.3, E 5,F 5,G 4 and 5, H 4).

H. View, looking west, across the ~ 3213Ma (Layer et al., 1998) Nelshoogte trondhjemite-gneiss pluton. Northwest-trending dykes (including the prominent Swartrand Dyke, left) can be seen in the middle distance. Proterozoic rocks of the Transvaal Drakensburg Escarpment occur in the far distance.

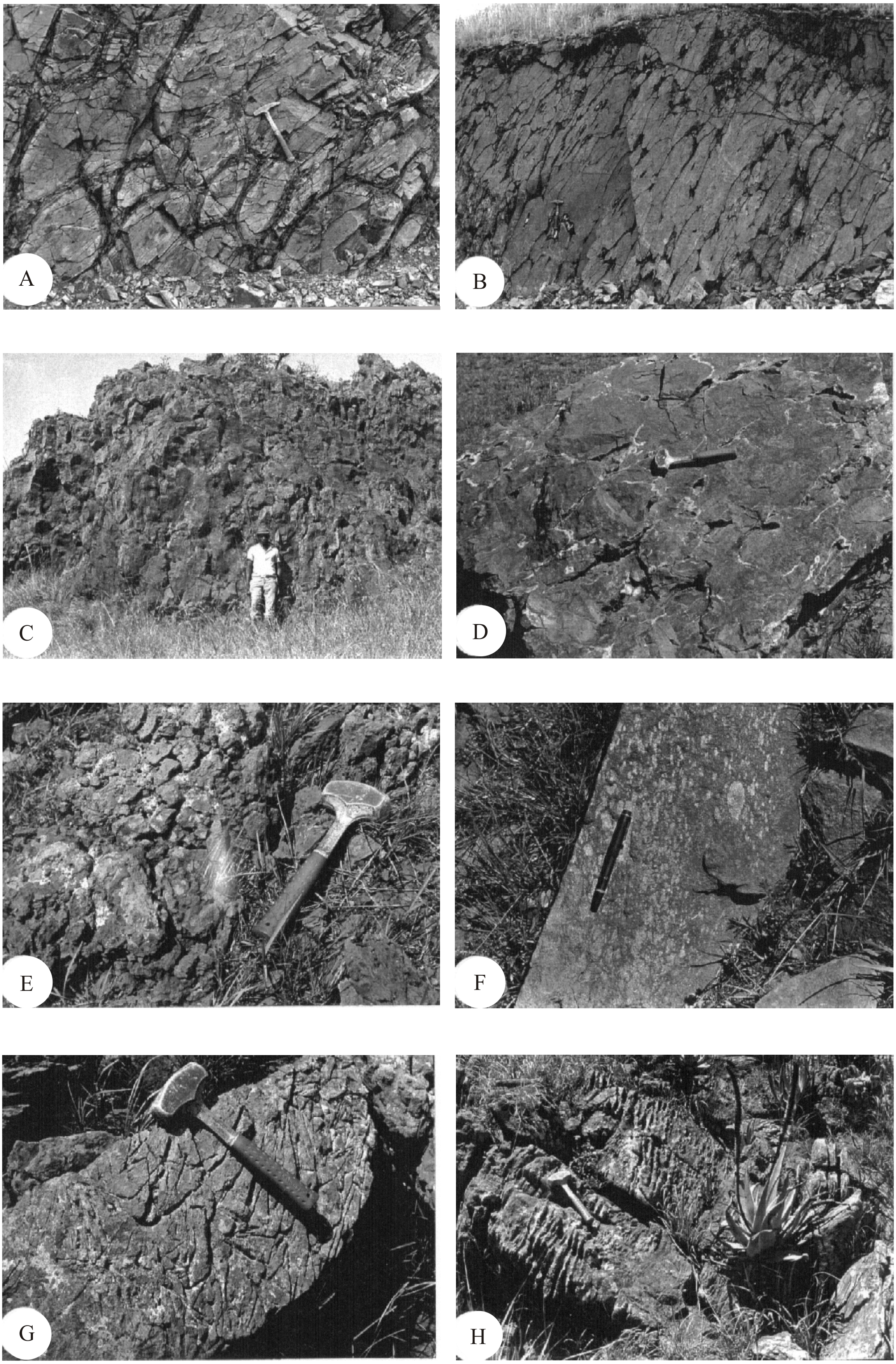
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Figure 5:

A. Forestry road-cutting on the farm Groenvaly 701 JT showing well-developed pillow structures in komatiitic basalts (Fig.3, F 3). The partly weathered pillows exhibit dark rims consisting of devitrified volcanic glass. Being located over 3km from the contact with the Nelshoogte pluton the pillows are still fairly bulbous in shape, but do show some effects of flattening. They indicate younging to the left.

B. Road-cutting exposure of deformed pillow lavas (komatiitic basalts) in the general vicinity of (A) above. The pillows, which also show younging to the left, have been more intensely flattened than those shown in (A).

C. Massive, relatively undeformed pillow breccia forming a blocky exposure in the central part of the Nelshoogte Schist Belt on the farm Doyershoek 702 JT (Fig.3, E 3).

D. Exposure of pillowed komatiitic basalt showing vesicular cavities caused by the entrapment of gas bubbles during solidification of the lava. Quartz and carbonate veins anastomose throughout the basalts filling openspaces between the pillows as well as some of the larger cavities. The exposure occurs towards the centre of the Nelshoogte Schist Belt on the farm Doyershoek 702 JT, well removed from the deformational influence of the Nelshoogte pluton.

E. Massive, undeformed, mafic breccia or agglomerate, consisting of komatiitic basalt, from the central part of the Nelshoogte Schist Belt on the farm Doyershoek 702 JT (Fig.3, E 3).

F. Mafic lapilli tuff, which occurs interlayered with komatiites on the farm Sterkspruit 709 JT, displaying flattened lapilli fragments (locality: approximately 600m from the Nelshoogte pluton contact, Fig.3, B 5).

G. Komatiite lava flow exposure on the farm Goedehoop 622 JT showing well-preserved, spinifex-textured, bladed crystals of olivine and clinopyroxene. The exposure, which is close to the Nelshoogte pluton contact (Fig.3, D 2), shows little sign of deformation and was probably preserved as a result of heterogeneous flattening strain (cp., the spinifex-textured komatiites preseved in the Schapenburg Schist Belt, described by Anhaeusser, 1983).

H. Massive serpentinized komatiite on the farm Sterkspruit 709 JT showing subvertically orientated pseudostratification or cryptic layering within a lava flow unit. Komatiite layers at this locality (Fig.3, B 6) alternate with komatiitic basalt layers or flow units. The massive serpentinized komatiite flow units generally consist of tiny (~1mm) pseudomorphs of equant olivine grains (cp., descriptions of similar rocks from the Komati Formation type locality by Viljoen et al. [1983], who regarded them as penecontemporaneous sills, and by Dann [2000] who considered them to be undifferentiated sheet flows).

Komatiite flow units interlayered with the komatiitic basalts generally crop out prominently relative to the basalts and often form layers that can be traced for long distances. As with the basalts the komatiitic flow units are generally subvertical in attitude and can be massive or schistose, again largely depending on the proximity to the granitoid contact. The flow units, in places, show olivine spinifex textures, but these are not as common as the more massive flow units displaying subvertical pseudostratification or cryptic layering (Fig. 5G-H).

The mafic and ultramafic rocks in the schist belt have all been deformed and metamorphosed to varying degrees. The komatiites have generally undergone alteration and now occur as massive serpentinites or as talc, talc-carbonate or talc ± tremolite ± chlorite schists. Mineralogically the komatiites contain varying amounts of relic olivine and clinopyroxene, but mainly consist of tremolite, chlorite, antigorite, talc, carbonate and magnetite. Table 1 provides a range of chemical analyses of the Nelshoogte komatiites showing the high level of hydration of these rocks (X = 9.88wt% H_2O). Other diagnostic charactersitics of the komatiites include high MgO and CaO/Al_2O_3 and low TiO_2, Na_2O and K_2O contents.

The komatiitic basalts are likewise altered, showing amphibolite grade rocks near the Nelshoogte and Goedehoop granitoid contacts and greenschist facies rocks over the remainder of the Nelshoogte Schist Belt. In areas affected by strong flattening and shear deformation the metabasalts have a schistose texture. Mineralogically, the metabasalts include hornblende ± tremolite/actinolite ± chlorite, together with variable, but generally subordinate amounts of quartz, plagioclase, epidote, garnet and magnetite.

Table 1: Komatiites, Nelshoogte Schist Belt

Column	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Sample	**S1**[1]	**S4**[1]	**S8**[1]	**S15**[1]	**S20**[1]	**S29**[1]	**S35**[1]	**DH39**[1]	**DH42**[1]	**SK6**[2]	**Sk9**[2]
wt %											
SiO_2	41.80	42.50	39.21	41.47	41.43	39.45	40.73	47.07	40.73	40.60	40.40
TiO_2	0.29	0.36	0.23	0.24	0.31	0.19	0.24	0.29	0.29	0.20	0.20
Al_2O_3	2.92	3.77	3.75	2.90	3.08	2.79	2.66	3.39	3.54	2.30	2.30
Fe_2O_3	4.13	4.73	5.10	4.39	4.50	5.17	4.32	2.57	3.78	1.90	1.90
FeO	6.77	6.90	4.74	7.16	5.65	6.64	6.13	5.24	7.04	9.40	9.70
MnO	0.20	0.18	0.14	0.19	0.17	0.26	0.16	0.15	0.22	0.30	0.20
MgO	30.00	28.80	33.44	30.54	31.36	33.00	30.91	26.60	31.33	32.20	32.30
CaO	3.78	4.86	2.71	2.12	3.15	0.26	3.01	8.14	1.73	1.20	0.90
Na_2O	0.20	0.19	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.00	0.00
K_2O	0.02	0.01	0.01	0.01	0.01	0.00	0.01	0.03	0.01	0.00	0.00
P_2O_5	0.03	0.04	0.04	0.04	0.05	0.03	0.04	0.06	0.04	0.03	0.03
H_2O+	9.53	7.46	9.85	10.18	9.59	11.59	10.05	5.85	10.67	11.87	12.07
CO_2	0.05	0.03	0.05	0.18	0.21	0.14	1.17	0.07	0.07	-	-
S	-	-	0.03	0.08	0.10	0.08	0.05	0.03	0.02	-	-
Total	99.72	99.83	99.34	99.54	99.65	99.64	99.52	99.53	99.42	100.00	100.00

Analysts: [1]Durham University and National Institute for Metallurgy (NIM, now MINTEK); [2]Conway (1997).

Table 2: Komatiitic basalts, Nelshoogte Schist Belt

Column1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Sample	S3[1]	S7[1]	S11[1]	S16[1]	S28[1]	S32[1]	S37[1]	S40[1]	S43[1]	DH38[1]	DH46[1]	DH52[1]	SB7[2]	SB10[2]	SB36[2]	SB37[2]
wt %																
SiO_2	51.80	51.20	50.90	50.44	51.69	51.51	46.61	48.22	51.99	47.69	51.81	51.56	51.60	48.90	51.50	51.10
TiO_2	0.33	0.52	0.50	0.37	0.48	0.60	0.49	0.43	0.47	0.49	0.42	0.45	0.40	0.60	0.40	0.60
Al_2O_3	3.02	5.37	4.65	7.01	3.02	3.99	5.31	4.42	12.67	6.37	4.04	3.97	3.10	5.10	9.60	11.90
Fe_2O_3	1.15	1.70	6.28	2.32	2.05	2.01	5.24	4.39	1.61	1.71	1.56	1.57	1.40	2.50	1.60	1.90
FeO	7.79	9.74	4.38	9.24	8.31	11.43	5.59	5.91	6.45	8.52	8.03	8.82	6.90	12.50	7.90	9.20
MnO	0.21	0.19	0.24	0.20	0.24	0.25	0.16	0.17	0.16	0.16	0.25	0.22	0.20	0.20	0.10	0.10
MgO	17.97	15.28	15.62	13.42	17.51	14.75	23.72	24.65	10.33	19.51	16.68	16.78	17.60	13.80	13.10	10.40
CaO	15.69	12.10	15.54	13.67	13.81	12.58	7.40	7.55	8.18	11.12	13.97	13.49	15.70	12.20	10.90	9.10
Na_2O	0.23	1.19	0.04	0.69	0.12	0.35	0.04	0.29	2.25	0.54	0.86	0.46	0.08	0.29	1.30	1.80
K_2O	0.03	0.20	0.10	0.24	0.10	0.13	0.04	0.07	2.48	0.10	0.13	0.20	0.05	0.16	0.35	0.07
P_2O_5	0.04	0.06	0.06	0.09	0.09	0.09	0.07	0.07	0.30	0.09	0.09	0.09	0.03	0.05	0.05	0.07
H_2O+	2.63	2.99	2.12	2.03	2.35	2.17	4.69	3.31	2.63	3.29	1.65	1.99	2.94	3.70	3.20	3.76
CO_2	0.06	0.05	0.06	0.09	0.08	0.10	0.14	0.07	0.40	0.07	0.12	0.08	-	-	-	-
S	-	-	-	-	-	0.01	0.08	0.04	0.01	0.03	-	-	-	-	-	-
Total	100.95	100.59	100.49	99.81	99.85	99.97	99.58	99.59	99.93	99.69	99.61	99.68	100.00	100.00	100.00	100.00

Analysts: [1]Durham University and National Institute for Metallurgy (NIM now MINTEK); [2]Conway (1997).

Table 2 lists the major element chemistry of 16 samples from different parts of the schist belt. In general, the analyses show consistent results with high SiO_2, MgO, CaO, TiO_2 and total alkalis and lower Al_2O_3 and H_2O contents relative to the komatiites listed in Table 1. The majority of the samples are komatiitic basalts, but some samples (e.g., S43 and SB37) fall into the category of high-magnesian basalts with approximately 10wt% MgO and CaO/Al_2O_3 <1. The komatiites and komatiitic basalts have physical properties and major element characteristics similar to the komatiitic rocks described in the Onverwacht type area (Viljoen and Viljoen, 1969a,b; Smith, 1980; Viljoen et al., 1983; Smith and Erlank, 1982). This similarity led to the situation described earlier regarding the correlation of the two areas.

Metasediments

Interlayered with the mafic and ultramafic rocks are a variety of metasediments that locally provide useful marker beds. Nowhere, except in the northeastern part of the farm Groenvaly 701 JT (Fig. 3, I 3; Fig.4D) and on Belvue 711 JT (Fig.3, J4) do the metasediments crop out prominently. In most cases they occur as thin, poorly exposed layers consisting of banded chert, banded iron formation, felsic tuffaceous schist, banded metaquartzite and calc-silicate rocks (Fig. 6A,E,H). The chert may have black, white, grey, brown or greenish bands and, where metamorphosed close to the granitoid contacts, these rocks may resemble quartzites (Fig. 6B). Some of the cherts occur as silicate facies banded iron formations containing grunerite. Elsewhere magnetite±hornblende/actinolite iron formations may occur (e.g., along the contact of the Nelshoogte Schist Belt with the Stolzburg Complex - Fig.3, E5, F4 and 5, G4). Cherts and felsic schists, which are greenish in colour, contain fuchsite mica.

The calc-silicate rocks occur sporadically within the metabasalt sequence and have a distinctive outcrop appearance, being finely banded and exhibiting what appears to be a boudinage structure (Fig. 6E). Rocks seemingly identical to these have been described in greenstone remnants in the granitic terrane south of the Barberton greenstone belt (Viljoen and Viljoen, 1969b; Anhaeusser and Robb, 1980). A detailed study of some of these metasediments yielded U-Pb zircon ages ranging between 3536 and 3442 Ma (Dziggel et al., 2001).

The different layers in the well-bedded calc-silicate metasediments are mineralogically variable. The peak metamorphic assemblage consists of pyroxene (diopside) + quartz + feldspar (andesine and rarely microcline) ± garnet (grossular-almandine) ± epidote. Where these rocks are gradational into the surrounding metabasalts they may also contain some hornblende or actinolite and accessory magnetite and sphene. The origin of the metasediments remains to be determined, but from their mineralogy Anhaeusser (1983) suggested that the calc-silicate rocks may have originally been pelagic calcareous marls that accumulated between episodes of volcanism.

Most of the metasediments are interlayered with pillowed lava sequences that were deposited in a subaqueous environment. Estimates of emplacement depths of the volcanic rocks in the Onverwacht type locality vary from ~700m to 4km (Cloete, 1999), with upward shoaling occurring in places leading to the development of shallow-water sediments in the Middle Marker at the top of the Komati Formation (Lanier and Lowe, 1982). No such estimates have been attempted in the Nelshoogte Schist Belt, but shallow-water to subaerial conditions appear to have occurred at times as desiccation cracks were recorded in some of the cherty units on the farm Groenvaly 701 JT (Fig. 3, I 3; Fig. 6F).

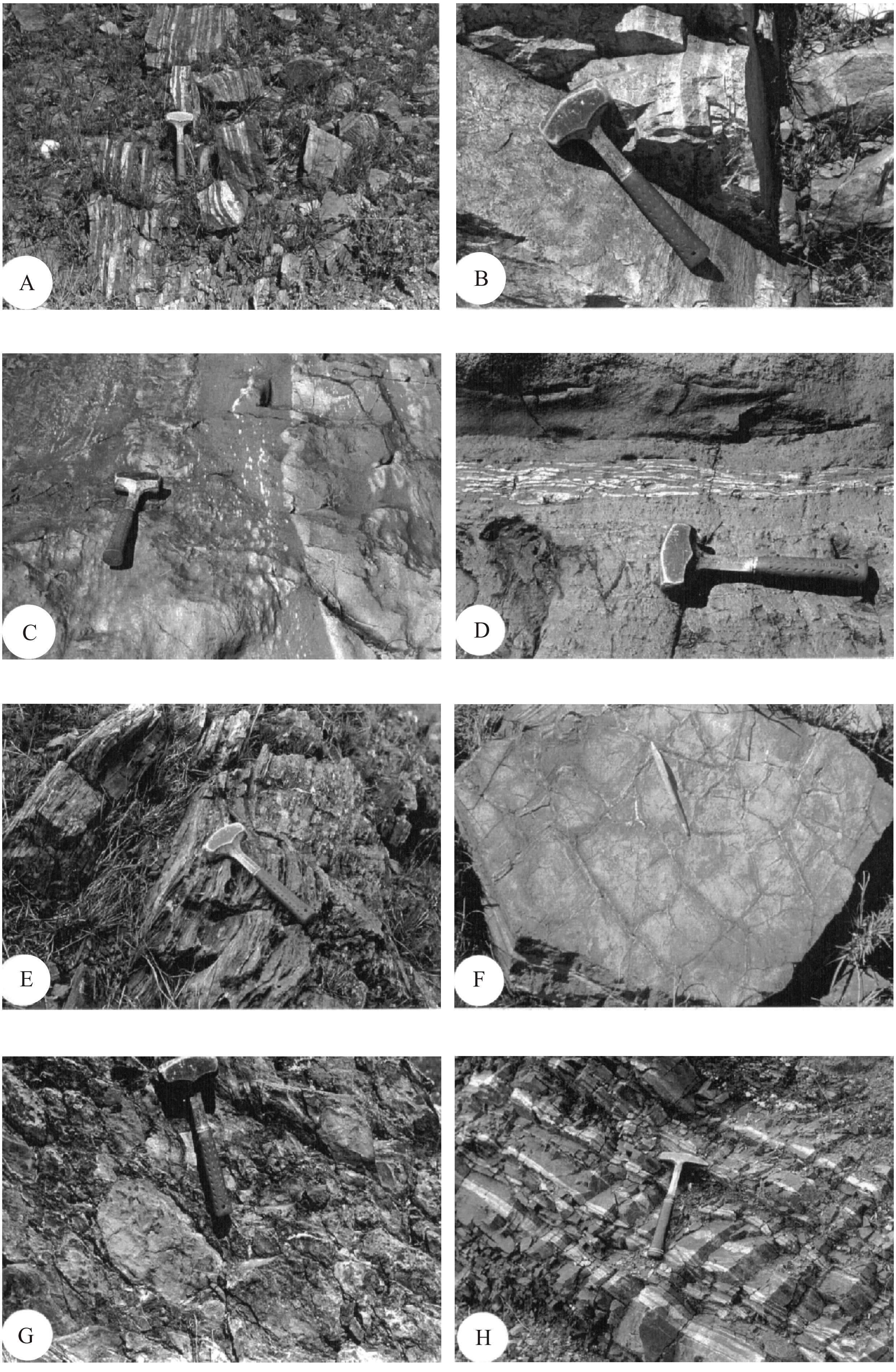
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Figure 6:

A. Banded ferruginous cherty iron formation, occurring interlayered with komatiitic basalts and komatiite flow units, typical of the type seen in numerous localities throughout the Nelshoogte Schist Belt (e.g., Fig.3, D 2, 3; C 4; E 5 - G 4; I 3). The cherty iron formation gives way in places to magnetite-rich iron formation. Metamorphic minerals in these rocks include garnet, hornblende, actinolite and grunerite.

