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THE STRUCTURAL SIGNIFICANCE OF THE STEYNSDORP PLUTON AND ANTICLINE WITHIN THE TECTONO-MAGMATIC FRAMEWORK OF THE BARBERTON MOUNTAIN LAND, SOUTH AFRICA

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by

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ABSTRACT

The Steynsdorp anticline in the Barberton greenstone belt, South Africa, forms a prominent, upright, northerly trending fold structure developed in greenstone lithologies of the Onverwacht Group and is cored by tonalitic gneisses of the Steynsdorp pluton. Different fold geometries within the Steynsdorp anticline, superimposed strains, and the orientation and interference of linear and planar fabrics suggest the doming of an older, gneissic basement of the Steynsdorp pluton during regional WNW-ESE crustal shortening. The portrayal of an older gneissic core of the Steynsdorp pluton, which is conformably overlain by younger, metamorphic supracrustals, is in accord with the classical description of a mantled gneiss dome as defined by Eskola (1949). In view of the geometric and structural evidence provided in this paper it is suggested that the Steynsdorp pluton should in future be preferentially referred to as the Steynsdorp dome. The synkinematism between regional folding and local gneiss doming is interpreted to have played an important role in the localization of gold mineralization in the region known as the Steynsdorp Goldfield.

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INTRODUCTION

The Steynsdorp pluton is one of several discrete Archaean tonalite-trondhjemite-granodiorite (TTG) gneissic plutons which occur along the southern margin of the Barberton greenstone belt (Fig. 1). This pluton has, in recent years, featured prominently in the controversy concerning early crustal evolution in southern Africa, particularly in the light of high-precision single-zircon dating which enables the intricate tectono-magmatic histories of Archaean granite-greenstone terranes to be deciphered (e.g. Armstrong et al., 1990; Kröner et al., 1991; Kröner, 1993; Kamo and Davis, 1994). The pervasively developed gneissosity and compositional banding in the Steynsdorp pluton (Viljoen et al., 1969) contrasts markedly with the development of fabrics observed in other TTG's. In addition, single zircon ages of 3509 +8/-7 Ma reported by Kamo and Davis (1994) for the pluton, pre-date those of adjacent tonalitic and trondhjemitic plutons by 50-70 Ma, underscoring the unique position of the Steynsdorp pluton within the tectono-magmatic framework of the Barberton granite-greenstone terrane. It is thus surprising that no detailed mapping or structural investigation of the granitoid body and its surrounding greenstone cover has been undertaken since the pioneering work of Viljoen and Viljoen (1969) and Viljoen et al. (1969).