B. Banded green and white granular "quartzite", considered to be a recrystallized fuchsitic chert unit, situated on the farm Groenvaly 701 JT (Fig. 3, E 2 - approximately 800m southeast of sample site TS 16). Heat accompanying the emplacement of the Goedehoop granitoid body was probably responsible for the metamorphic transformation of the banded chert.

C. River exposure on the farm Doyershoek 702 JT (Fig.3, E 4) showing mafic tuff and lapillii tuff laye together with spherulitic or ocelli structures in komatiitic basalt (right).

D. Thin band of flattened agglomerate in mafic tuff beds at same locality as (C) above.

E. Typical weathering style of calc-silicate rocks interlayered with mafic and ultramafic komatiites. The calc-silicate rocks mainly consist of amphibole (hornblende-actinolite), quartz, feldspar, diopside and garnet. The example shown occurs on the farm Goedehoop 622 JT (Fig.3, D 1) close to the Nelshoogte pluton contact.

F. Dessication or mud cracks in shale (phyllitic) layer in a banded chert succession developed on the far eastern portion of the farm Groenvaly 701 JT (Fig.3, I 3; see also Fig. 4 D). This suggests that some of the sedimentary rocks developed in the Nelshoogte Schist Belt were deposited in shallow water and were occasionally subjected to subaerial exposure.

G. Coarse, relatively undeformed, mafic agglomerate (or the remnants of a laharic debris flow) from the central part of the Nelshoogte Schist Belt on the farm Doyershoek 702 JT (Fig.3, E 3). Clast sizes vary from over 30 cm (left of hammer) to lapilli-sized fragments in a tuffaceous matrix.

H. Alternating chert and slate layers in metasediments occurring interlayered with mafic and ultramafic lavas on the farm Rous 621 JT (Fig. 3, C 4). The chert-slate units seldom exceed 3-4 m in width and do not always crop out very prominently. In places sedimentary structures (ripples and cross-bedding) may be seen.

GEOLOGY OF THE STOLZBURG LAYERED ULTRAMAFIC COMPLEX

General Geology

The southeastern sector of the map area (Fig. 3) is dominated by the Stolzburg Layered Ultramafic Complex, which is exposed over a strike length of 14km and is approximately 1.2km wide. The Complex, which has a subvertical attitude, is covered by pine forests in the northeast, but continues for several kilometers in this direction. The northwestern contact of the Complex appears to abut conformably against the Nelshoogte Schist Belt in places, but the contact relationship is unclear. A faulted contact was initially suggested by Anhaeusser (1976, 1979), but De Wit et al. (1987) claimed there was evidence for discordance along the contact and that the Stolzburg body was intrusive into the adjacent volcanic succession. Rodel (1993) reported what she believed to be a sharp igneous contact between the basal serpentinized dunites of the Complex and the adjacent basaltic komatiites. This chill contact was found immediately northwest of the Stolzburg asbestos mine (Fig. 3, D5). The apparent absence of shearing, the reported discordance and the possible chill zone noted by Rodel (1993) does appear to support an intrusive contact relationship.

The southeastern contact is clearly fault controlled with Moodies Group sediments of the Stolzburg Syncline abutting against the Stolzburg Complex along what has been termed the Belvue Fault (Anhaeusser, 1982). This fault may join with the Moodies Fault, which according to De Ronde and Kamo (2000), extends in a northeasterly direction from the Bellevue Gold Mine. The fault zone in the area between the Sterkspruit and Stolzburg mines (Fig.3, C6,D6) displays intensely sheared ultramafic rocks, mainly talcose schists and slickensided serpentinized dunite and orthopyroxenite. An alteration zone of quartz-carbonate breccia occurs adjacent to the fault zone northeast of the Stolzburg Mine (Fig. 3, F5).

The cyclically layered Complex is generally well exposed as may be seen in Figure 7, which is an aerial view of the central part of the intrusion extending from the Stolzburg Mine towards the Doyershoek asbestos workings in the northeast. Prominent ridges of orthopyroxenite occur interlayered with less prominent dunite or harzburgitic layers (see also Fig. 4E-G). The exposures deteriorate in the far northeastern part of the map area (e.g., Fig. 3, I 4) where higher rainfall has caused weathering of the rocks. In addition, the plantations of the Nelshoogte Forestry Reserve make it virtually impossible to undertake detailed mapping.

Anhaeusser (1979,1985) subdivided the Stolzburg Complex into a Lower and Upper Division (Fig. 8A). The Lower Division comprises upwards of six cyclic units, each cyclic unit consisting of cumulate dunite and orthopyroxenite rock types (Fig.8B). A calcium- metasomatized zone made up of rodingites, clinopyroxenites, gabbros and anorthositic gabbros separates the Lower Division from rocks of the Upper Division, which consists of a further ten or more cyclic units. These cyclic units, shown schematically in Figure 8B, consist of dunite, harzburgite, lherzolite, wehrlite, pyroxenite, gabbro and gabbroic anorthosite in varying combinations and proportions.

The cyclic units of the Upper Division generally include gabbroic rocks of variable thickness. Mostly, the gabbroic component is minor relative to the dominantly ultramafic component, but there appears to be a thickening of the gabbroic units in the northeastern part of the Complex. This, however, is not the case as the rocks in this area (e.g., Fig.3, I 4, J 3) have been rotated to flatter, westerly dipping layers wedged between two approximately southeast-trending faults (Fig. 3, H4, I 4 and J 3). This rotation of the layers resulted in larger surface areas of the gabbros being exposed.

Figure 7: Aerial photograph of the central portion of the Stolzburg Layered Ultramafic Complex in the vicinity of the Stolzburg chrysotile asbestos mine. North of the mine is the predominantly volcanic succession of the Nelshoogte Schist Belt, including also the Sterkspruit Gabbro intrusion (see Fig. 3), while to the south are Moodies Group sediments of the Stolzburg Syncline. The Mawelawela River, which flows parallel to the layered complex (top right of photograph), changes direction northeast of the mine workings and cuts across the Stolzburg Complex taking advantage of a prominent fault that displaces the layered units approximately 1km to the southeast.

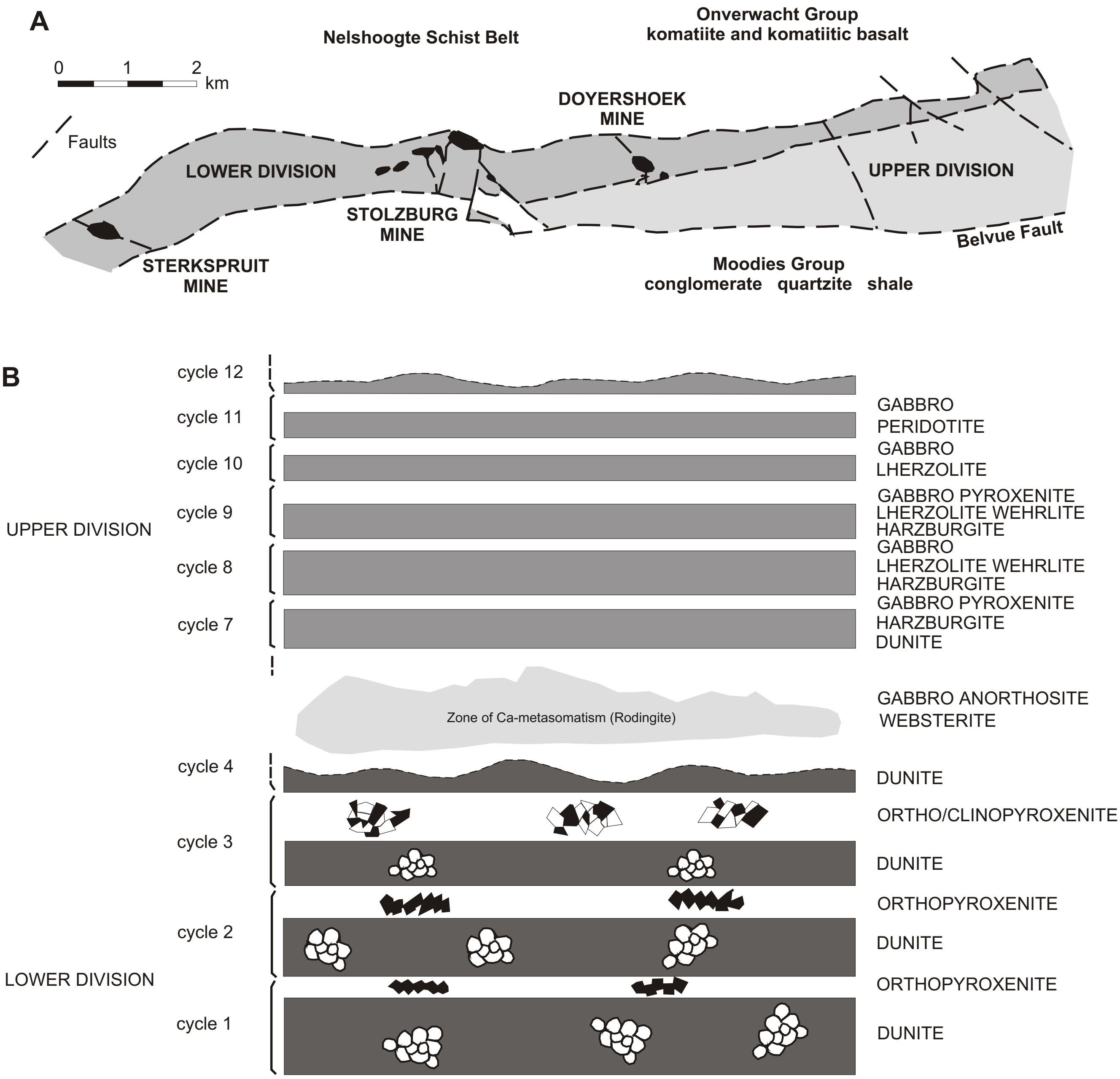

Figure 8: *(A) Simplified map of the Stolzburg Complex showing the subdivision of the intrusion into a Lower Division (consisting predominantly of cyclically repetitive cumulate dunite and orthopyroxenite layers), and an Upper Division (largely composed of alternating harzburgite, lherzolite, dunite, websterite and gabbro-norite layers). (B) Schematic section showing the cyclical repetition of rock types in the Lower and Upper Divisions of the Stolzburg Complex. A zone of calcium-metasomatized rock types (rodingites) separates the Upper and Lower Divisions (after Anhaeusser, 1979).*

De Wit et al. (1987) offered an alternative viewpoint to that outlined above when they presented what they believed to be evidence that the Stolzburg Complex is a peridotitic tectonite similar to those found in alpine-type ultramafic complexes. These authors claimed that “the entire Lower Division of the Stolzburg Complex represents a tectonic peridotite body, which disrupted and intruded a continuous Komati Formation-like rock sequence”. They interpreted the Stolzburg

Complex to be the lowest exposed section of the Barberton greenstone belt, and thus a fragment of the Archaean upper mantle. De Wit and Tredoux (1987) re-affirmed these views, interpreting the peridotites as suboceanic depleted (residual) mantle, similar to lowermost sections of Phanerozoic-style ophiolites. The Upper Division, by contrast, was considered to be analogous to the metabasalt-metaperidotite sequences in the adjacent Nelshoogte Schist Belt and in the Onverwacht type area, De Wit et al. (1987) referring to chemical, petrological and textural evidence to support their claims.

The well-layered stratigraphy of the Stolzburg Complex has been structurally disrupted by a number of east- or southeast-striking cross faults that are largely held responsible for the development of chrysotile asbestos mineralization found in the Sterkspriut, Stolzburg and Doyershoek mine areas (Van Biljon, 1964; Anhaeusser, 1976, 1986; Fig. 9). The chrysotile asbestos is best developed in the serpentinized dunites of the Lower Division, but veins of chrysotile fibre also occur in varying quantities in many of the ultramafic rocks found throughout the Complex, including those in the Upper Division to the northeast of the Doyershoek Mine. All the asbestos mines in the area are no longer in operation, the last mine to close being the Sterkspruit Mine, which ceased mining in the mid-1970s.

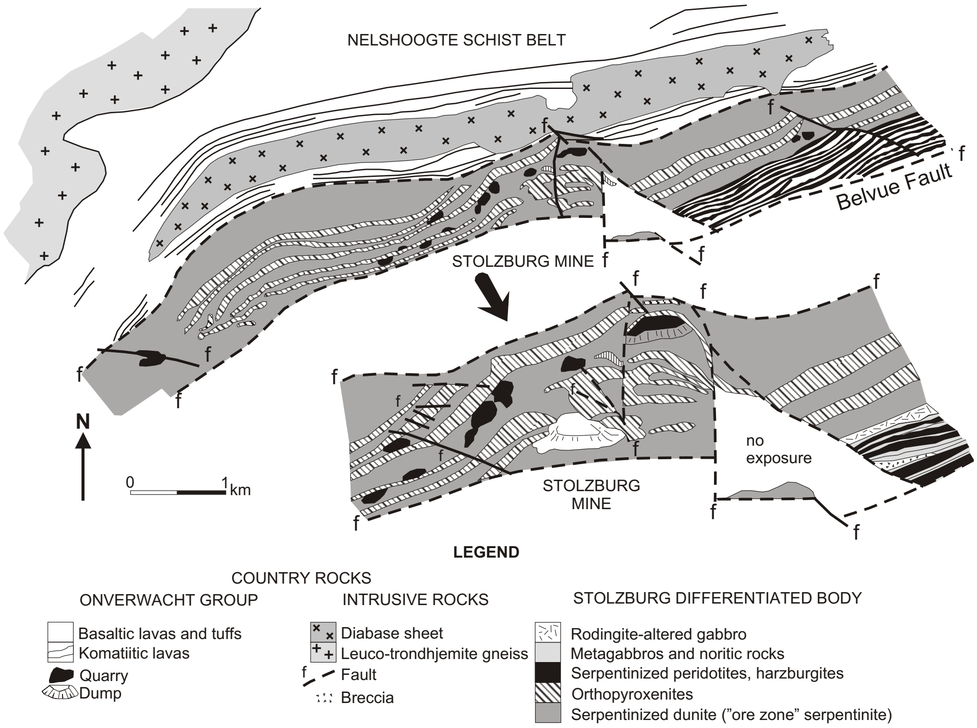

Figure 9: *Simplified geological map (after Anhaeusser, 1985) of the Stolzburg Layered Ultramafic Complex in the vicinity of the Sterkspruit, Stolzburg and Doyershoek chrysotile asbestos mines, all of which occur in serpentinized dunites of the Lower Division. All three asbestos deposits are closely associated with crosscutting faults, the most prominent being in the vicinity of the Stolzburg Mine (area enlarged). The "diabase sheet" northwest of the Complex is the Sterkspruit gabbro intrusion described by Conway (1997).*

Lower Division Dunites and Orthopyroxenites

Cyclically repetitive dunite and orthopyroxenite layered units make up the entire rock assemblage grouped in the Lower Division of the Stolzburg Complex. The best exposures of these rocks occur in the southwest between the Sterkspruit and Stolzburg mines (e.g, Fig. 3, C6). In this area upwards of six cyclic units consisting of dunite overlain by orthopyroxenite (Fig.10) form prominent outcrops like those illustrated in Figure 11A.

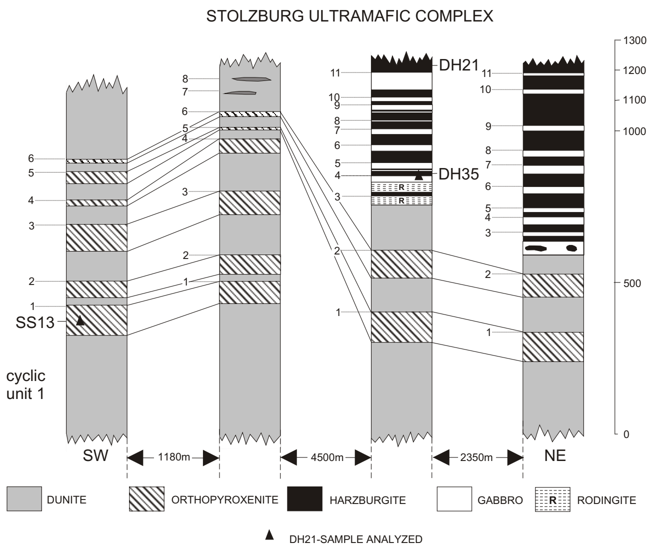

Figure 10: *Stratigraphic columns across various parts of the Stolzburg Complex (after Anhaeusser, 1985). Dunite and orthopyroxenite layers dominate in the southwest (see also Fig.11A), whereas further northeast the uppermost cycles consist mainly of harzburgitic and gabbroic rock types. Cyclically repetitive units (at least 6 of which have been identified in the Lower Division and 10 in the Upper Division) are a notable feature of the Stolzburg Complex.*

Dunites: In the field the dunites are less resistant to weathering than the orthopyroxenites and have a distinctive grey colour, being yellowish-green in places where chrysotile mineralization is developed (the "ore-zone serpentinites" of Viljoen and Viljoen, 1969d). The dunites are extensively serpentinized and contain more than 70% cumulus olivine or its alteration products, mainly antigorite, iddingsite, talc, tremolite and chrysotile. No relic olivine was encountered in any of the Stolzburg dunites, but antigorite pseudomorphs after olivine are common (Anhaeusser, 1985; Rodel, 1993). Orthopyroxene, which has been partly altered to bastite, chlorite and talc is the intercumulus mineral in the dunites. Magnetite occurs as an alteration product of the olivine, either as dust-like particles rimming olivine pseudomorphs, or as secondary magnetite veins. Magnetite also occurs with chrysotile veins where it is sometimes found intergrown with asbestos fibre or as thin partings disrupting the fibre seams (Viljoen and Viljoen, 1969d). Rodel (1993) reported small crystals of chromite and magnetite, but in general there is an absence of primary cumulate oxides. Variable amounts of carbonate also occur in the dunites throughout the area. Veins and irregular patches of secondary opaline silica and carbonate were also noted in some surface exposures.

Borehole core samples of dunites from a structurally disturbed part of the southern end of the Stolzburg Complex (north of the Sterkspruit Mine, Fig. 3, B7) were shown by De Wit et al. (1987) to contain olivine crystals with 120º triple junctions. These polygonization and annealing textures were interpreted to be examples of tectonites similar to those found in the high-temperature regime of ophiolites. Textures similar to those reported by De Wit et al. (1987) were reported for olivines in the dunites of the Perseverance Ultramafic Complex in Western Australia (Barnes et al., 1988). These authors, by contrast, regarded these textures as typical igneous adcumulate textures characteristic of igneous olivines that had experienced high metamorphic temperatures.