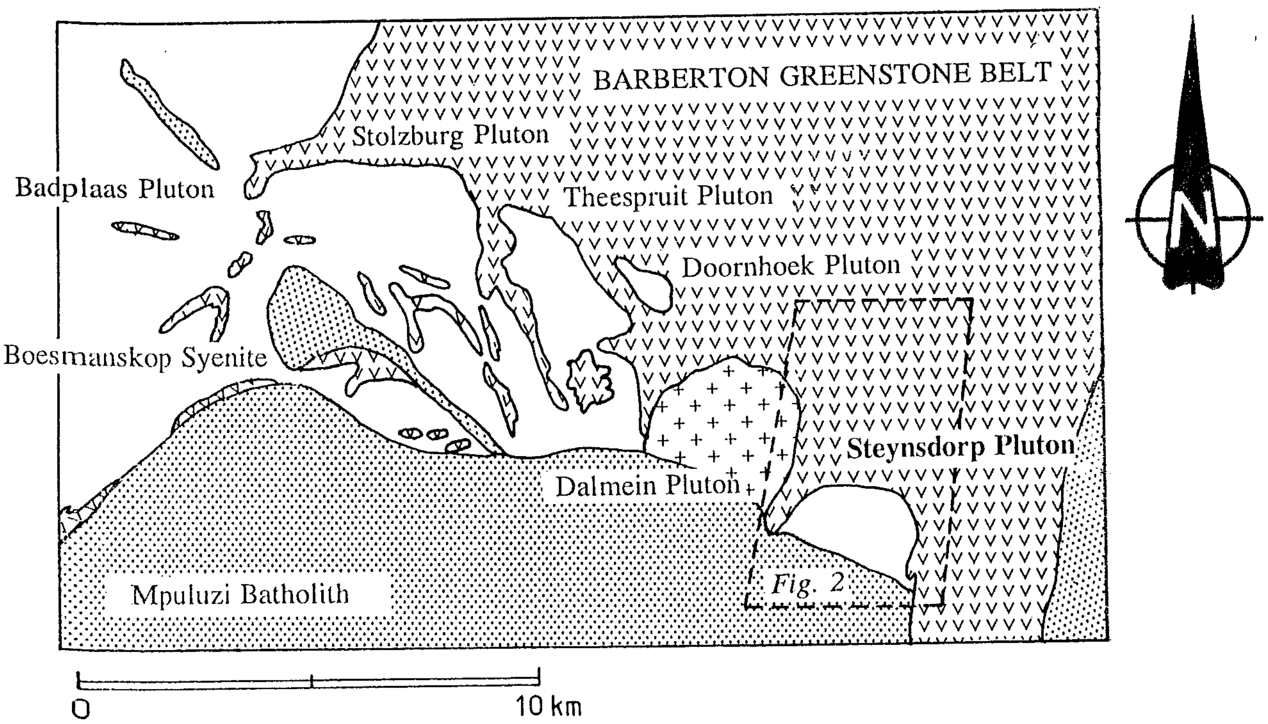


Figure 1: Simplified locality and geological map of the Barberton greenstone belt and adjacent granite-greenstone terrane along the southwestern margin (modified after Anhaeusser, 1981).

In this paper, the authors report the results of structural investigations of the Steynsdorp pluton and its enveloping greenstone cover, the latter comprising mainly mafic and ultramafic lithologies of the Onverwacht Group. Special emphasis is paid to fabric development and the structural and contact relationships between various units in order to illustrate the tectonic position of the Steynsdorp pluton with respect to the Barberton greenstone belt.

REGIONAL GEOLOGY

The Steynsdorp pluton forms part of the TTG suite that constitutes the granitoid gneisses of the granite-greenstone terrane along the southern margin of the Barberton greenstone belt (Fig. 1). The Badplaas, Stolzburg, Theespruit, and Doornhoek plutons are the most prominent amongst numerous other TTG's in the area (Anhaeusser and Robb, 1980; Anhaeusser, 1981; Robb and Anhaeusser, 1983), and yield consistent radiometric ages of 3440-3460 Ma (Armstrong et al., 1990). Younger granitic phases, dated by Kamo and Davis (1994), include the Dalmein pluton (3216 +2/-1 Ma), the Mpuluzi batholith (3107 +4/-2 Ma) and the Boesmanskop syenite pluton (3107 $\pm$ 2 Ma) all of which are intrusive into the TTG granitoids and gneisses (Anhaeusser and Robb, 1983a).

The Steynsdorp pluton occurs as a half-dome-shaped body which is enveloped to the north by greenstone units of the Onverwacht Group (Fig. 2). These greenstone lithologies have been folded into the northerly plunging and northerly trending, upright fold structure of the Steynsdorp anticline (Figs. 2 and 3) (Viljoen et al., 1969). Lithologies of the lower Onverwacht Group (Tjakstad Subgroup) include, in stratigraphic succession, the Sandspruit, Theespruit, and Komati Formations. The Sandspruit Formation comprises mainly ultramafic rocks such as metakomatiites and talc-carbonate schists and is only sporadically developed along the eastern flank of the Steynsdorp pluton (Fig. 2). The Theespruit Formation is characterized by aluminous quartz-sericite schists and subordinate cherty horizons interlayered with prominent metabasaltic (commonly amphibolitic) and minor ultramafic (talcose) units. The Komati Formation, in contrast, is dominated by mafic and ultramafic rocks, mainly massive or pillowed lavas of komatiitic or basaltic komatiitic composition. The rocks of the Komati Formation are pervasively altered, showing intense carbonatization and chloritization. Separated by the thin, but persistent cherty horizon of the Middle Marker, the Komati Formation is overlain by pillowed and massive basaltic (tholeiitic) lavas, interspersed with minor felsic volcanics and cherts of the Hooggenoeg Formation (lowermost unit of the upper Onverwacht Group or Geluk Subgroup). For a detailed lithological description of the various units within the Steynsdorp anticline, the reader is referred to Viljoen et al. (1969).

Single-zircon ages for felsic units of the Theespruit Formation vary considerably, ranging from 3547 $\pm$2 Ma, obtained from a pyroclastic unit in the Steynsdorp anticline (Kröner, 1993) and 3511 $\pm$3 Ma (Kröner et al., 1992) to 3453 $\pm$ 6 Ma (Armstrong et al., 1990). This wide spread of radiometric ages led to the interpretation of the Theespruit Formation being a tectonic melange (Lowe, 1991). The deposition of the mafic and ultramafic units of the Komati Formation has been bracketed between 3458 $\pm$ 2 Ma (Kamo and Davis, 1994) and 3472 $\pm$5 Ma (Armstrong et al., 1990) while the formation of the Hooggenoeg Formation is radiometrically constrained between 3445 $\pm$8 Ma (Armstrong et

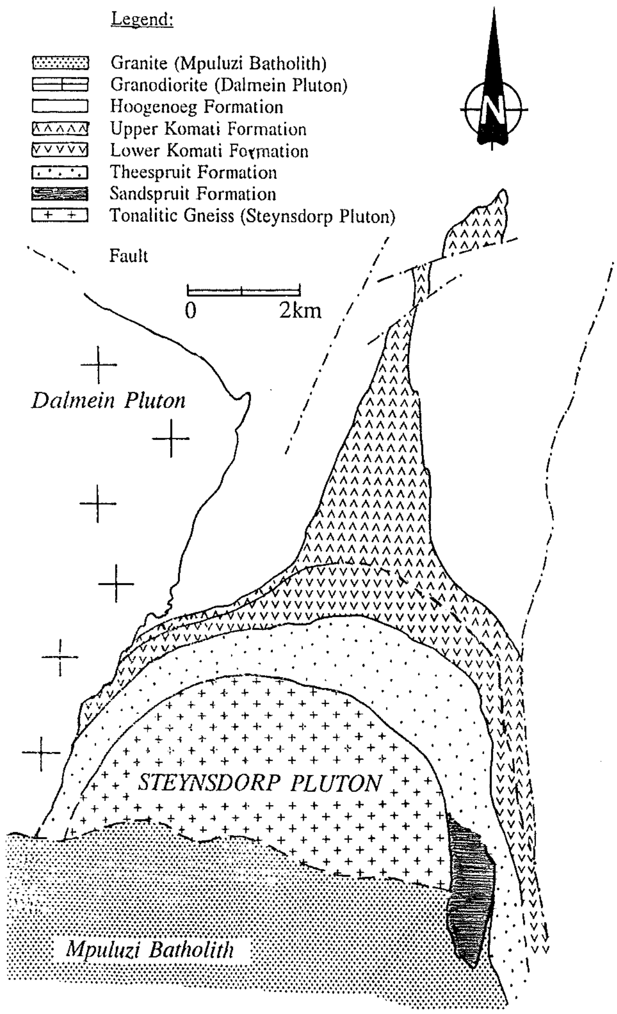


Figure 2: Schematic geological map of the Steynsdorp anticline (modified after Viljoen et al., 1969).

al., 1990) and 3416 ±5 Ma (Kröner et al., 1991). These ages suggest a normal stratigraphic succession in the Steynsdorp anticline without structural inversion as has been proposed for other areas along the southern part of the Barberton greenstone belt (De Wit, 1982; De Wit et al., 1983).