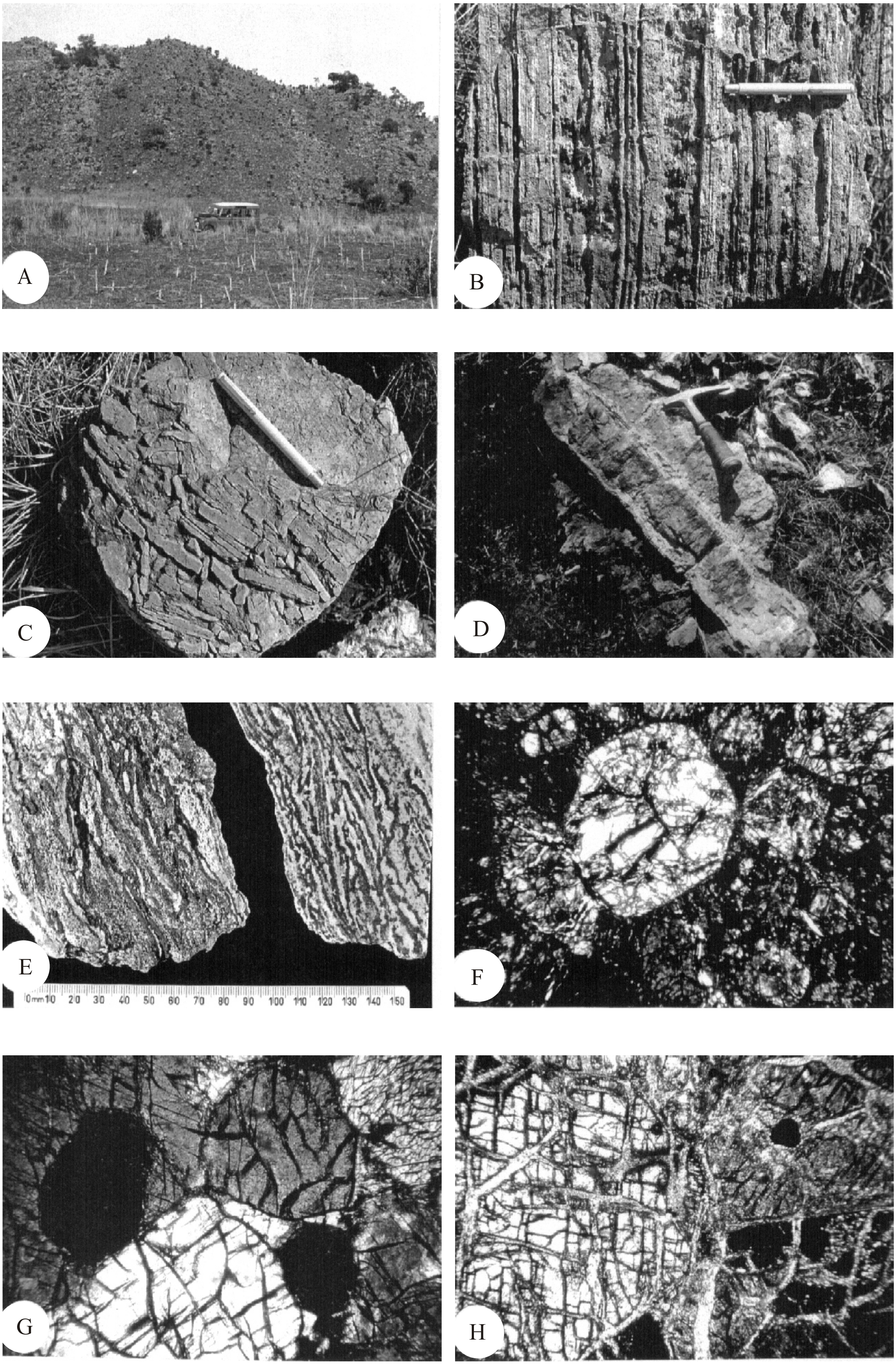
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Figure 11:

A. View looking south on the farm Sterkspruit 709 JT (Fig.3, C6), showing the cyclical, subvertical, dunite and orthopyroxenite layers forming part of the Lower Division of the Stolzburg Layered Ultramafic Complex. The dunites (grey) are host rocks to the chrysotile asbestos deposits that were mined at the Sterkspruit, Stolzburg and Doyershoek mines.

B. Inch-scale layering in gabbroic-anorthositic rocks of the Upper Division of the Stolzburg Complex approximately 500m south of the Doyershoek Mine (Fig. 3, F5, sample locality HD 1)

C. Brecciated chert fragments in a zone adjacent to the Rodingite Zone, shown in Figure 3, which separates the Lower and Upper Divisions of the Stolzburg Complex. The brecciated chert zone, which is best developed south of the Doyershoek Mine near sample site HD 1, can be traced for over 4km in a northeasterly direction, the chert fragments becoming smaller and the rock becoming siliceous and slaty in appearance.

D. Rodingite dyke intruded into serpentinized dunite on the farm Stolzburg 710 JT (Fig.3, F5 near sample site DH 13). The chill zones to the dyke consist of hydrogarnet (amorphous hydrogrossular or hibschite). Anhaeusser (1979) recorded a wide range of calc-silicate minerals in the rodingites, including nephrite, prehnite, vesuvianite, lawsonite, diopside and scapolite to name a few.

E. Banded pyroxene-plagioclase rock occurring in the Rodingite Zone south of the Doyershoek Mine (Fig.3, F5). The dark layers consist of pyroxene (diopside) partially altered to tremolite-actinolite. The white layers consist of a mosaic of plagioclase (albitized calcic plagioclase) with accessory zoisite, epidote and sphene (after Anhaeusser, 1979).

F. Photomicrograph showing cumulate olivine crystals in harzburgite from sample locality DH 26 approximately 1km south of the Doyershoek Mine (Fig.3, F5). Most of the dunitic and harzburgitic rocks in the Stolzburg Complex are generally serpentinized and only rarely are fresh olivine crystals encountered. Incipient serpentinization is evident in the cracks developed in the olivine.

G. Photomicrograph of cumulate orthopyroxenite crystals from a well-preserved, largely monomineralic orthopyroxenite layer from locality (A) above. Minor amounts of intercumulus plagioclase can be seen in places between the orthopyroxene crystals. As with the dunites and harzburgites described in (C) above, fresh orthopyroxenites are also relatively rare, the rocks generally being altered to serpentinite, or steatitized to talc.

H. Photomicrograph showing cumulate orthopyroxene crystals with well-developed cleavage, partly altered along anastomosing veins to steatite (talc). Some intercumulus plagioclase and a grain of chromite (black spot, top right) is also evident. The example is typical of a relatively well-preserved orthopyroxenite from the Lower Division of the Stolzburg Complex.

In this study, and that undertaken by Anhaeusser (1985) and Rodel (1993), the majority of dunite samples examined petrologically, from widely separate areas of the Complex, display cumulus olivine crystals. In places, where intercumulus material is minimal or absent, the unzoned olivine crystals are closely packed and have attained textural equilibrium. This, according to Hunter (1996) results in the grain boundaries possessing constant curvature and dihedral angles at triple junctions, which remain constant at 120º. In general, therefore, the static re-equilibration textures seen in the Stolzburg dunites suggest that the rocks have been subjected to some post-cumulate compaction and metamorphism resulting in thermal recrystallization or annealing, and the squeezing out of intercumulus phases by the growing crystals. This type of crystal growth has been termed the 'adcumulus process' by Cox et al. (1980). Highly strained rocks also reduce their internal strain energy by increasing their grain size (Hunter, 1996). Thus, it is evident that the olivine textures described by De Wit et al. (1987) for the Stolzburg Complex are not solely diagnostic of an ophiolitic tectonite, but may be encountered in a variety of moderate-to large-sized layered intrusions (e.g.,Skaergaard, Bushveld Complex) where primary and secondary textures result from recrystallization, compaction and cementation.

Geochemically the dunites, as well as the other olivine-bearing ultramafics in the Stolzburg Complex, show consistently high MgO and H_2O contents reflecting their general alteration to serpentinites (Table 3). Low SiO_2, Al_2O_3, CaO, TiO_2, P_2O_5, MnO and total alkalis reflect the almost monomineralic state of the ultramafic cumulates. As the rocks are serpentinized relic olivine is rarely encountered. Anhaeusser (1985) reported compositions ranging between Fo_{88} to Fo_{90} for olivines poikilitically encased in harzburgites, but no olivine compositions are available from the dunites. Total iron is relatively abundant in the ultramafic rocks reflecting the prominent occurrence of magnetite, which is largely secondary and derived from the serpentinization of the olivine.

Orthopyroxenites: These essentially monomineralic, orthopyroxene-dominant rocks form topographically distinct layers or ridges in the study area and occur stratigraphically above the dunites (Figs. 4E-G, 7, 11A). They can be traced continuously along the entire length of the Complex and are locally disrupted by faulting and associated drag folding, particularly in the Stolzburg and Sterkspruit mine areas (Fig. 3, B6, E5). The deformation, coupled with the massive and generally competent structural nature of these rocks, was held to be mainly responsible for the development of chrysotile asbestos fibre in the closely associated, relatively incompetent, serpentinized dunites (Van Biljon, 1964; Viljoen and Viljoen, 1969d; Anhaeusser, 1976, 1986).

In the field the orthopyroxenites have a distinctive brownish-red surface weathering, but on fresh surfaces the rocks have dark waxy greenish colour. The exposures are generally massive or jointed in places and show no signs of mineral or other layering. In most cases, like the dunites, the orthopyroxenites have been extensively altered and large cumulate orthopyroxene crystals can be seen prominently developed on weathered surfaces. Alteration to bastite and talc is variable. In places the orthopyroxenite is completely unaltered (Fig.11G), but a few metres away may be partly or totally altered. Alteration begins with veins and stringers of talc and bastite penetrating fractures and cleavage planes in orthopyroxene crystals (Fig.11H) Advanced alteration results in talc or bastite totally pseudomorphing the orthopyroxene.

Mineralogically, the orthopyroxenites are dominated by cumulus enstatite-bronzite (En_{87-88}, Anhaeusser, 1985), but minor intercumulus plagioclase (bytownite, Fig.11G) and accessory magnetite and chromite may also be encountered. A 20-30cm thick, undeformed chromitite layer was reported by De Wit and Tredoux (1988) near the Sterkspruit asbestos mine (Fig.3, B7). The chromitite, which can be traced for approximately 10m, occurs interlayered with the pyroxenites and consists of a massive aggregate of well-packed chromite of presumed cumulate origin. The chromite grains have lobate rims of magnetite, and ilmenite occurs in small amounts, typically as cement between the chromite grains. De Wit and Tredoux (1988) noted further that poikiloblastic

Table 3: Dunites, harzburgites and lherzolites, Stolzburg Ultramafic Complex

Column	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Sample	**DH21**	**DH25**	**DH26**	**DH35**	**DH49**	**DH65**	**DH70**	**DH78**	**DH84**	**DH86**	**DH90**	**SS20**	**SS39**	**SS45**
wt %														
SiO_2	40.50	41.10	39.40	39.60	43.70	38.99	39.28	40.34	40.30	40.70	41.53	45.22	40.40	37.53
TiO_2	0.12	0.21	0.10	0.10	0.24	0.11	0.11	0.14	0.11	0.08	0.18	0.09	0.05	0.04
Al_2O_3	3.16	4.68	2.09	2.32	4.42	2.40	3.01	3.49	3.65	2.31	4.11	2.06	0.76	0.52
Fe_2O_3	4.92	2.95	2.19	6.49	2.68	6.26	4.46	3.58	4.13	3.24	2.71	2.85	5.96	3.21
FeO	3.22	6.82	8.04	2.87	7.87	1.07	3.15	4.39	3.66	3.65	5.86	7.23	3.37	2.95
MnO	0.10	0.16	0.15	0.15	0.17	0.12	0.13	0.12	0.16	0.13	0.16	0.19	0.11	0.07
MgO	34.10	29.25	35.70	36.60	26.5	37.90	36.12	33.88	34.50	36.28	31.14	30.26	36.69	37.18
CaO	2.68	3.88	1.88	1.64	4.85	0.04	1.02	2.70	1.09	0.24	3.34	2.40	0.03	0.02
Na_2O	0.12	0.04	0.03	0.11	0.29	0.03	0.03	0.04	0.21	0.03	0.04	0.04	0.03	0.03
K_2O	0.06	0.03	0.02	0.02	0.06	0.01	0.01	0.01	0.02	0.00	0.03	0.02	0.01	0.00
P_2O_5	0.03	0.05	0.04	0.03	0.05	0.03	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.02
H_2O+	10.32	9.47	9.25	10.08	7.45	12.43	11.46	10.30	11.04	12.14	10.00	8.65	11.54	10.60
CO_2	0.18	0.57	0.10	0.11	0.05	0.16	0.18	0.23	0.39	0.61	0.17	0.26	0.11	7.27
S	-	0.14	-	-	-	0.07	0.14	0.09	0.12	0.08	0.06	0.07	0.00	0.07
Total	99.51	99.35	98.99	100.12	98.33	99.62	99.13	99.35	99.42	99.52	99.37	99.38	99.09	99.51

Analysts: Durham University and National Institute for Metallurgy (NIM, now MINTEK).

pyroxene megacrysts, now chlorite pseudomorphs, give the rock a porphyritic texture. These authors also reported chromite-magnetite pods in talc-carbonate rocks 20-30cm below the chromitites described above and writer (Anhaeusser, 1985) also noted the presence of 2-5cm thick cumulus magnetite layers or pods in the area north of the Sterkspruit Mine (near sample SS40, Fig.3, B7).

Geochemically the orthopyroxenites appear to be compositionally consistent throughout the entire region (Table 4). Anhaeusser (1985) noted that there was also little or no upward major element compositional change in the various pyroxenitic units sampled, the biggest differences being in the H_2O contents (0.7 to 8.25 wt%). The rocks containing the least H_2O (Table 4, columns 12,13, 16) show well-preserved orthopyroxene crystals like those shown in Figure 11G. The fresh rocks also display higher MgO (~33%) and SiO_2 (55%), contents. With increasing H_2O the alteration to talc and bastite intensifies (Fig. 11H), coinciding with reduced MgO (~28%) and SiO_2 (~52%) contents, respectively. Totally altered rocks, where no vestiges of pyroxenes remain and where only talc pseudomorphs are preserved, are relatively depleted in SiO_2, TiO_2, Al_2O_3, and MgO, and are somewhat enriched in Fe_2O_3, MnO, CaO and CO_2 (cp., columns 2 and 20 with columns 12,13 and 16 in Table 4).

Upper Division Harzburgites, Websterites, Gabbro-norites and Rodingites

As with the Lower Division, the Upper Division, as defined by the writer (Anhaeusser, 1979), consists of repetitive cyclic units consisting mainly of layered ultramafic rocks (dunite, harzburgite, wehrlite, lherzolite and orthopyroxenite in varying quantities and combinations) and a mafic component consisting of clinopyroxenites (websterite), gabbro, norite and anorthositic gabbro (Fig.8). In the central part of the Complex, northeast of the Stolzburg Mine, is a transitional zone, separating the Lower from the Upper Division, which consists of rocks that have undergone varying degrees of calcium metasomatism. These mainly include rodingites or garnetized gabbros.

Harzburgitic Rocks: The ultramafic rocks in the Upper Division generally occur as thinner layers that are also extensively altered to serpentinites and massive and schistose talcose rocks, but may locally be relatively well preserved. For example at sample locality DH 26 (Fig.3, F5) exposures of partly serpentinized nodular harzburgitic rocks are preserved that show relic cumulate olivine crystals (Fig. 11F), many of which are poikilitically enclosed in enstatite megacrysts (Anhaeusser, 1985; Rodel, 1993). Varying proportions of ortho- and clinopyroxene, together with olivine yield harzburgite, wehrlite and lherzolite cumulates, and in places olivine cumulates occur as serpentinized dunites. Cumulate textures are not everywhere apparent in the field, the rocks being generally finer-grained than those in the thicker sequences found in the Lower Division. Chrysotile asbestos veins are not uncommon in most of the ultramafic rocks. However, although prospecting pits occur in a number of localities, no asbestos deposits have been mined. This is ascribed to the dominance of harzburgites and the relative paucity of dunites, particularly of the “ore zone” type described earlier. Samples for which major element chemical analyses are available (Table 3) are shown in the areas southwest and northeast of the Doyershoek Mine (Fig. 3, F5, G5).

Websterites: The cyclic layers in the Upper Division have variable, but generally subordinate thicknesses of clinopyroxenite - this in contrast to the thick orthopyroxenite layers described in the Lower Division. These rocks are sheared in places and alteration is prevalent with the clinopyroxene (diopside) uralitized to tremolite-actinolite, the orthopyroxene (enstatite) altered to chlorite, bastite or talc and the plagioclase feldspar (bytownite-labradorite) now altered to albite or saussuritized to epidote and/or zoisite (Anhaeusser, 1985; Rodel, 1993). Accessory ilmenite and leucoxene occurs in places.

Table 4: Orthopyroxenites, Stolzburg Layered Ultramafic Complex

Column	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Sample	**DH3**	**DH4**	**DH7**	**DH8**	**DH62**	**DH63**	**DH66**	**DH68**	**SS4**	**SS9**	**SS11**	**SS12**	**SS13**	**SS14**	**SS18**	**SS19**	**SS30**	**SS32**	**SS35**	**SS40**
wt%																				
SiO_2	52.37	50.31	52.60	52.14	54.13	52.54	51.42	52.93	54.19	54.78	52.60	54.80	55.20	53.50	51.77	54.77	53.97	52.48	52.90	49.33
TiO_2	0.06	0.06	0.10	0.11	0.10	0.11	0.11	0.11	0.08	0.07	0.06	0.06	0.06	0.05	0.06	0.07	0.07	0.06	0.09	0.10
Al_2O_3	1.16	0.90	1.78	2.03	2.17	2.42	2.56	2.02	1.62	1.46	0.97	1.19	1.22	0.97	1.07	1.41	1.14	0.95	1.36	1.51
Fe_2O_3	1.07	1.68	0.96	1.05	0.64	0.62	0.79	0.71	0.67	0.40	1.01	0.91	1.03	1.37	1.01	0.37	0.95	0.88	0.85	1.91
FeO	4.95	5.45	6.07	6.89	7.58	8.25	6.43	7.24	6.66	6.08	5.76	6.36	6.59	4.79	4.36	6.10	5.53	5.50	7.01	6.23
MnO	0.14	0.21	0.16	0.18	0.20	0.21	0.18	0.18	0.18	0.18	0.15	0.17	0.17	0.12	0.18	0.17	0.16	0.15	0.19	0.22
MgO	31.69	29.76	28.70	28.74	30.19	29.29	29.64	28.83	31.36	33.01	31.00	32.50	32.00	29.90	31.16	33.10	32.57	30.56	30.26	28.66
CaO	1.05	2.69	2.65	2.28	2.06	2.88	4.68	2.51	1.69	1.32	1.08	1.23	1.20	1.01	2.02	1.33	1.14	0.95	1.43	3.71
Na_2O	0.04	0.04	0.08	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.07	0.08	0.04	0.04	0.04	0.04	0.04	0.04
K_2O	0.07	0.03	0.16	0.27	0.19	0.08	0.11	0.18	0.15	0.10	0.04	0.08	0.08	0.02	0.01	0.11	0.05	0.02	0.09	0.02
P_2O_5	0.03	0.03	0.02	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.03	0.03	0.03	0.03	0.03	0.04
H_2O+	6.07	8.25	4.95	5.58	2.03	2.93	3.33	4.56	2.66	1.85	7.43	1.10	0.70	7.73	7.59	1.80	3.47	7.68	5.02	7.42
CO_2	0.65	0.11	0.03	0.10	0.07	0.07	0.09	0.15	0.07	0.08	0.02	0.03	0.01	0.14	0.06	0.09	0.25	0.12	0.17	0.21
S	0.06	0.50	0.00	0.06	0.04	0.05	0.04	0.07	0.04	0.05	0.00	0.00	0.00	0.00	0.06	0.05	0.07	0.06	0.07	0.06
Total	99.41	100.20	98.26	99.51	99.48	99.53	99.46	99.57	99.44	99.45	100.18	98.50	98.36	99.69	99.42	99.44	99.44	99.48	99.51	99.45

Analysts: Durham University and National Institute for Metallurgy (NIM, now MINTEK)

Chemical analyses of the websterites are provided in Table 5 (columns 1-5). Relative to the orthopyroxenites (Table 4) these rocks show depletion in SiO_2, MgO and H_2O and substantial increases in TiO_2, Al_2O_3, CaO and Na_2O. Most notable is the variation in the CaO/Al_2O_3 ratio which for the orthopyroxenites is ~1, whereas for the websterites it is increased to ~2, reflecting the increased abundance of diopsidic pyroxene and plagioclase in these rocks relative to the almost monomineralic orthopyroxenites.

Gabbro-norites: Collectively grouped under this category are rocks in which plagioclase is a prominent, but variable constituent. These generally "gabbroic" rocks frequently terminate cyclic units, not only in the Stolzburg Complex, but also in most other layered complexes in the Barberton greenstone belt (Anhaeusser, 1985). In the field these rocks are not always well exposed, and have a tendency to weather negatively relative to the more resistant ultramafic components of the cyclic units. They are usually overlain by harzburgitic rocks of the immediately following cyclic unit and in some places may be buried beneath scree from the ultramafic ridges.