An early deformation phase consisting of recumbent, isoclinal folding and thrusting has been proposed by De Wit (1982) and De Wit et al. (1983) to be responsible for the structural repetition of parts of the greenstone sequence. The regional structural grain of the Barberton greenstone belt and the Steynsdorp area is, however, dominated by northeasterly to northerly trending, upright, commonly steeply plunging regional-scale folds (Viljoen and Viljoen, 1969; Anhaeusser, 1981; Lamb, 1984), but little consensus has been found as to the relative timing of deformation phases. Tomkinson and King (1991) emphasized the possible diachronism of deformation phases in various parts of the belt which is complicated by the co-axiality of deformations (De Ronde and De Wit, 1993). The upright, large-scale folding that produced the NE-SW structural pattern of the Barberton greenstone belt is radiometrically constrained between 3227 ±1 Ma and 3216 +2/-1 Ma (Kamo and Davis,

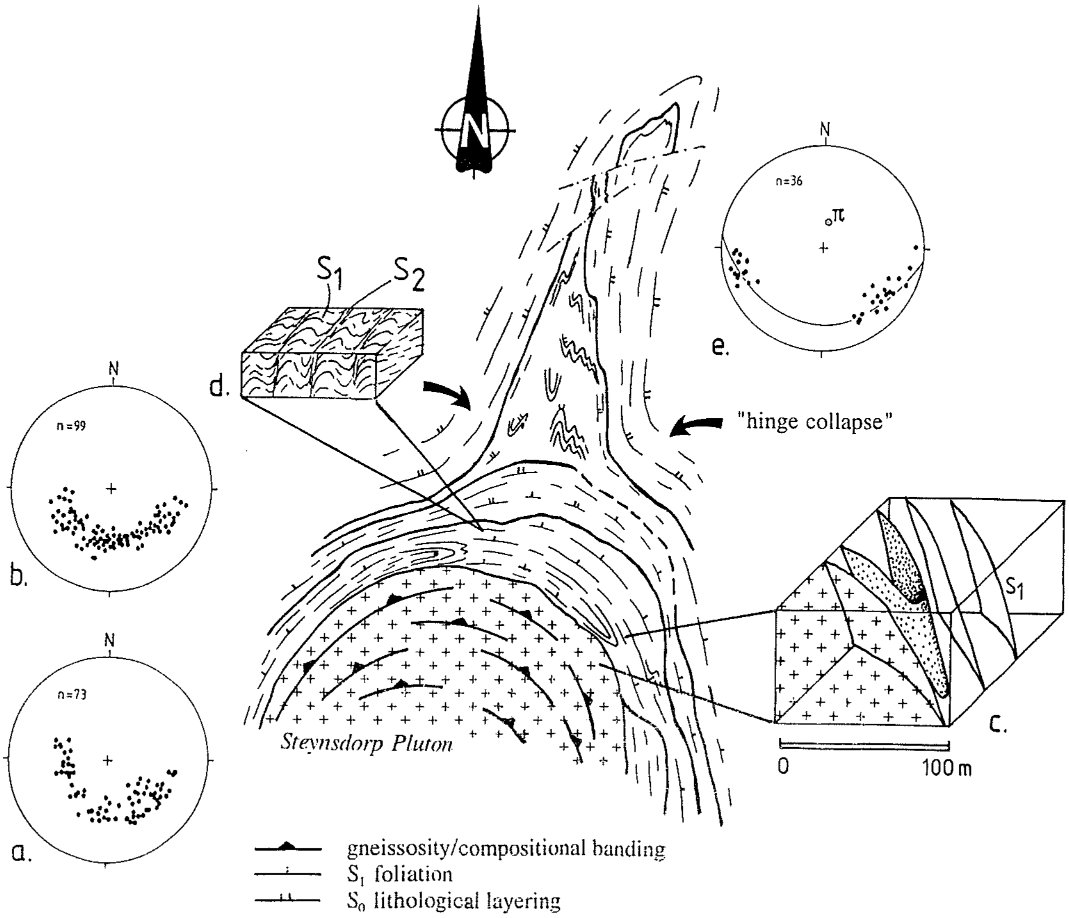


Figure 3: Simplified structural map of the Steynsdorp anticline and formline trajectories for S_o, S_1, and the gneissosity within the Steynsdorp pluton.

a,b, Lower hemisphere equal area projection of poles to the gneissosity in the Steynsdorp pluton (a), and the S_1 foliation within the Theespruit Formation.

c. Schematic sketch of the disposition of isoclinal folds within the Theespruit Formation wrapped around the Steynsdorp pluton. S_1 is axial planar to the large-scale isoclinal folds.

d. Schematic sketch of the geometric relationship between S_1 and the crenulation cleavage S_2, the latter being axial planar to the Steynsdorp anticline.

e. Lower hemisphere equal area projection of poles to S_o in basaltic units of the Hooggenoeg and upper Komati Formations recorded in the hinge of the Steynsdorp anticline. Note the great-circle distribution of poles to S_o indicating a concentric fold geometry; π: plunge of the Steynsdorp anticline (007/71).

1994), the latter age marking the emplacement of the Dalmein pluton which truncates regional-scale folds to the immediate northwest of the Steynsdorp pluton.

STRUCTURAL GEOLOGY OF THE STEYNSDORP ANTICLINE

Steynsdorp pluton

The Steynsdorp pluton, located along the southwestern margin of the Barberton greenstone belt, covers an area of approximately 8 km^2. Rocks comprising the Steynsdorp pluton are of tonalitic to trondhjemitic composition, showing quartz, plagioclase, biotite, and hornblende as their major constituents (Anhaeusser and Robb, 1983b), and occupy the core of the Steynsdorp anticline (Figs. 2 and 3). To the south the pluton merges, in a strongly migmatized zone, with the potassic granites of the Mpuluzi batholith (Anhaeusser and Robb, 1983a) and the northern, convex, outward-dipping contact is overlain by greenstone lithologies of the lower Onverwacht Group (Viljoen and Viljoen, 1969; Viljoen et al., 1969).

Gneissosity and compositional banding

The Steynsdorp pluton is characterized by a pervasively developed gneissosity and parallel compositional banding, mimicking the convex shape of the pluton. The gneissosity generally dips outwards at angles of 25 to 80° and parallels the contact with the overlying greenstone lithologies of the Theespruit Formation. Poles to the gneissosity in stereographic projections describe a partial small circle giving the pluton the geometry of a steep northeasterly plunging, conical antiform (Fig. 3a). Strongly recrystallized and granoblastic textures, plagioclase augen and rotated and/or asymmetric feldspar porphyroblasts, as well as elongated, highly undulose quartz observed in thin sections, point to an origin of the gneissosity and compositional banding due to solid-state, plastic deformation. This is also suggested by the locally observed isoclinal folding of the compositional banding and aplitic veins, with the gneissosity being axial planar to the folds (Fig. 4). No indications were found of magmatically formed foliations like those commonly encountered in the younger TTG's to the northwest (Kisters and Anhaeusser, 1994).

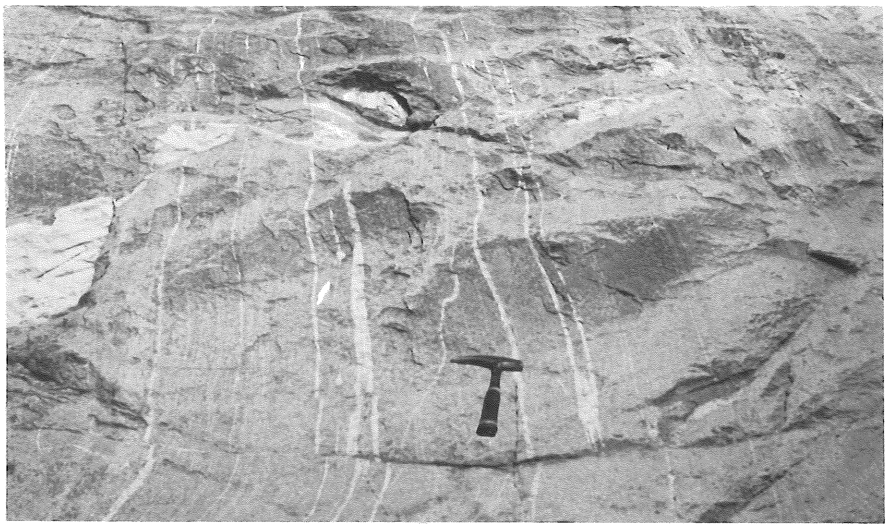


Figure 4: Isoclinal folding of aplitic veinlets contained within the gneissosity of the Steynsdorp pluton; locality, northwestern flank, of the Steynsdorp pluton looking southwest.