The variability in the proportions of plagioclase and ferromagnesian minerals accounts for the range of rock types that may be encountered. These include gabbro, norite, anorthositic gabbro and even some anorthosites occurring as thin bands, as in the inch-scale layering seen in the area southeast of the Doyershoek Mine (Fig. 3, F5, near sample HD2; Fig. 11B; Anhaeusser, 1985; Rodel, 1993). Mineralogically, the plagioclases are generally replaced (metamorphosed) by albite or oligoclase and the pyroxenes by tremolite-actinolite or chlorite. In addition to the albitization of plagioclase there have been variable degrees of saussuritization and sericitization producing epidote, zoisite and sericite. Prior to metamorphism and alteration the plagioclases were predominantly calcic (bytownite-labradorite) as were the pyroxenes (diopside-calcic augite). Intercumulus clinopyroxene and some orthopyroxene are also encountered in places.

Chemically, the gabbroic and noritic rocks show a range of compositions (Table 5, columns 6-12), the most notable variations being seen in the contents of Al_2O_3, CaO and Na_2O (reflecting changing plagioclase compositions) and MgO, FeO, Fe_2O_3 and TiO_2 (reflecting compositional variations in the pyroxenes and amphiboles).

The gabbroic rocks generally have medium-to fine-grained intergranular to subophitic textures, but locally may be coarse-textured or even pegmatoid-like in places. Some of the gabbroic rocks may not be cumulates, but rather residual liquids or magma left over following crystallization of earlier-formed phases. As mentioned earlier, De Wit et al. (1987) were of the opinion that the rocks, here defined as part of the Upper Division, were not part of the Stolzburg Complex, but were more akin to the finer-grained and texturally similar mafic and ultramafic extrusive rocks of the Komati Formation. Even coarse amphibole spinifex textures were cited in support of this argument.

The writer concedes that this comparison may well be valid for some of these rocks and that they could constitute remnants of the pre-existing extrusive sequence. However, the cyclical nature of the layered sequence, the progressive chemical and mineralogical differentiation from the Lower to the Upper Division, and the similarity of this chemical and mineralogical variation with other cyclically layered ultramafic complexes in the Barberton region (e.g.,the Handsup and Mundt's Concession complexes, Anhaeusser, 1972b; the Pioneer, Sawmill, Emmenes and Morgenson complexes, Wuth, 1980; and the Koedoe, Ship Hill and Budd complexes, Viljoen and Viljoen, 1970) are not supportive of the interpretation placed on these rocks by De Wit et al. (1987).

Table 5: Websterites, gabbro-norites and rodingites, Stolzburg Layered Ultramafic Complex

Column	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Sample	**DH12**	**DH72**	**DH80**	**DH14A**	**DH24**	**DH88**	**DH89**	**DH14B**	**DH19**	**DH85**	**DH91**	**HD2**	**DH17**	**DH71**	**DH13**
wt%															
SiO_2	43.60	48.81	52.96	51.97	53.30	52.00	52.86	52.88	53.33	53.62	54.90	56.90	46.66	46.69	43.20
TiO_2	0.93	0.17	0.29	0.26	0.39	0.50	0.47	0.30	0.48	0.62	0.68	0.54	0.79	0.78	0.58
Al_2O_3	6.25	4.99	5.25	6.23	6.19	9.30	9.28	11.09	12.27	15.51	13.10	13.24	7.19	7.18	11.50
Fe_2O_3	1.80	1.03	1.05	0.84	1.57	1.21	1.45	1.38	1.12	1.16	2.31	1.62	2.25	2.32	3.14
FeO	11.11	6.63	6.74	7.67	7.84	8.71	8.76	5.48	9.17	7.38	6.31	3.22	2.41	2.36	3.30
MnO	0.22	0.11	0.18	0.14	0.18	0.18	0.16	0.11	0.15	0.13	0.09	0.09	0.19	0.19	0.14
MgO	17.03	23.16	17.46	16.59	14.67	14.05	11.59	12.57	8.77	6.30	6.18	6.64	7.87	8.00	7.43
CaO	14.42	10.13	11.87	11.23	12.13	8.44	9.27	10.39	8.34	6.83	10.76	9.95	30.79	30.72	29.40
Na_2O	0.21	0.04	1.12	1.16	1.45	1.99	2.65	2.96	3.07	5.71	2.86	5.07	0.04	0.04	0.01
K_2O	0.04	0.05	0.13	0.39	0.08	0.08	0.18	0.22	0.71	0.13	0.13	0.15	0.01	0.01	0.01
P_2O_5	0.15	0.06	0.06	0.06	0.08	0.09	0.08	0.06	0.09	0.09	0.11	0.04	0.16	0.14	0.11
H_2O+	3.94	4.40	2.34	2.65	2.13	3.16	2.21	2.36	2.30	2.39	1.60	1.41	1.53	1.46	1.56
CO_2	0.02	0.08	0.21	0.51	0.03	0.13	0.71	0.08	0.12	0.09	0.01	0.18	0.08	0.60	0.06
S	-	0.06	0.01	0.01	-	0.04	0.47	-	-	0.04	-	-	-	-	-
Total	99.72	99.72	99.67	99.71	100.04	99.88	100.14	99.88	99.92	100.00	99.04	99.05	99.97	99.99	100.44

Analysts: Durham University and National Institute for Metallurgy (NIM, now MINTEK).

Rodingites: In the Stolzburg Complex rodingites occur in two distinctive varieties. They may be found, firstly, as transgressive dykes, such as the example shown in Figure 11D. These dykes vary in width from a few centimetres upwards to 5m wide and are mainly encountered in the cumulate dunites near the top of the Lower Division of the Complex. Some of the best examples of this type can be found east of the Stolzburg Mine (Fig. 3, F5), where they occur as very fine-grained, pinkish-to beige-coloured exposures. The second variety occurs in a broad zone, in places over 100m wide, where the dominant rock types are gabbros or gabbroic pegmatoids with interlayers of altered websterite and norite. This zone may be traced for over 3km from northeast of the Stolzburg Mine, to beyond the Doyershoek Mine (Fig.3, F5 to H4). Here the rodingitic rocks are represented by calcium-metasomatised gabbroic phases, including garnetised (grossular) gabbros. Some unusual rocks, like the banded pyroxene-plagioclase rock shown in Figure 11E, are encountered in this zone.

Mineralogically, the rodingites are extremely complex rocks and contain a wide variety of calcium or calcium-aluminium-rich minerals, including hydrogrossular, hibschite, vesuvianite, diopside, nephrite, prehnite, zoisite, tremolite, and many others (Anhaeusser, 1979). Their origin is believed to be multifaceted, involving the release of calcium from Ca-rich mineral phases, such as clinopyroxene and plagioclase, and the preferential metasomatic replacement of suitable host rocks, such as dykes in the serpentinized dunites, and dykes, lenses and irregular patches in the relatively coarse-grained gabbros and pegmatoids.

Chemically, the rodingitic rocks are distinguished by their extremely high CaO contents, their relatively high Al_2O_3, and generally low amounts of SiO_2 and MgO (Table 5, columns 13-15). Ca-metasomatised gabbros ranging from 10wt% CaO upwards to rodingites with approximately 30 wt% CaO occur in the study area (Anhaeusser, 1979).

Other Rock Types: The Stolzburg Complex consists predominantly of cumulate igneous rocks, possibly interspersed with remnants of an earlier extrusive sequence of metavolcanics as advocated by De Wit et al. (1987). One such remnant, in this case not comprised of metavolcanic rocks, but a zone consisting of hornfelsed and brecciated chert (Fig. 11C), can be traced intermittently in a northeasterly direction from the Doyershoek Mine area (De Wit et al., 1987; Rodel, 1993). The writer also noted sheared and siliceous slaty serpentinites, hornfelsic slates and fine-grained grey-green cherty grits and microbreccia, the latter containing siliceous mafic-ultramafic and chert clasts. This varied assemblage extends parallel to, and is integrated with, the rodingite zone over a distance of approximately 4km (Fig.3, F5 to I 4).

Cyclic Layering

In reviewing the mechanisms of formation of igneous layering Naslund and McBirney (1996) pointed out that layering is a common, almost ubiquitous feature of igneous intrusions, and that a wide variety of layer-forming mechanisms have been proposed. These include some that operate during the initial filling of the magma chamber as a result of the settling of crystals carried in suspension, flow segregation during magma transport, magma chamber recharge, or magma mixing. Other proposed mechanisms operate in response to continuous, intermittent, or double-diffusive convection. Layering, they added, may also form as the result of mechanical processes, such as gravity settling, crystal sorting by magma currents, magmatic deformation, compaction, seismic shocks, or tectonic deformation. Variations in the rates of nucleation and growth of crystals, oxygen fugacity, pressure, and rates of separation of immiscible liquids, as well as many others, demonstrate that the simple concept of a magma chamber undergoing differentiation as a result of early formed crystals settling out of the magma and accumulating in layers on the floor of the chamber have been discarded by most petrologists. Instead, Naslund and McBirney (1996) pointed out, models currently in favour involve *in situ* crystallization in which magma chambers are thought to have the general form of a central mass of nearly crystal-free magma that gradually loses heat and crystallizes inwards from its margins. As magmas crystallize and differentiate, components included in early-crystallizing minerals are depleted, while those excluded from these phases are enriched.

Just how the cyclic layering in the Stolzburg Complex developed is not clear in view of all the possibilities that have been outlined above. The repetition of almost identical cyclic units may be explained by multiple injections of batches of fresh magma into the magma chamber while it was solidifying in a manner suggested for the Muskox Intrusion (Irvine, 1970). Many of the complexes in the Barberton greenstone belt were thought by Anhaeusser (1985) to have developed in magma chambers that may have acted as staging points for the distribution of lower melting fraction basaltic komatiites. These lava flows, ranging in composition from approximately 10-20 wt% MgO, are envisaged as having been squeezed out of relatively shallow-seated, ultramafic (komatiite) magma repositories. The filter-pressed magma would leave behind a residue consisting of cumulus-enriched minerals, particularly the more refractory phases olivine and orthopyroxene, which are the dominant constituents of the Barberton layered complexes. The trapped magma would also allow additional mineral growth according to a crystallization order dictated by the physico-chemical conditions of the environment.

Crystallization Order

Petrological studies undertaken on a number of Barberton layered complexes have established a crystallzation order common to most of the intrusions (Anhaeusser, 1969, 1985; Viljoen and Viljoen, 1970; Rodel, 1993; Wuth, 1980). The earliest mineral to crystallize was olivine, which formed in abundance to produce the extensive dunite layers. The olivine was followed by orthopyroxene (enstatite-bronzite), which also formed thick and extensive orthopyroxenite layers. Minor amounts of pyroxene (diopside) and calcic plagioclase was trapped as intercumulus phases. Olivine and orthopyroxene, crystallizing simultaneously, later produced the harzburgitic layers higher in the sequence. Next followed the crystallization of clinopyroxene, which together with the earlier-formed minerals resulted in the crystallization of wehrlite (ol + cpx) or lherzolite (ol + opx + cpx). Later, clinopyroxene crystallized in amounts required to produce websteritic layers (cpx ± opx) with intercumulus plagioclase. Increasing amounts of calcic plagioclase, together with the various pyroxenes, produced norites (opx + pl), gabbroic rocks (cpx ± opx + pl) or anorthositic gabbros (pl + cpx), which terminate many of the cyclic layers in the Upper Division of the Complex.

Bulk Composition

Several attempts have been made to estimate the bulk composition of the magmas from which the Barberton layered ultramafic complexes were derived (Viljoen and Viljoen, 1970; Anhaeusser, 1976, 1985; Wuth, 1980; Rodel, 1993). Two approaches to determining the composition of the intrusions have been adopted: (1) establishing the bulk composition directly from the chemistry of chilled margins of the layered bodies; and (2) weighting the chemical analyses of rock types in accordance with their proportions in each layered body.

Chilled margins of the layered intrusions are either not exposed or were found to be altered to the extent of being unreliable for the determination of magma compositions. Hence, most attempts relied on weighting analyses in what were estimated to be their correct volumetric proportions. Without exception, all the complexes yielded bulk magma compositions closely resembling the komatiite lavas of the type commonly developed in the Barberton greenstone belt. Rodel (1993) found what she believed was a reliable chill contact to the Stolzburg body in the area immediately west of the Stolzburg Mine. Material from this locality was, however, found to be unsuitable for chemical analysis, but a sample considered to be a chill-zone equivalent, located approximately 3km to the northeast (DH 49, Fig.3, F4), yielded results confirming the komatiitic nature of the Stolzburg magma.

Anhaeusser (1985) drew comparisons with other Archaean layered intrusions around the world and concluded that the Barberton ultramafic complexes, with their distinctive compositions, particularly their high MgO contents, appeared to make them chemically unique. The closest analogues were found to be the ultramafic sills and lenses of the Dundonald Sill in Ontario, Canada described by Naldrett and Mason (1968).

GRANITOID ROCKS IN THE NELSHOOGTE AREA

As shown earlier (Fig. 2) the Nelshoogte Schist Belt is flanked by two granitoid gneiss plutons. In the west is the Nelshoogte pluton, consisting predominantly of trondhjemitic gneisses, whereas in the northeast the Kaap Valley pluton consists almost exclusively of tonalitic gneisses. A third and smaller tonalitic granitoid body (Goedehoop) is intruded into the schist belt on the farms Goedehoop 622 JT and Groenvaly 701 JT (Fig.3, D1, 2 and E1, 2).

Nelshoogte Pluton (Trondhjemite Gneiss)

The Nelshoogte pluton extends from the southwestern edge of the Barberton greenstone belt for a distance of approximately 20km and disappears beneath the Proterozoic cover rocks of the Transvaal Drakensberg Escarpment approximately 10km north of Badplaas. In the southwest the pluton intrudes the Kalkkloof Schist Belt, a greenstone remnant with geological characteristics very similar to those of the Nelshoogte Schist Belt (Mennell et al., 1986). The pluton, which occupies a large circular valley surrounded by mountainous terrain, is traversed by the Komati River and is intruded by a mafic dyke swarm that provides most of the relief in the form of prominent northwest-trending ridges.

Previous work on the Nelshoogte pluton has been largely of a reconnaisance type (Visser et al., 1956). Viljoen and Viljoen (1969c), Glikson (1976) and Mennell et al. (1986) carried out limited petrological and geochemical studies confirming the trondhjemitic nature of the granitoids. Geochronological studies by Oosthuyzen (1970) provided the first U-Pb zircon data on the age of the pluton (3220±40 Ma). This was followed by age determinations by Barton et al. (1983) who reported a Rb-Sr whole rock isochron age of 3180± 75 Ma (initial $^{87}Sr/^{86}Sr$ ratio of 0.7010± 0.0011) and a biotite whole rock age of 2993±60 Ma. A model $^{207}Pb/^{206}Pb$ age of 3220± 80 Ma was also reported for apatite separates. Kober (1986, 1987) undertook $^{207}Pb/^{206}Pb$ single-grain evaporation dating and obtained an age of 3213±4 Ma for zircons analysed. York et al. (1989) recorded a similar age of 3212±2 Ma, also using the Pb evaporation technique. Layer et al. (1998) reported $^{40}Ar/^{39}Ar$ single-grain hornblende and biotite, and $^{40}Ar/^{39}Ar$ bulk-sample muscovite and biotite age determinations which showed that the Nelshoogte granitoid had a protracted thermal history spanning 3213±4 Ma to about 3000 Ma. During this 200 Myr period these authors were of the opinion that the body was subjected to slow cooling from 700ºC to 200ºC, and was influenced by resetting events later in its history when mafic dykes were intruded at about 1900 Ma. Layer et al. (1998) also undertook palaeomagnetic studies showing that the pluton has a well-defined palaeomagnetic pole which is dated at 3179±18 (2) Ma by $^{40}Ar/^{39}Ar$ dating of hornblende. They also reported evidence in support of significant apparent polar wander during the Archaean.

The most recent geochronological dating of the Nelshoogte pluton was that undertaken by De Ronde and Kamo (2000) using isotope dilution thermal ionization mass spectrometry (i.e., the ID-TIMS U-Pb zircon dating technique). They reported an age of 3236±1 Ma (within error of the 3220±40 Ma U-Pb age first reported by Oosthuyzen, 1970).

Field evidence in support of a complex history for the pluton is provided in this study. Towards the centre of the pluton the leuco-trondhjemite gneiss is homogeneous, but has a weakly developed foliation. Nearer the contacts with the greenstones of both the Nelshoogte and Kalkkloof schist belts the gneisses are strongly foliated and may be relatively homogeneous, or intruded by aplitic dykes and veins which, in turn, are also foliated (Fig.12 A-D). The gneisses exposed along the contact with the Nelshoogte Schist Belt are sheared or may show augen textures. In places, xenolithic lenses of amphibolite, or unusual amphibole "trains" (Fig.13A,B), may be found aligned parallel to the foliation of the gneisses (including also some serpentinite and quartz-chlorite schist remnants at Kalkkloof - Mennell et al., 1986). Rocks in the adjacent schist belts have also been extensively flattened, sheared and metamorphosed by the Nelshoogte granitoids (e.g., Fig. 16D).

The intrusive nature of the Nelshoogte granitoids can be demonstrated in a number of localities. Subvertical lit-par lit granitoid dykes conformably intrude contact amphibolites on the farm Sterkspruit 709 JT (Fig. 3, C4) in much the same manner as on the farm Theeboom 729 JT (Fig. 12F; Anhaeusser and Robb, 1980; Robb, 1981). Brecciation of the contact amphibolites has locally produced agmatites with trondhjemitic magma injected between amphibolite fragments (Figs. 3, D1; 12 G-H). Some granitoid dykes which intrude the Nelshoogte Schist Belt clearly show transgressive relationships with the schists and are texturally homogeneous (Fig.13C) while others are deformed (e.g., boudinaged dykes, Fig. 16G).

Petrological examination showed that the Nelshoogte granitoids are mainly leuco-biotite trondhjemite gneisses, comprising mainly quartz, plagioclase (albite-oligoclase), microcline and biotite, together with accessory amounts of muscovite, sphene, zircon, calcite and apatite. The plagioclase feldspars show variable alteration to sericite and epidote. Hornblende may occur in places, particularly near amphibolite xenoliths.

Chemical analyses of the Nelshoogte granitoids are listed in Table 6 (columns 1-7). All samples show the distictive trondhjemite characteristics defined by Barker (1979) and which include, among others, SiO_2 > *c.* 68%, usually < 75%; Na_2O typically 4.0 to 5.5 % and K_2O < *c.* 2.5%, and typically < 2%. The trondhjemites are also of the high Al_2O_3 type (Al_2O_3> 15% at *c.* 70% SiO_2).

Goedehoop Pluton (Tonalite/Diorite)

This granitoid body embays into the western part of the Nelshoogte Schist Belt and straddles the farms Goedehoop 622 JT, The Strip 700 JT and Groenvaly 701 JT (Fig. 3; areas adjacent to E2). Exposures vary from deeply weathered "badland type" (Fig. 13D) to massive, homogeneous tonalite or diorite, depending on the amount of assimilation of greenstone belt country rocks. The granitoid body contains numerous unaligned, variably sized, mafic enclaves or xenoliths of amphibolite (Fig. 13E). In places the rock has a blotchy appearance, which is ascribed to varying degrees of assimilation of the mafic inclusions. Where ferromagnesian minerals are abundant the rocks are mesocratic and dioritic. Elsewhere the rocks are more leucocratic and tonalitic.

Mineralogically the Goedehoop granitoid contains mainly quartz, hornblende, sericitized and saussuritized plagioclase (albite altered to sericite and epidote) and microcline with accessory chlorite (altered from hornblende), magnetite, apatite, sphene, leucoxene and zircon. Where the granitoid is more leucocratic, hornblende is absent or altered to chlorite, and plagioclase is altered to sericite and epidote.

A chemical analysis of the tonalite/diorite is given in Table 6 (column 8) and shows the lower SiO_2, Al_2O_3, and alkali contents, relative to the trondhjemites, and greater abundances of TiO_2, total iron, MnO, MgO, CaO and P_2O_5, the latter reflecting the higher ferromagnesian content of these rocks.

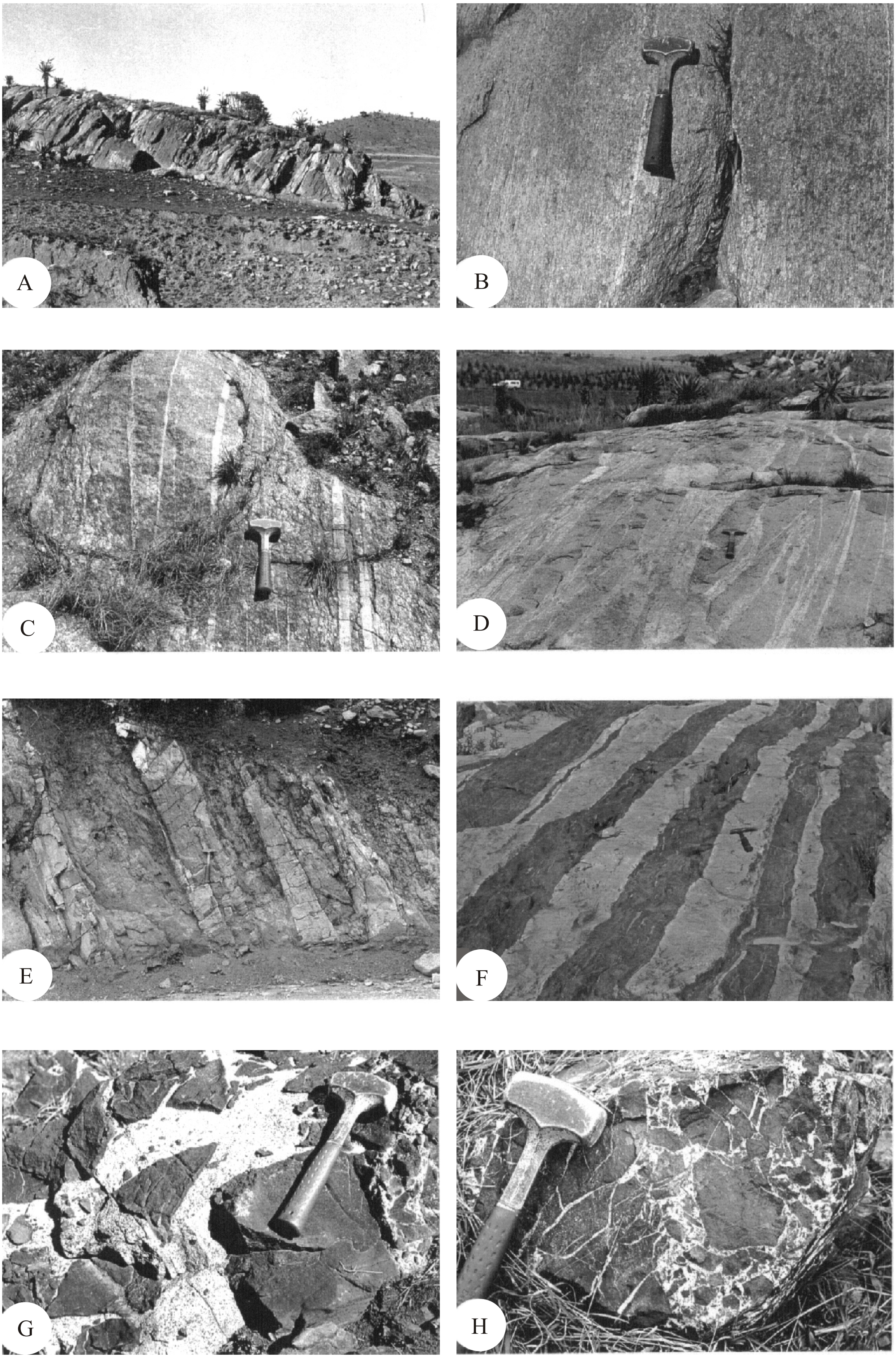
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Figure 12:

A. Field exposure of Nelshoogte trondhjemitic gneiss on the farm Rous 621 JT near the contact with the Nelshoogte Schist Belt (Fig.3, D 2). The gneiss dips steeply (~ 80ºE) towards the greenstone contact (approximately 50m to the left of photograph).

B. Close-up view of the strongly foliated leuco-biotite trondhjemite gneiss near the Nelshoogte Schist Belt contact shown in (A) above. The gneiss has an augen texture and a mineral lineation (not shown) plunging approximately 43º NE in the plane of the foliation. A few thin stringers of aplite (up to 10mm wide) are aligned parallel to the foliation.

C. Strongly foliated trondhjemitic augen gneiss near (A) above showing veins of aplite (up to 10cm wide) that are mainly orientated parallel to the foliation. Some veins do, however, cut obliquely across the foliation.

D. Leuco-biotite trondhjemitic gneisses of the Nelshoogte pluton showing numerous aplitic dykes and veins aligned within and subparallel to the near-vertically foliated augen gneisses on the farm Rous 621 JT (Fig.3, C 3). The granite-greenstone contact is close to the vehicle.

E. Forestry road cutting showing lit-par-lit tongues of foliated trondhjemitic gneisses of the Nelshoogte pluton alternating with amphibolite schists along the contact of the Nelshoogte Schist Belt on the farm Sterkspruit 709 JT (Fig.3, C 4).

F. Lit-par-lit veins of subvertically aligned quartzo-feldspathic anatectite (associated with the Stolzburg pluton), intruded into amphibolites (metabasaltic komatiites) on the farm Theeboom 729 JT (location: approximately 5km southeast of the Nelshoogte pluton). This exposure, with characteristics similar to the example depicted in (E) above, was by Anhaeusser and Robb (1980) and Robb (1981).

G. Agmatite, comprised of fragments of hornblende amphibolite intruded by homogeneous, non-foliated, Goedehoop leuco-tonalite on the farm Goedehoop 622 JT (Fig. 3, D 1).

H. Agmatitic breccia from the same general locality as (G) above, but on the farm Groenvaly 701 JT (Fig.3, E 2, east of sample locality TS 16). Fragmentation of the hornblende-amphibolite resulted from the forcible or explosive injection of the Goedehoop granitoid magma into the metabasaltic lavas of the Nelshoogte Schist Belt.

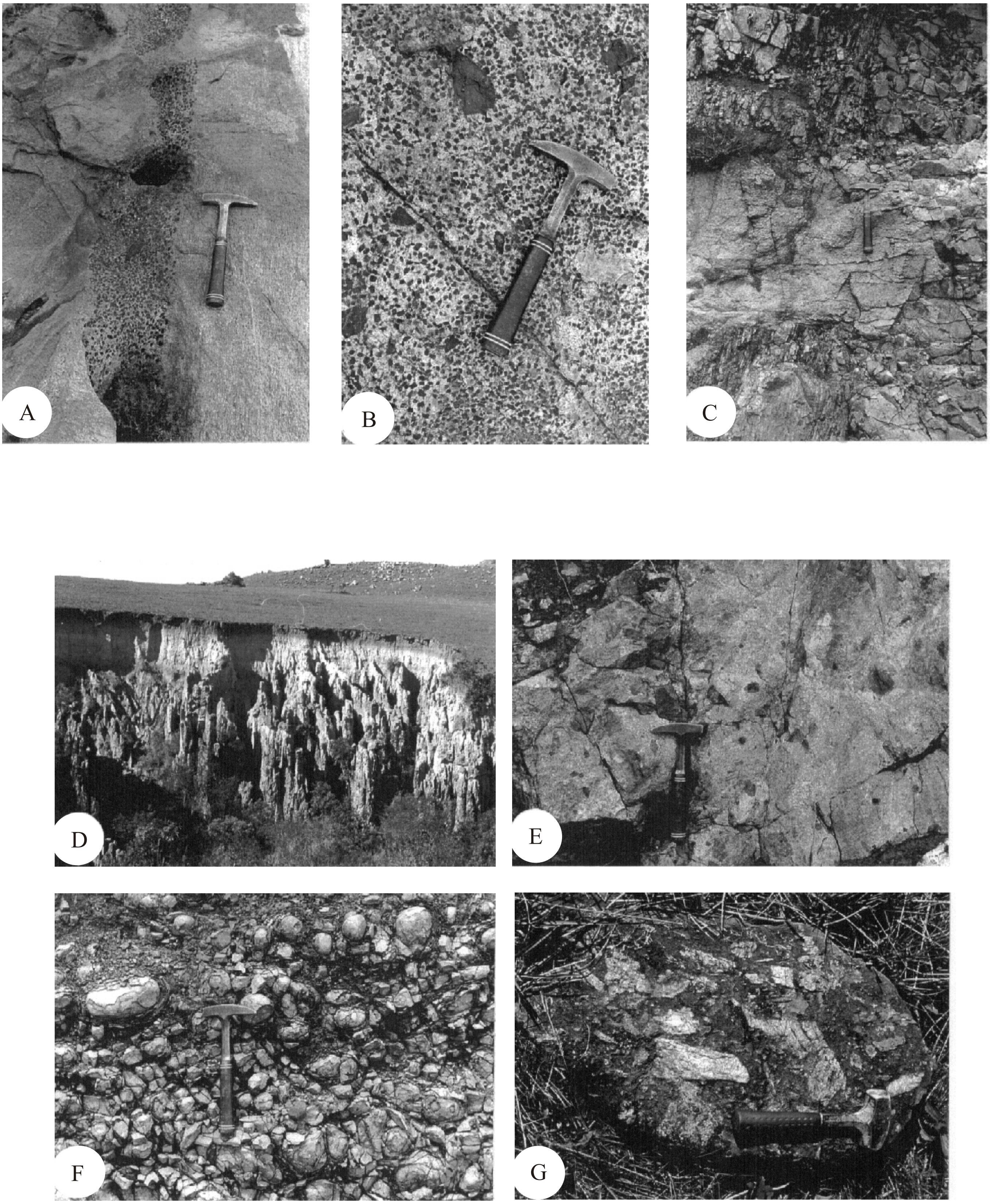
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Figure 13:

A. Foliated leuco-trondhjemitic gneiss of the Nelshoogte pluton on the farm Roux 621 JT (Fig.3, C 3) showing a train of coarse-grained amphibole crystals and amphibolite fragments. An aplitic dyke (top) can be seen crosscutting the gneiss and the entrapped amphibole remnants.

B. Photograph showing enlargement details of the unusual development of amphibolite remnants and associated coarse-grained amphibole (hornblende) crystals from the same locality as (A) above. The exposure is located in the Nelshoogte pluton, close to the Nelshoogte Schist Belt contact.

C. Photograph showing a homogeneous granitoid dyke intruded into and cross-cutting amphibolite schists near the Nelshoogte Schist Belt contact on the farm Rous 621 JT (Fig.3, C 4). Intrusive dykes of this type clearly point to more than one stage of granitoid emplacement being associated with the Nelshoogte pluton.

D. Deeply weathered "badland" erosion associated with the homogeneous Goodehoop hornblende-tonalite granitoid body intruded into the Nelshoogte Schist Belt on the farms Goedehoop 622 JT, The Strip 700 JT and Groenvaly 701 JT (Fig.3, E 1,2).

E. Homogeneous, hornblende-tonalite granitoid with amphibolite xenoliths near sample locality TS 16 (Fig.3, E 2). The xenoliths show various stages of assimilation and are believed to be responsible for the contamination of parts of the Goedehoop granitoid intrusion which, in places, has a mesocratic colour index and is dioritic in composition.

F. Onion-skin or spheroidal weathering seen in some diabase dykes in the vicinity of the greenstone-granite contact on the farm Sterkspruit 709 JT

G. Altered granitoid inclusions (now mainly displaying graphic-intergrowth textures) from a dyke intruded into the Stolzburg Complex on the farm Sterkspruit 709 JT (Fig.3, B 6). The granitic clasts have contributed to the contamination of the dyke, which was originally diabasic in composition, but which is now siliceous in character.

Table 6: Trondhjemitic, tonalitic and dioritic granitoid rocks from the Nelshoogte, Goedehoop and Kaap Valley plutons adjacent to the Nelshoogte Schist Belt

Column	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Sample	**RM8[4]**	**KL6[1]**	**KL7[1]**	**AT117[3]**	**AT118[3]**	**V17[5]**	**S60[2]**	**TS16[2]**	**NW[2]**
wt%									
SiO_2	72.70	68.07	70.57	68.93	70.63	72.55	70.70	57.24	66.55
TiO_2	0.06	0.29	0.29	0.30	0.31	0.16	0.21	0.72	0.44
Al_2O_3	15.41	15.53	15.01	16.21	15.29	14.82	15.26	12.62	15.92
Fe_2O_3	0.11	0.37	0.36	0.38	0.37	0.28	0.22	1.48	0.43
FeO	0.56	1.85	1.82	1.91	1.84	1.39	1.11	7.39	2.17
MnO	0.00	0.04	0.03	0.03	0.03	0.08	0.04	0.19	0.08
MgO	0.17	1.08	0.87	1.22	1.06	0.37	0.54	5.89	1.93
CaO	2.24	3.24	3.02	3.69	3.34	2.24	2.71	7.84	3.89
Na_2O	5.69	5.70	5.54	5.16	4.95	6.30	4.97	2.50	4.68
K_2O	2.17	1.10	1.36	0.62	1.15	2.08	1.66	1.56	0.98
P_2O_5	0.00	0.15	0.13	0.09	0.09	0.04	0.08	0.47	0.16
Loi	0.89	0.81	0.82	1.29	0.84	0.42	1.17	1.56	1.56
Total	100.07	98.43	100.03	100.05	100.11	100.88	98.79	100.28	99.04
ppm									
Rb	-	47	17	-	-	57	-	80	34
Sr	-	605	548	-	-	366	-	480	613
Ba	-	205	22	-	-	-	-	550	360
Zr	-	-	-	-	-	-	-	90	150

Analysts: [1]Department of Geology, University of the Witwatersrand, Johannesburg; [2]National Institute for Metallurgy (NIM, now MINTEK); [3]Glikson (1976); [4]Menell et al. (1986); [5]Viljoen and Viljoen (1969c).

Kaap Valley Pluton (Tonalite Gneiss)

The Kaap Valley pluton occurs to the north of the Nelshoogte Schist Belt (Fig. 2), but does not crop out in the area mapped (Fig. 3). The pluton, which has been dated at 3227±1Ma (Kamo and Davis, 1994), is distictive in that it is tonalitic in bulk composition (as opposed to the trondhjemitic compositions for most of the TTG plutons surrounding the Barberton greenstone belt - Anhaeusser et al., 1981; Robb et al., 1986). The pluton is the largest single body of its kind in the region, being approximately 30km in diameter. It is strongly foliated around the margins becoming less foliated towards the centre of the body. Amphibolite and serpentinite xenoliths occur in places, the larger ones possibly representing roof pendants or remnants rafted off the greenstones surrounding the pluton. Smaller enclaves, often in various stages of digestion and reaction with the surrounding tonalite, were viewed by Robb et al. (1986) as possibly being cognate in origin.

Mineralogically, the Kaap Valley pluton is dominated by hornblende (± biotite) as the major mafic phase. Quartz, plagioclase (albite variably altered to sericite and epidote) and small amounts of interstitial microcline occur together with accessory apatite, zircon and sphene. A chemical analysis of a sample from the Nelshoogte Forest Reserve north of the study area is provided in Table 6 (column 9). It can be seen that the tonalite is intermediate in composition between the Nelshoogte trondhjemite and the Goedehoop tonalite/diorite, but still retains the distictive Na-rich TTG granitoid characteristics.

YOUNGER MAFIC INTRUSIVES

A variety of mafic intrusions, younger than the granites and greenstone belt rocks so far described, intrude the study area. These occur (1) as dykes with a preferred northwest southeast orientation (a regional trend developed across the entire southern part of the Barberton Mountain Land - see Visser et al., 1956); and (2) as larger, more massive, mafic intrusive bodies, (e.g., the Sterkspruit Intrusion), developed within the Nelshoogte Schist Belt (Fig.14).

Mafic Dykes

A variety of mafic dykes intruded the Archaean basement granitoids and associated greenstones in the Nelshoogte region. Most of these dykes produce positive topography and form part of a northwest-trending dyke swarm (Hall, 1917; Hunter and Halls, 1992). Two of the most prominent dykes include the Nelshoogte Dyke in the north (Fig.3, F1) and the Swartrand Dyke in the south (Fig.3, B5), the latter studied by Bailie (1995). A few dykes have a northeasterly trend.

The dykes are texturally very similar and consist mainly of diabases. Petrological investigations showed that the mafic dykes have undergone varying degrees of alteration (mostly deuteric), resulting in the saussuritization of the feldspars and the uralitization of the pyroxenes. In places surface weathering has produced the "onion skin" or spheroidal type of alteration shown in Figure 13F. Some unusual dykes contain numerous inclusions of reconstituted county rock, mainly granitic material, which has presumably been spalled off the surrounding wall rocks. The inclusions have mostly been transformed into coarse-grained, graphic-textured granite and irregular blebs of quartz (Fig. 13G). Two dykes of this type occur in the Stolzburg Complex, the one in the southeast near the Sterkspruit Mine (Fig.3, B6) and the other east of the Doyershoek Mine (Fig.3, G5). Granitic remnants in these dykes have either been derived from depth or have been conveyed laterally over distances of between 2 and 6 km from the known granitic intrusions in the region.

Mineralogically the dykes consist mainly of ortho- and clinopyroxene (enstatite-augite), plagioclase (largely altered to sericite and epidote/zoisite), with lesser amounts of quartz, amphibole (uralitized pyroxene), chlorite, magnetite and ilmenite. Chemical analyses for a selection of dykes is provided in Table 7. Columns 1and 2 are samples from the Swartrand Dyke, one in the map area (Fig. 3, B6) and the other from approximately 12 km to the west immediately north of the Vygeboom Dam. An analysis of one of the inclusion-bearing dykes (column 3) shows a significant increase in SiO_2 and Na_2O and a corresponding decrease in total iron, MgO and CaO reflecting the assimilation of the granitic components.

The ages of the dykes in the study area are not well constrained. Visser et al. (1956) maintained that the relative ages of the dykes in the region could be determined from their relationship with the sedimentary formations resting on the granitic basement along the Transvaal Drakensberg Escarpment. The dykes were designated as Pre-granite, Pre-Godwan, Pre-Transvaal, or Post-Karoo. Hunter and Halls (1992) suggested that the majority of northwesterly trending dykes were emplaced between 3000 and 2700 Ma. More recently, Layer et al. (1998) reported whole-rock $^{40}Ar/^{39}Ar$ ages of 1876±6 and 1902±6 Ma for dykes cross-cutting the Nelshoogte pluton.

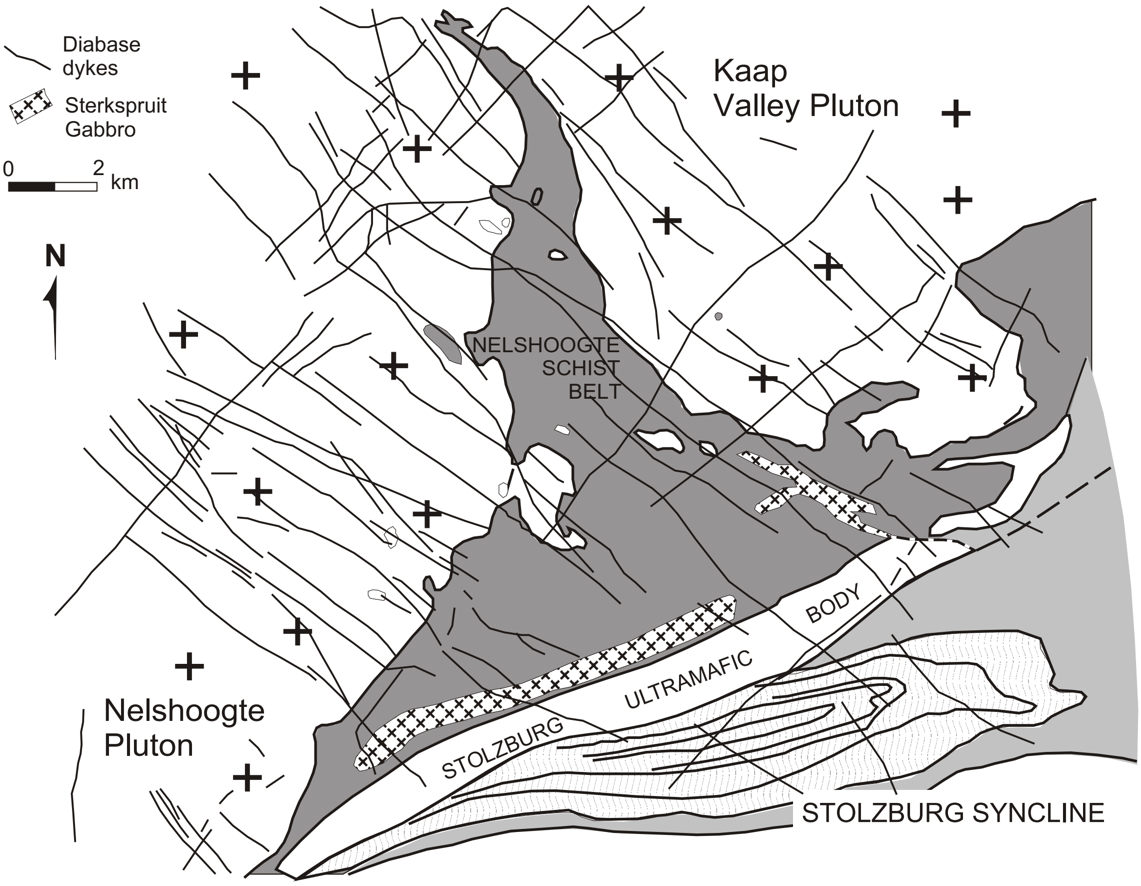

Figure 14: *Simplified map of the Nelshoogte Schist Belt showing the distribution of mafic (diabase) dykes. Although many of the dykes intrude the greenstone succession they are more prominently developed in the adjacent granitic terrane. The dykes, which are predominantly Proterozoic in age, generally postdate the Sterkspruit gabbro intrusion situated northwest of the Stolzburg Complex (see Fig. 3).*

Sterkspruit Intrusion

Immediately northwest of the Stolzburg Complex, and separated from it by a narrow zone of komatiitic basalts and komatiites (Figs. 3, 14) is the Sterkspruit Intrusion. This sill-like body consists mainly of gabbroic-to-dioritic rocks, lacks ultramafic components and has no affinities with the surrounding mafic-to-ultramafic lavas. According to Conway (1997) the Sterkspruit gabbroic suite contains an unusual abundance of quartz and the chill margin shows an evolved quartz-normative, tholeiitic parental magma. The intrusion was subdivided into four gabbroic zones and a quartz diorite, which was regarded as the end product of a differentiating magma. The basal portion of the body, on the northwestern side of the intrusion, has a 2m-wide chill zone and the quartz-diorite zone, which is less than 50m wide, occurs roughly in the centre of the body. The sill-like nature of the intrusion, indicated by the geochemical trends and the steep subvertical layering (the latter being well developed in a river section northeast of the Stolzburg Mine - Fig.3, E4 and E5, near sample locality DH55), point to a body that has been tilted along with the surrounding lavas (Pospisek, 1991; Conway, 1997).

The gabbro/diorite suite is extensively altered with the ferromagnesian minerals (ortho- and clinopyroxene) partly or completely uralitized and the plagioclase phases having undergone saussuritization, albitization, epidotization and sericitization to varying degrees. The main minerals encountered in the gabbros include actinolite, chlorite, epidote, zoisite, albite and

Table 7: Intrusive dykes a nd Sterkspruit Intrusion gabbros

Column	1	2	3	4	5	6	7
Sample	SS15[1]	KL5[1]	SS27[1]	S13[1]	DH55[1]	SG chill[2]	SG bulk[2]
wt%							
SiO_2	49.98	54.49	73.26	50.34	52.78	52.54	52.55
TiO_2	0.20	0.35	0.10	0.60	0.88	1.36	1.39
Al_2O_3	12.77	14.57	8.43	15.62	12.46	13.62	13.61
Fe_2O_3	7.31	1.18	0.33	2.35	4.49	2.39	2.09
FeO	0.89	5.90	2.52	7.67	9.64	11.98	10.46
MnO	0.15	0.15	0.06	0.15	0.20	0.20	0.19
MgO	14.41	7.74	5.88	9.27	6.24	4.83	5.42
CaO	7.49	8.95	3.55	7.95	7.43	7.24	8.29
Na_2O	1.58	2.33	4.48	2.00	2.23	2.82	2.15
K_2O	1.00	1.42	0.20	0.31	0.12	0.10	0.16
P_2O_5	0.09	0.14	0.05	0.13	0.20	0.16	0.14
Loi	-	2.22	-	-	-	-	-
H_2O+	3.77	-	0.87	3.50	3.07	-	-
CO_2	0.08	-	0.07	0.08	0.20	-	-
S	0.04	-	-	0.02	0.10	-	-
Total	99.76	99.44	99.80	99.99	100.04	97.24	96.45

Analysts: [1]Department of Geology, University of the Witwatersrand, Johannesburg; [2]Average chill margin (col.6) and calculated bulk rock compositions (col.7) of the Sterkspruit gabbro intrusion after Conway (1997).

leucoxene. Some pyroxenes are preserved in the marginal and lower zones. The quartz diorite has less-altered plagioclase and quartz in roughly equal amounts, uralitized clinopyroxene, together with chlorite, carbonate, epidote, minor biotite, ilmenite and leucoxene.

Geochemical analyses presented in Table 7 (columns 4 -7) show a range of compositions with the chill margin (column 6) thought to be representative of the parent magma composition (Conway, 1997). Calculations of the bulk composition (column 7), using a weighted-average method, shows good correlation with the chill composition (~ 5%MgO), adding support to the tholeiitic magma parentage. From this it can be concluded that the Sterkspruit Intrusion differs markedly from the neighbouring Stolzburg Complex, which has an ultramafic (komatiitic) parental composition (~34% MgO Rodel, 1993).

STRUCTURE

The southwestern extremity of the Barberton greenstone belt has experienced a complex structural history. Philpot (1979) undertook structural mapping of a reconnaisance nature south of the Stolzburg Complex and north of the Komati River and recorded at least two stages of deformation (D_1 and D_2). D_1 was responsible for the formation of large amplitude isoclinal folds and faults (referred to as slides), including the major synclines with near vertically dipping limbs, such as the Stolzburg Syncline (Fig. 15). D_2 was regarded as a superimposed event producing interference or refolded folds.

A detailed structural analysis coupled with high precision U-Pb zircon age dating was carried out in the adjoining Weltevreden area, northeast of the Nelshoogte Schist Belt (De Ronde and Kamo, 2000) where these authors recorded what they believed to be a short-lived (*c.*3 Myr) arc-arc collision event. Prior to this, De Ronde and De Wit (1994) had discussed the main phases of deformation seen across the Barberton greenstone belt as D_1 through D_4. The collision event (D_2) in the Weltevreden area, was subdivided by De Ronde and Kamo (2000) into D_2 early and D_2 late. D_2 early, bracketed as having occurred between 3229 and 3227 Ma, was typified by isoclinal folding of Fig Tree Group sediments, but not the overlying Moodies Group rocks. The D_2 late deformation occurred at 3226 Ma, or later, with large open-tight folds and late D_2 faults, such as the Moodies Fault converging with the Saddleback Fault south of the Stolzburg Syncline (Figs. 2, 15). The Moodies Fault, as mentioned earlier, possibly connects with the Belvue Fault on the southeast side of the Stolzburg Complex.

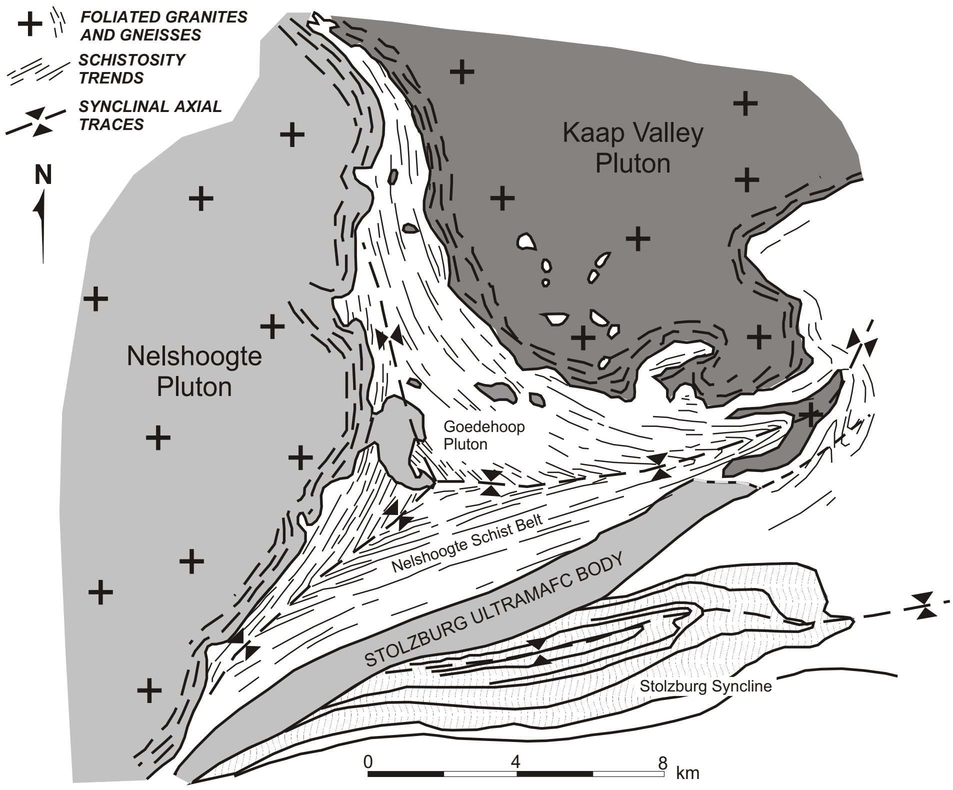

Figure 15: *Simplified structural map (after Anhaeusser, 1984) showing the triangular symmetry of the Nelshoogte Schist Belt and the synformal fold axes that plunge towards the core of the infolded sequences. The adjacent Kaap Valley and Nelshoogte tonalitic and trondhjemitic gneiss plutons are considered to have been emplaced diapirically into the Barberton greenstone belt and are regarded as being responsible for the structural complexity seen in the adjacent schist belt.*

Anhaeusser (1984) ascribed the structure of the Nelshoogte Schist Belt to the diapiric emplacement of “close-packed“ TTG granitoid plutons and the buttressing effect of the adjacent greenstone sequence in the southeast. Figure 15 shows the triangular symmetry of the schist belt and the synformal fold axes that plunge towards the core of the infolded sequences producing a funnel-shaped regional structure. Fold closures can be seen in some localities (Fig.3, I3, D3, E3), but mostly they are sheared out and conformable with the schists. Both the Nelshoogte and Kaap Valley plutons have strongly developed subvertical foliations and lineations adjacent to the greenstone contacts and the greenstones themselves show progressive flattening, folding and boudinaging of lithotypes as the contact zones are approached (Fig. 16A-G). The granitoid diapirs are also held responsible for the structures and the metamorphism encountered in the lava sequences in the schist belt. Massive jointed amphibolitic basalts, flattened pillow lavas, progressively deformed quartz- and carbonate-filled gas- or lava-withdrawal cavities and flattened spherulitic features, such as the ocelli that can be utilized as strain indicators (Fig. 17, A-H), all developed as a consequence of the emplacement of the granitic plutons flanking the schist belt.

The position of the Goedehoop granitoid body in relation to the overall funnel-shaped structure of the Nelshoogte Schist Belt is noteworthy. It can be seen in Figure 15 that this body occupies a site close to the point where the three fold axes converge into what amounts to the stem of the funnel. Could it be possible that the collapse of the metavolcanic rocks into the funnel may have triggered some degree of partial melting or anatexis at depth, thereby resulting in the generation of a syn-to post-tectonic dioritic/tonalitic magmatic body?

Mention has been made earlier of the faulting prevalent in the Stolzburg Complex. The Belvue Fault on the southeastern side of the Complex is the most conspicuous regional fault.
De Wit et al. (1987) were of the opinion that the Stolzburg Complex had been thrust southwards during a late stage of deformation, with the Complex being forced to override the western parts of the Moodies sedimentary succession of the Stolzburg synclinorium. However, this suggestion does not appear to be supported by the mapping of Reimer (1967) or the present study.

Another fault may exist on the northwest side of the Complex, but this could not be confirmed because of poor exposure along the Mawelawela River valley north of Stolzburg Mine and the Sterkpruit valley to the south. The rocks wherein such a fault might well occur are serpentinized dunites, which are noted for their tendency to form slickensided or sheared contacts with adjacent lithologies. The discordance noted between the trend of the Stolzburg Complex and the adjacent rocks west of the Sterkspruit Mine (Fig.3, A7, B7), and again west of the Stolzburg Mine (Fig.3, D5), does, however, support the existence of a fault.

The numerous ESE-trending cross faults (Figs.3, 8A), which have been held responsible for the development of chrysotile asbestos deposits in the Stolzburg Complex (Van Biljon, 1964; Anhaeusser, 1976,1986), are believed to have formed as a result of differential northeast-southwest shearing along the faults bounding the Complex. The subhorizontal shear fabrics found in places in the serpentinized dunites, particularly in the area northeast of the Sterkspruit Mine may also be ascribed to differential shearing of the Complex in areas affected by faulting.

The suggestion has been made (Visser et al., 1956; De Wit et al., 1987) that the dunite-orthopyroxenite layering of the Lower Division of the Stolzburg Complex can be traced into an irregular fold and pod-shaped pattern in the southwest (i.e., immediately northeast of the Sterkspruit Mine). Mapping by the writer shows the orthopyroxenite layers converging (Fig. 3, B6), but no unequivocal fold closure could be identified. In the adjacent Weltevreden region northeast of the present study area, De Ronde and Kamo (2000) contended that their D_2 late deformation was responsible for large F_3 folding of the Stolzburg Complex and adjacent chert or sericite schist unit in a structure they called the Belvue Synform. As the present study did not extend sufficiently far enough to the northeast, and because of extensive forestry cover, it was not possible to verify this observation.

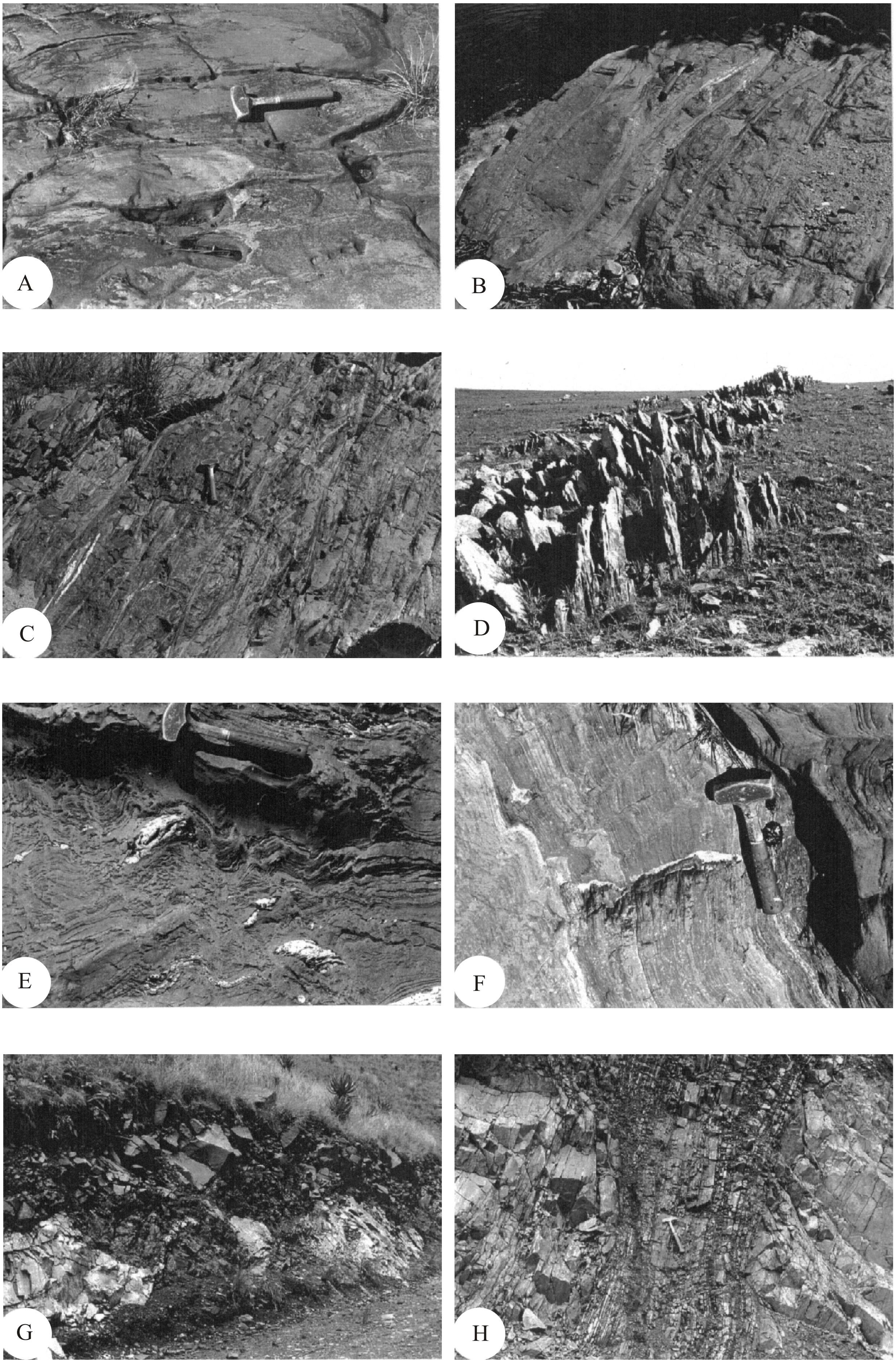
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Figure 16:

A. Elliptical pillow structures in komatiitic basalts seen in a river section on the farm Stolzburg 710 JT (Fig.3, F 2). The flattened pillows have retained their bulbous shapes and well-defined glassy pillow selvages, and facing directions can still be discerned (top is above the hammer).

B. Flattened and sheared pillow structures in komatiitic basalts in a river section, west of (A) above, on the farm Doyershoek 702 JT (Fig.3, C 4). The pillows themselves are relatively undeformed internally, most of the strain having been partitioned into the pillow selvages and inter-pillow pelagic sediments.

C. Intensely flattened and sheared pillow lavas, west of (B) above (Fig.3, C 4), showing almost complete internal and external deformation of the pillows, and the development of progressive schistosity in lavas as the contact of the Nelshoogte Schist Belt with the adjacent Nelshoogte granitoid pluton is approached.

D. Nelshoogte Schist Belt close to the contact with the Nelshoogte pluton on the farm Rous 621 JT (Fig.3, D 2). The ultramafic layer, formerly a komatiite flow unit, alternates with less prominently exposed komatiitic basalt flow units that have been deformed and metamorphosed to various amphibolite schists (hornblende-actinolite±chlorite±garnet schists). Exposures of the type shown can be seen at many other localities along the granite-greenstone contact.

E. Chevron folds in amphibolite schists near the Nelshoogte pluton contact on the farm Sterkspruit 709 JT (Fig.3, A 6). It seems likely that the amphibolite schists were originally pillowed komatiitic basalts, as remnant blebs and irregular stringers of quartz and carbonate, reminiscent of inter-pillow material, occur throughout the exposure.

F. Crenulation folds (with fold axes producing a lineation) occurring in mafic schists exposed in a river section on the farm Doyershoek 702 JT (Fig.3, E 4).

G. Granitoid dyke, believed to be linked to an early stage in the emplacement history of the Nelshoogte pluton, intruded into amphibolite schists of the Nelshoogte Schist Belt on the farm Rous 621 JT (Fig.3, C 4). The dyke has, in turn, been deformed and now occurs as boudinaged lenses shown in the photograph.

H. Zone of banded ferruginous chert and slaty metasediment wedged between massive-to-schistose amphibolite (metamorphosed komatiitic basalt) on the farm Rous 621 JT (Fig.3, C 4). The metavolcanic and metasedimentary sequence at this locality displays differential flattening and the development of large-scale boudinage structures.

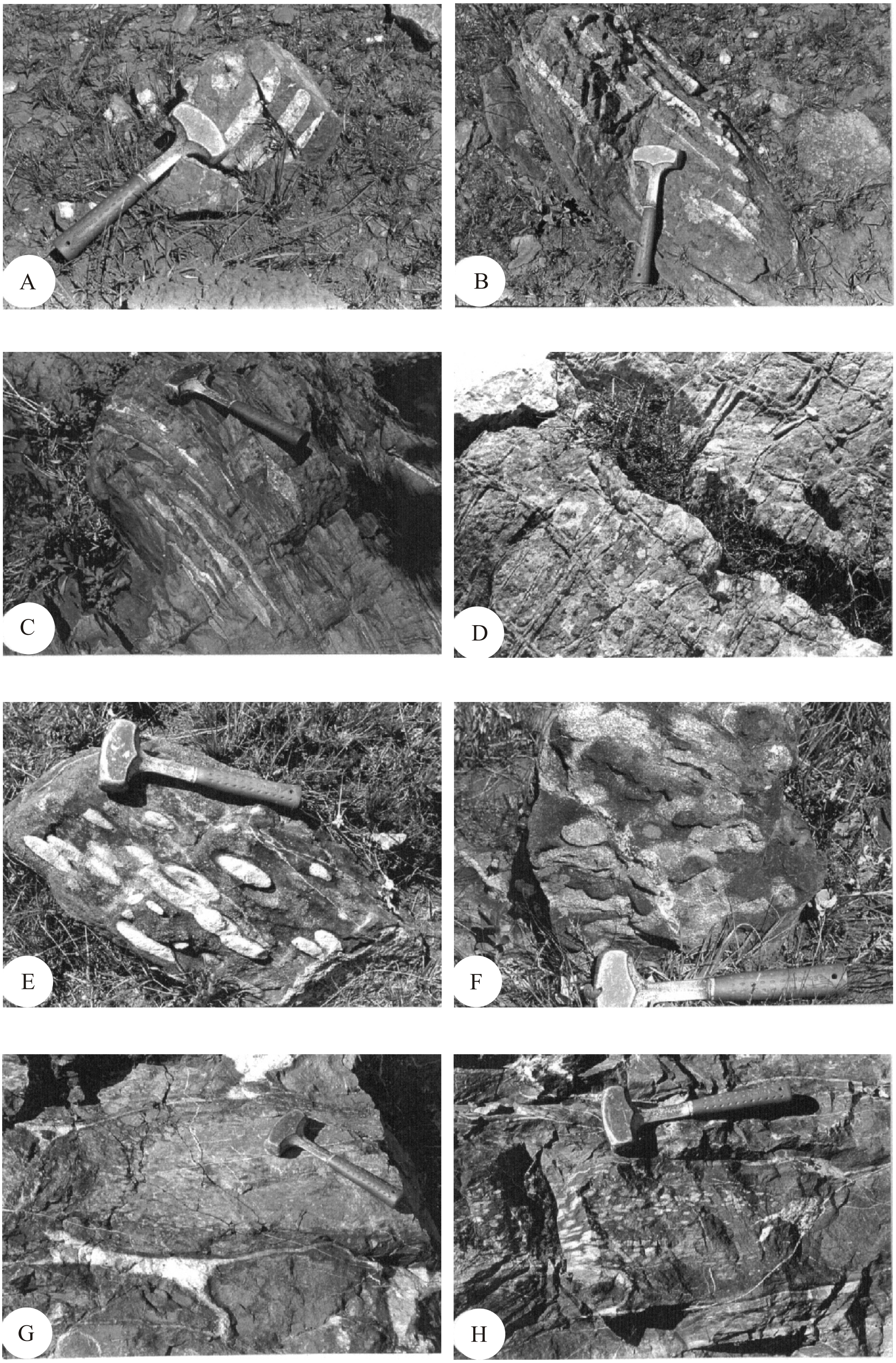
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Figure 17:

A. Drainage or withdrawal cavities filled with white vein quartz and carbonate in portion of a pillow structure. Withdrawal cavities of this type usually occur towards the tops of pillows and may provide reliable outcrop-scale stratigraphic orientations. The example shown has not experienced much flattening deformation and occurs on the farm Stolzburg 710 JT (Fig.3, C5 - near sample site S16).

B. Quartz and carbonate filling withdrawal cavities in deformed pillows in komatiitic basalts located approximately 500m from the Nelshoogte pluton contact on the farm Rous 621 JT (Fig. 3, C4). Most of the quartz-filled cavities occur above the hammer head indicating the direction of younging towards the top of the photograph (i.e., towards the southeast).

C. Exposure in the same general vicinity as (B) above showing more intense flattening of the volcanic succession. Pillow structures are barely recognizable, yet the deformed, quartz-filled withdrawal cavities have survived and assist with field identification.

D. Massive komatiitic basalt, displaying well-developed joints, occurring on the farm Groenvaly 701 JT (Fig.3, E2). The Goedehoop granitoid body, which intruded into the general area, does not appear to have been responsible for any flattening deformation of the rocks in the vicinity.

E. Large, flattened ocelli structures consisting of lighter-coloured felsic material hosted in hornblende amphibolite (metamorphosed komatiitic basalt) on the farm Groenvaly 701 JT (Fig.3, F2). Ferguson and Currie (1972) suggested the ocelli owed their origin to immiscibility of the komatiitic magma. The ocelli, which originally had spherical shapes, can be useful strain indicators.

F. Ocelli structures in metamorphosed komatiitic basalt from the same general area as (E) above. These felsic ocelli structures appear to have undergone some irregular diffusion into the adjacent mafic component of the lava.

G. Pillow structures in hornblende amphibolite (metamorphosed komatiitic basalt) seen along the Barberton-Badplaas main road, approximately 1km west of the Nelshoogte trigonometrical beacon (Fig. 3, E1). The inter-pillow material consists of white quartz while the centre of the pillow consists of ocelli largely nucleated together to form a more felsic core.

H. Hornblende amphibolite from the same locality as (G) above showing flattened ocelli hosted in deformed pillow structures. As can be seen in the photographs (E-H) the size of ocelli vary considerably from place to place. Cloete (1999) reported a range in size, in the Komati Formation type locality, from 0,5-10cm diameter to occasional examples of ocelli up to 15cm in diameter. Cloete (1999) and Viljoen and Viljoen (1969) also noted a close association of ocelli with pillow lavas.

ECONOMIC GEOLOGY

Historically, the most important mineralization in the Nelshoogte region has centred around the chrysotile asbestos deposits that were last mined in the early 1970s. Detailed descriptions of the mines and the nature and controls of the asbestos mineralization have been provided by Hall (1930), Van Biljon (1964), Viljoen and Viljoen (1969e), Groeneveld (1973) and the writer (Anhaeusser, 1976, 1986) and will not be repeated here.

A small gold occurrence (Sterkspruit Gold Mine) on the farm Sterkspruit 709 JT was described by Groeneveld (1973). The mineralization was claimed to be associated with banded chert-shale and banded chert of the Fig Tree Group. However, investigations by Philpot (1979) led him to conclude that Fig Tree rocks are not represented in the area and that the banded cherty sediments are probably westerly correlatives of the cherty sediments of the upper Onverwacht Group (Hooggenoeg Formation, Geluk Subgroup). The small deposit, mined in 1908 and 1909, is reported to have produced 285 ounces of gold and 71 ounces of silver at an average grade of 1.8g/t (Groeneveld, 1973).

A gossanous outcrop displaying copper carbonates (malachite and azurite) was discovered by the writer whilst mapping on the farm Stolzburg 710 JT (Fig. 3, centre of block D5). Subsequent investigations by African Selection Trust Exploration (Pty) Ltd., delineated a prospective zone of copper-nickel mineralization extending southwest and northeast of the gossan site, but no mining of the deposit was undertaken. Details of the geology and the nature of the Stolzburg copper/nickel occurrence are to be described elsewhere (C.R.Anhaeusser, in prep.). Minor showings of sulphide mineralization (pyrite, pyrrhotite, chalcopyrite) were also encountered in the gabbroic rocks of the Sterkspruit Intrusion, but do not appear to be of economic significance.

SUMMARY AND CONCLUSIONS

The foregoing account of the geology of the southwestern extremity of the Barberton greenstone belt, in particular the region occupied by the Nelshoogte Schist Belt and adjacent granitoid terrane, demonstrates that this sector of the Barberton greenstone belt is both lithologically and structurally multifaceted and complex. The following are the main features and conclusions drawn from the study:

(1) The Nelshoogte Schist Belt consists predominantly of massive and pillowed komatiitic basalts as well as mafic agglomerates and tuffs, subordinate komatiite interflow units and felsic tuffaceous schists. Minor sedimentary interlayers include banded chert, banded iron formation, banded metaquartzite and calc-silicate rocks;

(2) The Stolzburg Layered Ultramafic Complex, which occurs to the southeast of the Nelshoogte Schist Belt, has been subdivided into a Lower Division comprising cyclically layered dunite and orthopyroxenite units, and an Upper Division consisting of cyclically repetitive units containing various combinations of mafic and ultramafic rocks. These include harzburgite, wehrlite, lherzolite, websterite, gabbro, norite and minor anorthositic gabbro and anorthosite. A zone of calcium metasomatised rocks consisting of rodingites, pyroxene-plagioclase rocks and garnetised gabbros separates the Upper and Lower Divisions;

(3) The rocks in the Nelshoogte Schist Belt and Stolzburg Complex have all been subjected to variable degrees of metamorphic and metasomatic alteration. The highest metamorphic grades are encountered near the contacts with the Nelshoogte and Goedehoop granitoids. Hornblende-bearing amphibolites near the contacts give way progressively to greenschist-

grade actinolite-tremolite-chlorite rocks over most of the remainder of the region. The ultramafic rocks, both in the schist belt and in the Stolzburg Complex (komatiites, dunites, harzburgites, orthopyroxenites), have been extensively serpentinized and/or steatized. Rodingites, which separate the Lower from the Upper Division in the Stolzburg Complex, have resulted from Ca-metasomatism, the calcium having been derived from the alteration of diopside-rich clinopyroxenites and plagioclases (labradorite, bytownite, anorthite) in the gabbros, norites and gabbroic anorthosites;

(4) The mafic and ultramafic successions in the Barberton greenstone belt (including those in the Nelshoogte Schist Belt and Stolzburg Complex) have been likened to a pseudostratigraphy comparable to that of Phanerozoic ophiolites (De Wit and Stern, 1980; De Wit et al., 1987; De Wit and Tredoux, 1988; De Wit and Hart, 1993). Apart from the aforementioned citations only a few additional reports in support of Archaean or early Proterozoic ophiolites have been forthcoming (e.g., Helmstaedt and Padgham, 1986; Helmstaedt et al., 1986; Kontinen, 1987; Kusky, 1991; Helmstaedt and Scott, 1992; Fripp and Jones, 1997). The presence of ophiolites in Archaean greenstone belts worldwide has proved to be controversial and has not received widespread acceptance. Bickle et al. (1995), in reviewing the geology of a number of purported Archean ophiolites, concluded "on the basis of basal unconformities, presence of xenocryst zircons, geochemical and isotopic evidence for crustal contamination, intrusive relationships with older basement and their internal stratigraphy, that none of these examples is derived from Archean oceanic crust". Hamilton (1998) fully supported these views claiming that "the distinctive array of petrologic, structural and stratigraphic features that characterize Phanerozoic convergent-plate systems ophiolites, magmatic arcs, accretionary wedges, fore-arc basins, etc. have no viable analogues in Archean terrains".

(5) The interpretation by De Wit et al.(1987) of a vertically rotated volcanic sequence as a right-way-up sheeted dyke complex in the Onverwacht type locality as well as in the Nelshoogte-Stolzburg region has not found support from past as well as recent investigations in these areas (Viljoen et al., 1983; Cloete,1991,1999; Dann, 2000; this study). Furthermore, the introduction and use of the term 'Jamestown Ophiolite Complex' by De Wit et al. (1987) and some subsequent workers, appears to have been ill-advised for what have clearly been shown to be volcanic sequences.

(6) Nowhere in the Barberton greenstone belt can unequivocal sheeted dykes be identified and hence a mid-oceanic ridge (MOR) origin is regarded as untenable. Cloete (1999) provided a comprehensive summary of the characteristic volcanological features associated with the Onverwacht succession in the type locality and concluded that an oceanic origin for the komatiitic sequences remained a viable option, but favoured a plume-related oceanic plateau geotectonic setting. By implication an oceanic setting renders support for Archaean plate-tectonics to have been operative as far back as *c.*3500 Ma. Lowe (1999) was also of the opinion that theoretical and actualistic models surrounding the nature of Archaean geodynamics point strongly to an Archaean tectonic regime not fundamentally different from that of today. The debate continues - solutions to the ongoing controversy will have to await further advances in our understanding of the temporal, geochemical and lithological characteristics of Archaean greenstone terranes in general and the Barberton Supergroup in particular.

(7) The structural evolution of the Nelshoogte Schist Belt has largely been controlled by the emplacement of the Kaap Valley and Nelshoogte tonalite-trondhjemite gneiss plutons, which were intruded approximetely 3227-3236 Ma ago (deformation stage D_2). Depending upon the interpretation placed on the stratigraphic position of the rocks in the Nelshoogte Schist Belt the area may have been subjected to earlier tectonism (deformation stage D_1),

the latter seen as being responsible for the formation of the large amplitude folds and associated faults which are prevalent throughout the Barberton greenstone belt;

(8) The granitoid plutons abutting the Nelshoogte Schist Belt are regarded as having been emplaced as diapiric bodies, the latter forcing the volcano-sedimentary successions into a triangular-shaped structure (plan view) with synformal fold axes plunging towards the core of the infolded sequences, thereby producing a funnel-shaped structure. The Goedehoop granitoid body (an anatectic melt product derived from the partial melting of metabasalts ?) was subsequently intruded into the core of this funnel structure resulting in some localized structural disruption;

(9) The Stolzburg Complex appears to be sandwiched on either side by major faults that appear to merge, in a northeasterly direction, with prominent regional faults that occur in the southwestern and central parts of the Barberton greenstone belt. A number of cross faults displace the layering of the Complex. In places (e.g., Stolzburg Mine area) the faulting is accompanied by folding of some of the more competent layers (mainly the orthopyroxenites). These structurally disturbed areas provided ideal conditions for chrysotile asbestos fibre development in the adjacent serpentinized dunites. Three mines (Sterkspruit, Stolzburg, Doyershoek) were significant producers of asbestos prior to the 1970s when mining in the area ceased;

(10) The Stolzburg Complex appears, from field and petrological evidence, to young from northwest to southeast (i.e., from the dunite-orthopyroxenite basal layers in the Lower Division, upwards into the harzburgite-clinopyroxenite-gabbro layers in the Upper Division). Suggestions that the layers form fold closures in the northeast and southwest could not be confirmed in this study and conflict with the consistent (NW-SE) younging direction mentioned above;

(11) The age of the rocks of the Nelshoogte Schist Belt remains enigmatic. All that can be stated in this regard is that the mafic-ultramafic assemblages pre-date the surrounding granitoid plutons, which have yielded ages of *c*. 3230Ma. In the past the lithological, petrological and geochemical similarity of the Nelshoogte komatiites and basaltic komatiites with those of the Onverwacht type locality 15 km to the east, led to them being correlated with these 3470 Ma rocks. However, Lowe and Byerly (1999) have recently proposed a new formation (Weltevreden Formation), which they claim to have identified in the area southwest of the town of Barberton. This succession is considered similar in many respects to another newly defined stratigraphic unit at the top of the Onverwacht Group in the type locality (Mendon Formation - Byerly, 1999). Lowe and Byerly (1999, fig. 1), furthermore, include the mafic and ultramafic rocks of the Nelshoogte Schist Belt with those of the Weltevreden Formation, thereby suggesting that this succession is younger than that of the komatiitic assemblage in the Onverwacht type locality;

(12) The granitoid rocks intruding the Nelshoogte Schist Belt constitute a TTG suite that includes hornblende-tonalite gneiss (Kaap Valley pluton), biotite-trondhjemite gneiss and leuco-trondhjemite dykes and veins (Nelshoogte pluton) and hornblende tonalite and/or diorite (Goedehoop pluton). Although the Nelshoogte pluton has been ascribed an age of 3236±1 Ma (De Ronde and Kamo, 2000) field evidence demonstrates that the granitoid body has had a multi-phase history involving syn- and post- emplacement intrusion of granitoid dykes. The age of emplacement of the Goedehoop body remains to be determined, but probably occurred shortly after the collapse of the schist belt into the present-day funnel-shaped structure. The eastern margin of the Nelshoogte pluton has also been subjected to post-emplacement shearing and the development of augen gneisses;

(13) A variety of mafic dykes and sill-like intrusions occur in the study area, including the Sterkspruit gabbro body, which shows subvertical layering in places, suggesting that this body may have been emplaced and rotated late in the deformation history of the Nelshoogte Schist Belt. The Sterkspruit gabbro body (of tholeiitic magma parentage) also appears to be unrelated to the adjacent Stolzburg Complex, which has a komatiitic bulk composition. Mafic dykes and sheets occur prominently in the Nelshoogte pluton and adjacent schist belt. The dykes have a preferred NW-SE trend, orthogonal to the regional NE-SW strike of the Barberton greenstone belt. Most of the dykes are diabases displaying varying degrees of deuteric alteration. Some dykes are siliceous, having been contaminated by inclusions of granitic country rock. Recent whole rock $^{40}Ar/^{39}Ar$ ages of *c.*1876 1902 Ma have been recorded by Layer et al. (1998) for dykes cross-cutting the Nelshoogte pluton. However, relationships with supracrustal rocks along the Transvaal Drakensberg Escarpment in the west suggest that some of the dykes in the region may be older (i.e., pre-Bushveld in age) or even as old as 2700-3000 Ma (Hunter and Halls, 1992); and

(14) Economic mineralization in the southwestern part of the Barberton greenstone belt has, in the past, been confined to chrysotile asbestos, which was mined at the Sterkspruit, Stolzburg and Doyershoek mines in the Stolzburg Complex. Gold was exploited on a small scale at the Sterkspruit Gold Mine (not linked to the Sterkspruit asbestos mine). Cu-Ni mineralization associated with komatiite flows was identified from surface gossans. Subsequent drilling intersected sulphide mineralization, which was deemed to be uneconomic. Chromitite, magnetite and minor opal were noted in the Stolzburg Complex and some disseminated sulphide mineralization was observed in the Sterkspruit gabbro intrusion. Potential may also exist for platinum group mineralization in the Barberton layered ultramafic complexes. To date no exploration for these minerals has been attempted in the region.

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REFERENCES

Anhaeusser, C. R. (1969). The stratigraphy, structure and gold mineralization of the Jamestown and Sheba Hills area of the Barberton Mountain Land. Ph.D thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 322pp.

Anhaeusser, C. R. (1972a). The Stolzburg differentiated ultramafic body, Barberton Mountain Land. 13^{th} Ann. Rep. for 1971, Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, p. 9.

Anhaeusser, C. R. (1972b). The geology of the Jamestown Hills area of the Barberton Mountain Land, South Africa. Trans. Geol. Soc. S. Afr., **75** (3), 225- 263.

Anhaeusser, C. R. (1976). The nature of chrysotile asbestos occurrences in southern Africa: a review. Econ. Geol., **71**, 96-116.

Anhaeusser, C. R. (1979). Rodingite occurrences in some Archaean ultramafic complexes in the Barberton Mountain Land, South Africa. Precambrian Res., **8**, 49-76.

Anhaeusser, C. R. (1982). *A contribution to the Archaean geology of southern Africa with particular reference to aspects involving metallogeny, granite-greenstone belt development and crustal evolution.* D.Sc thesis (unpubl.), Univ. Witwatersrand, Johannesburg (2 volumes).

Anhaeusser, C. R. (1983). Geology of the Schapenburg greenstone remnant and surrounding Archaean granitic terrane south of Badplaas, Eastern Transvaal. Spec. Publ. Geol. Soc. S. Afr., **9**, 31- 44.

Anhaeusser, C. R. (1984). Structural elements of Archaean granite-greenstone terranes as exemplified by the Barberton Mountain Land, South Africa, 57-78. *In*: Kröner, A. and Greiling, R. (eds.), *Precambrian Tectonics Illustrated.* E. Schweizerbart'sche Verlagsbuchhandlung (Nägele u Obermiller), Stuttgart, 419pp.

Anhaeusser, C. R. (1985). Archaean layered complexes in the Barberton Mountain Land, South Africa, 281-301. *In*: Ayres, L. D., Thurston, P. C., Card, K. D. and Weber, W. (eds.), *Evolution of Archean Supracrustal Sequences.* Spec. Paper, Geol. Assoc. Canada, **28**, 380pp.

Anhaeusser, C. R. (1986). The geological setting of chrysotile asbestos occurrences in southern Africa, 359-376. *In*: Anhaeusser, C. R. and Maske, S. (eds.), *Mineral Deposits of Southern Africa,* **I**. Geol. Soc. S. Afr., 1020pp.

Anhaeusser, C.R. and Robb, L.J. (1980). Regional and detailed field and geochemical studies of Archaean trondhjemite gneisses, migmatites and greenstone xenoliths in the southern part of the Barberton Mountain Land, South Africa. Precambrian Res., **11**, 373-397.

Anhaeusser, C. R. and Robb, L. J. (1981). Magmatic cycles and the evolution of the Archaean granitic crust in the Eastern Transvaal and Swaziland. Spec. Publ. Geol. Soc. Aust., **7**, 457-467.

Anhaeusser, C. R. and Viljoen, M. J. (1965). The base of the Swaziland System in the Barberton-Noordkaap-Louw's Creek area, Barberton Mountain Land. Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, **25**, 32pp.

Anhaeusser, C. R., Robb, L. J. and Viljoen, M. J. (1981). Provisional geological map of the Barberton greenstone belt and surrounding granitic terrane, eastern Transvaal and Swaziland. Geological Society of South Africa, scale 1:250 000.

Anhaeusser, C. R., Viljoen, M. J. and Viljoen, R. P. (1966). A correlation of pre-Fig Tree rocks in the northern and southern parts of the Barberton Mountain Land. Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, **31**, 22pp.

Anonymous (1972). Ophiolites. Geotimes, **17**, 24-25.

Armstrong, R. A., Compston, W., De Wit, M.J. and Williams, I. S. (1990). The stratigraphy of the 3.5-3.2 Ga Barberton greenstone belt revisited: a single zircon ion microprobe study. Earth Planet. Sci Lett., **101**, 90-106.

Bailie, R. H. (1995). *Variations in chemistry and petrology of the Swartrant Dyke, Barberton Mountainland.* B.Sc Hons. Project (unpubl.), Dept. Geology, Univ. Witwatersrand, Johannesburg, 98pp.

Barker, F. (1979). Trondhjemite: definition, environment and hypotheses of origin, 1-12. *In:* Barker, F. (ed.), *Trondhjemites, Dacites, and Related Rocks.* Developments in Petrology 6, Elsevier, Amsterdam, 659pp.

Barnes, S. J., Hill, R. E. T. and Gole, M. J. (1988). The Perseverence Ultramafic Complex, Western Australia: the product of a komatiite lava river. J. Petrol., **29** (2), 305-331.

Barton, J. M. Jr., Robb, L. J., Anhaeusser, C.R. and Van Nierop, D. A. (1983). Geochronologic and Sr-isotopic studies of certain units in the Barberton granite-greenstone terrane, South Africa. Spec. Publ. Geol. Soc. S. Afr., **9**, 63-72.

Bickle, M. J., Nisbet, E. G. and Martin, A. (1995). Archaean greenstone belts are not oceanic crust. J. Geol., **102**, 121-138.

Byerly, G. R. (1999). Komatiites of the Mendon Formation: late-stage ultramafic volcanism in the Barberton greenstone belt, 189-211. *In*: Lowe, D. R. and Byerly, G.R. (eds.), *Geologic Evolution of the Barberton Greenstone Belt, South Africa.* Spec. Paper Geol. Soc. Amer., **329**, 319pp.

Byerly, G. R., Kröner, A., Lowe, D. R., Todt, W. and Walsh, M. M. (1996). Prolonged magmatism and time constraints for sediment deposition in the early Archean Barberton greenstone belt: evidence from the upper Onverwacht and Fig Tree Groups. Precambrian Res., **78**, 125-138.

Cloete, T. (1991). Structure and metamorphism of the Komati Formation at Spinifex Stream and Hooggenoeg Formation in the Songimvelo Game Reserve, 123-133. *In*: Ashwal, L. D. (ed.), *Two Cratons and an Orogen Excursion Guidebook and Review Articles for a Field Workshop through Selected Archaean Terranes of Swaziland, South Africa and Zimbabwe.* IGCP Project 280, Dept. Geology, Univ. Witwatersrand, Johannesburg, 312pp.

Cloete, M. (1999). Aspects of volcanism and metamorphism of the Onverwacht Group lavas in the southwestern portion of the Barberton greenstone belt. Mem. Geol. Surv. S. Afr., **84**, 232pp.

Conway, G. P. (1997). *The geology and geochemistry of the Sterkspruit intrusion, Barberton Mountain Land, Mpumalanga Province.* M.Sc thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 164pp.

Cox, K. G., Bell, J.D. and Pankhurst, R. J. (1980). *The Interpretation of Igneous Rocks.* George Allen & Unwin, London, 450pp.

Dann, J. C. (2000). The 3.5 Ga Komati Formation, Barberton greenstone belt, South Africa, Part I: new maps and magmatic architecture. S. Afr. J. Geol., **103** (1), 47-68.

De Ronde, C.E.J. and De Wit, M.J. (1994). Tectonic history of the Barberton greenstone belt, South Africa: 490 million years ofArchean crustal evolution. Tectonics, **13** (4), 983-1005.

De Ronde, C.E.J. and Kamo, S. (2000). An Archaean arc-arc collisional event: a short-lived (*ca 3 Myr*) episode, Weltevreden area, Barberton greenstone belt, South Africa. J. Afr. Earth Sci., **30** (2), 219-248.

De Wit, M. J. (1983). Notes on a preliminary 1:25 000 geological map of the southern part of the Barberton greenstone belt, 185-187. *In*: Anhaeusser, C. R. (ed.), *Contributions to the Geology of the Barberton Mountain Land*. Spec. Publ Geol. Soc. S. Afr., **9**, 223pp.

De Wit, M.J. (1986). Extensional tectonics during the igneous emplacement of the mafic-ultramafic rocks of the Barberton greenstone belt (Abstract). *In*: De Wit, M. J. and Ashwal, L.D. (eds.), *Workshop on Tectonic Evolution of Greenstone Belts*. Lunar Planetary Institute, Houston, Texas. Lunar Planet. Inst, Tech. Rep., **86-10**, 84-85.

De Wit, M. J. (1991). Archaean greenstone belt tectonism and basin development: some insights from the Barberton and Pietersburg greenstone belts, Kaapvaal Craton, South Africa. J. Afr. Earth Sci., **13** (1), 45-63.

De Wit, M. J. and Hart, R.A. (1993). Earth's earliest continental lithosphere, hydrothermal flux and crustal recycling. Lithos, **30**, 309-335.

De Wit, M. J. and Stern, C. R. (1980). A 3500 Ma ophiolite complex from the Barberton greenstone belt. South Africa: Archaean oceanic crust and its geotectonic implications. Abstr. 2[nd] Int. Archaean Symp., Perth, 85-87.

De Wit, M. J. and Tredoux, M. (1988). PGE in the 3.5 Ga Jamestown Ophiolite Complex, Barberton greenstone belt, with implications for PGE distribution in simatic lithosphere, 319-342. *In*: Pritchard, H. M., Potts, P. J., Bowels, J. F.W. and Cribb, S. J. (eds.), *Geoplat 1987*. Elsevier Applied Science, London, 420pp.

De Wit, M. J., Hart, R. A. and Hart, R. J. (1987). The Jamestown Ophiolite Complex, Barberton Mountain Land: a section through 3.5 Ga oceanic crust. J. Afr. Earth Sci., **6** (5), 681-730.

Dziggel, A., Stevens, G., Poujol, M., Anhaeusser, C. R. and Armstrong, R.A. (2001). Metamorphism of the granite-greenstone terrane south of the Barberton greenstone belt, South Africa: an insight into the tectono-thermal evolution of the lower portions of the Onverwacht Group. Inform. Circ. Econ . Geol. Res. Inst., Univ. Witwatersrand, Johannesburg, **352**, 35pp.

Ferguson, J. and Currie, K. L. (1972). Silicate immiscibility in the ancient “basalts” of the Barberton Mountain Land, Transvaal. Nature, **235**, 86-89.

Fripp, R. E. P. and Jones, M. G. (1997). Sheeted intrusions and peridotite-gabbro assemblages in the Yilgarn Craton, Western Australia: elements of Archaean ophiolites, 422-437. *In*: De Wit, M. J. and Ashwal, L. D. (eds.), *Greenstone Belts*.Clarendon Press, Oxford, 809pp.

Glikson, A.Y. (1976). Trace element geochemistry and origin of early Precambrian acid igneous series, Barberton Mountain Land, Transvaal. Geochim. Cosmochim. Acta, **40**, 1261-1280.

Groeneveld, D. et al. (Compiler) (1973). The economic mineral deposits in the Archaean complex of the Barberton area. Unpubl. Rep. Geol. Surv. S. Afr., 353pp.

Hall, A.L. (1917). The dyke system of the Kaap and Komati river valleys. Trans. Geol. Soc. S. Afr., **20**, 37-47.

Hall, A. L. (1918). The geology of the Barberton gold mining district. Mem. Geol. Surv. S. Afr., **9**, 347pp.

Hall, A. L. (1930). Asbestos in the Union of South Africa. Mem. Geol. Surv. S. Afr., **12**, 324pp.

Hamilton, W. B. (1998). Archean magmatism and deformation were not products of plate tectonics. Precambrian Res., **91**,143-179.

Helmstaedt, H. and Padgham, W. A. (1986). A new look at the stratigraphy of the Yellowknife Supergroup at Yellowknife, N.W.T. implications for the age of gold-bearing shear zones and Archean basin evolution. Can. J. Earth Sci., **23**, 454-475.

Helmstaedt, H. and Scott, D. J. (1992). The Proterozoic ophiolite problem, 55-95. *In*: Condie, K. C. (ed.). *Proterozoic Crustal Evolution*. Elsevier, Amsterdam, 537pp.

Helmstaedt, H., Padgham, W. A. and Brophy, J. A. (1986). Multiple dikes in lower Kam Group, Yellowknife greenstone belt: evidence for Archean sea-floor spreading? Geology, **14**, 562-566.

Hill, R.E.T., Gole, M. J. and Barnes, S. J. (1989). Olivine adcumulates in the Norseman-Wiluna greenstone belt Western Australia: implications for the volcanology of komatiites. *In*: Prendergast, M.D. and Jones, M. J. (eds.), *Magmatic Sulphides - the Zimbabwe Volume*. Inst. Min. Metall., London, pp. 189-206.

Hill, R.E.T., Barnes, S. J., Gole, M. J. and Dowling, S. E. (1995). The volcanology of komatiites as deduced from field relationships in the Norseman-Wiluna greenstone belt, Western Australia. Lithos, **34**, 159-188.

Hunter, D. R. and Halls, H. C. (1992). A geochemical study of a Precambrian mafic dyke swarm, Eastern Transvaal, South Africa. J. Afr. Earth Sci., **15** (2),153-168.

Hunter, R. H. (1996). Texture development in cumulate rocks, 77- 101. *In*: Cawthorn, R. G. (ed.), *Layered Intrusions.* Developments in Petrology 15, Elsevier, Amsterdam, 531pp.

Irvine, T.N. (1970). Crystallization sequences in the Muskox Intrusion and other layered intrusions: 1. Olivine-pyroxene-plagioclase relations, 441-476. *In*: Visser, D. J. L. and Von Gruenewaldt, G. (eds.), *Symposium on the Bushveld Igneous Complex and other Layered Intrusions.* Spec. Publ. Geol. Soc. S. Afr., **1**, 763pp.

Kamo, S. L. and Davis, D. W. (1994). Reassessment of Archean crustal development in the Barberton Mountain Land, South Africa based on U-Pb dating. Tectonics, **13** (1), 167-192.

Kober, B. (1986). Whole-grain evaporation for ^{207}Pb/^{206}Pb-age investigations on single zircons using a double filament thermal ion source. Contrib. Mineral. Petrol., **93**, 482-490.

Kober, B. (1987). Single zircon evaporation combined with Pb+ emitter-bedding for ^{207}Pb/^{206}Pb-age investigations using thermal ion mass spectrometry and implications to zirconology. Contrib. Mineral. Petrol., **96**, 63-71.

Kontinen, A. (1987). An early Proterozoic ophiolite - the Jormua Mafic-Ultramafic Complex, northeastern Finland. Precambrian Res., **35**, 313-341.

Kröner, A., Byerly, G. R. and Lowe, D. R. (1991). Chronology of early Archaean granite-greenstone evolution in the Barberton Mountain Land, South Africa, based on precise dating by single zircon evaporation. Earth Planet. Sci. Lett., **103**, 41-54.

Kröner, A., Hegner, E., Wendt, J. I. and Byerly, G. R. (1996). The oldest part of the Barberton granitoid-greenstone terrain, South Africa: evidence for crust formation between 3.5 and 3.7 Ga. Precambrian Res., **78**, 105-124.

Kusky, T.M. (1991). Structural development of an Archean orogen, western Point Lake, Northwest Territories. Tectonics, **10**, 820-841.

Lanier, W.P. and Lowe, D. R. (1982). Sedimentology of the Middle Marker (3.4 Ga), Onverwacht Group, Transvaal, South Africa. Precambrian Res., 18, 237-260.

Layer, P. W., López-Martínez, M., Kröner, A., York, D. and McWilliams, M. (1998). Thermochronometry and palaeomagnetism of the Archaean Nelshoogte Pluton, South Africa. Geophys. J. Int., **135**, 129-145.

Lowe, D. R. (1994). Accretionary history of the Archean Barberton greenstone belt (3.55-3.22 Ga), southern Africa. Geology, **22**, 1099-1102.

Lowe, D.R. (1999). Geologic evolution of the Barberton greenstone belt and vicinity, 287-312. *In*: Lowe, D. R. and Byerly, G.R. (eds.), *Geologic Evolution of the Barberton Greenstone Belt, South Africa.* Spec. Paper Geol. Soc. Amer., **329**, 319pp.

Lowe, D.R. and Byerly, G.R. (1999). Stratigraphy of the west-central part of the Barberton greenstone belt, South Africa, 1-36. *In*: Lowe, D. R. and Byerly, G.R. (eds.), *Geologic Evolution of the Barberton Greenstone Belt, South Africa.* Spec. Paper Geol. Soc. Amer., **329**, 319pp.

Lowe, D.R., Byerly, G.R. and Heubeck, C. (1999). Structural divisions and development of the west-central part of the Barberton greenstone belt, 37-82. *In*: Lowe, D.R. and Byerly, G.R. (eds.), *Geologic Evolution of the Barberton Greenstone Belt, South Africa.* Spec. Paper Geol. Soc. Amer., **329**, 319pp.

Menell, R. P., Brewer, T. H., Delve, J. R. and Anhaeusser, C. R. (1986). The Kalkkloof chrysotile asbestos deposit and surrounding area, Barberton Mountain Land, 427-435. *In*: Anhaeusser, C. R. and Maske, S. (eds.), *Mineral Deposits of Southern Africa, **I***. Geol. Soc. S. Afr., 1020pp.

Naldrett, A. J. and Mason, G. D. (1968). Contrasting Archean ultramafic igneous bodies in Dundonald and Clergue Townships, Ontario. Can. J. Earth Sci., **5**, 111-143.

Naslund, H.R. and McBirney, A.R. (1996). Mechanisms of formation of igneous layering, 1-43. *In*: Cawthorn, R. G. (ed.), *Layered Intrusions.* Developments in Petrology 15, Elsevier, Amsterdam, 531pp.

Oosthuyzen, E. J. (1970). *The geochronology of a suite of rocks from the granitic terrain surrounding the Barberton Mountain Land.* Ph.D thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 94pp.

Philpot, H. G. (1979). *The geology of a portion of the Stoltzburg schist belt, Barberton Mountain Land, Eastern Transvaal.* B.Sc Hons. Project (unpubl.), Dept. Geology, Univ. Witwatersrand, Johannesburg, 44pp.

Pospisek, P. (1991). *A geochemical study of the Sterkspruit Gabbro, Eastern Transvaal.* B.Sc Hons. Project (unpubl.), Dept. Geology, Univ. Witwatersrand, Johannesburg, 74pp.

Reimer, T. O. (1967). *Die Geologie der Stolzburg Synclinale im Barberton Bergland (Transvaal-Südafrika).* Diplom-Arbeit thesis (unpubl.), J.W. Goethe Univ. Frankfurt/Main, 112pp.

Robb, L. J. (1981). *The geological and geochemical evolution of tonalite-trondhjemite gneisses and migmatites in the Barberton region, eastern Transvaal.* Ph.D thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 342pp.

Robb, L. J., Barton, J.M. Jr., Kable, E. J. D. and Wallace, R.C. (1986). Geology, geochemistry and isotopic characteristics of the Archaean Kaap Valley pluton, Barberton Mountain Land, South Africa. Precambrian Res., **31**, 1-36.

Rodel, J. E. (1993). *The petrography and geochemistry of the Stolzburg and Rosentuin layered ultramafic complexes, Barberton Mountain Land, Eastern Transvaal.* M.Sc thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 232pp.

SACS (South African Committee for Stratigraphy) (1981). Stratigraphy of South Africa: Part I: Lithostratigraphy of the Republic of South Africa, South West Africa/Namibia and the Republics of Bophuthatswana, Transkei and Venda. Handbook, Geol. Surv. S. Afr., **8**, 690pp.

Smith, H.S. (1980). *Aspects of the geochemistry of the Onverwacht Group lavas from the Barberton greenstone belt.* Ph.D thesis (unpubl.), Univ. Cape Town, 233pp.

Smith, H.S. and Erlank, A. J. (1982). Geochemistry and petrogenesis of komatiites from the Barberton greenstone belt, South Africa, 347-397. *In*: Arndt, N. T. and Nisbet, E. G. (eds.) *Komatiites*, George Allen & Unwin, London, 526pp.

Tegtmeyer, A. R. and Kröner, A. (1987). U-Pb zircon ages bearing on the nature of early Archaean greenstone belt evolution, Barberton Mountain Land, southern Africa. Precambrian Res., **36** (1), 1-20.

Van der Heyde, H. A. (1985). *A geochemical study of some volcanic and related rocks from the Barberton greenstone belt.* M.Sc thesis (unpubl.), Univ. Cape Town, 178pp.

Van Biljon, W. J. (1964). The chrysotile deposits of the Eastern Transvaal and Swaziland, 625-669. *In*: Haughton, S. H. (ed.), *The Geology of Some Ore Deposits in Southern Africa, **I***. Geol. Soc. S. Afr., 739pp.

Viljoen, M. J. and Viljoen, R. P. (1967). A reassessment of the Onverwacht Series in the Komati River Valley. Inform. Circ. Econ. Geol. Res. Unit, Univ. Witwatersrand, Johannesburg, 36, 35pp.

Viljoen, M. J. and Viljoen, R. P. (1969a). Evidence for the existence of a mobile extrusive peridotitic magma from the Komati Formation of the Onverwacht Group. Spec. Publ. Geol. Soc. S. Afr., **2**, 87-112.

Viljoen, M. J. and Viljoen, R. P. (1969b). The geology and geochemistry of the Lower Ultramafic Unit of the Onverwacht Group and a proposed new class of igneous rocks. Spec. Publ. Geol. Soc. S. Afr., **2**, 55-85.

Viljoen, M. J. and Viljoen. R. P. (1969c). The geochemical evolution of the granitic rocks of the Barberton region. Spec. Publ. Geol. Soc. S. Afr., **2**. 189-219.

Viljoen, R. P. and Viljoen, M. J. (1969d). The relationship between mafic and ultramafic magma derived from the upper mantle and the ore deposits of the Barberton region. Spec. Publ. Geol. Soc. S. Afr., **2**, 221-244.

Viljoen, R. P. and Viljoen, M. J. (1970). The geology and geochemistry of the layered ultramafic bodies of the Kaapmuiden area, Barberton Mountain Land. Spec. Publ. Geol. Soc. S. Afr., **1**, 661-688.

Viljoen, M. J., Viljoen, R. P., Smith, H. S. and Erlank, A. J. (1983). Geological, textural, and geochemical features of komatiite flows from the Komati Formation. Spec. Publ. Geol. Soc. S. Afr., **9**, 1-20.

Visser, D. J. L. et al. (Compiler) (1956). The geology of the Barberton area. Spec. Publ. Geol. Surv. S. Afr., **15**, 253pp.

Wuth, M. (1980). *The geology and mineralization potential of the Oorschot Weltevreden schist belt, south-west of Barberton Eastern Transvaal.* M.Sc thesis (unpubl.), Univ. Witwatersrand, Johannesburg, 185pp.

York, D., Layer, P. W., López-Martínez, M. and Kröner, A. (1989). Thermal histories from the Barberton greenstone belt, southern Africa. Abstr. Int. Geol. Congress, Washington, D.C., p. 413.

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