Amphibolitic enclaves are locally contained within the gneissosity and compositional banding of the Steynsdorp pluton (Fig. 5). Xenoliths may range in size from a few centimetres to tens of metres along strike, with maximum widths recorded of up to 6m. The amphibolites are commonly boudinaged or show pinch-and-swell structures (Fig. 5) and conjugate extensional shears lying within in the plane of the gneissosity.

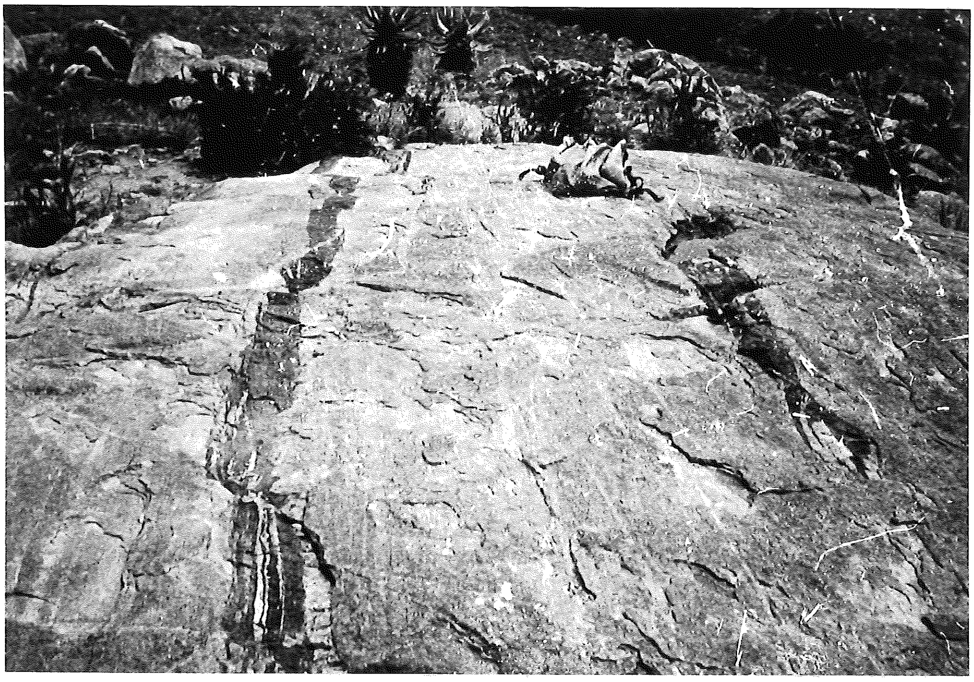


Figure 5: Amphibolitic xenoliths contained within the gneissosity of the Steynsdorp pluton, looking southwest. Note the pinch-and-swell structure and extensional conjugate shearing of the amphibolitic fragments in the plane of the gneissosity.

Lineations

A prominent mineral stretching lineation is commonly associated with the gneissose banding of the pluton and is expressed by the preferred orientation of hornblende and/or biotite or quartz-plagioclase aggregates. The lineation shows consistently shallow-to-moderate northeasterly plunges throughout the pluton (Figs. 6 and 6a).

Contact relationships

Contacts between the tonalitic/trondhjemitic gneisses and the overlying Theespruit Formation describe a broad, northwards convex arc, lacking obvious transgressive relationships. Figure 7 illustrates the contact between the gneisses and the overlying amphibolitic metabasalts of the Theespruit Formation in a river section along the northwestern margin of the Steynsdorp pluton. A compositional banding within the amphibolitic units, manifested by alternating zones rich in plagioclase and amphibole, is conformable with the contact of the Steynsdorp pluton and its internal gneissosity respectively. The compositional banding, resembling a metamorphic banding, is only recorded within the 10-15m wide contact zone with the Steynsdorp pluton. Amphibolites occurring beyond this narrow contact zone are foliated, but massively developed, and lack

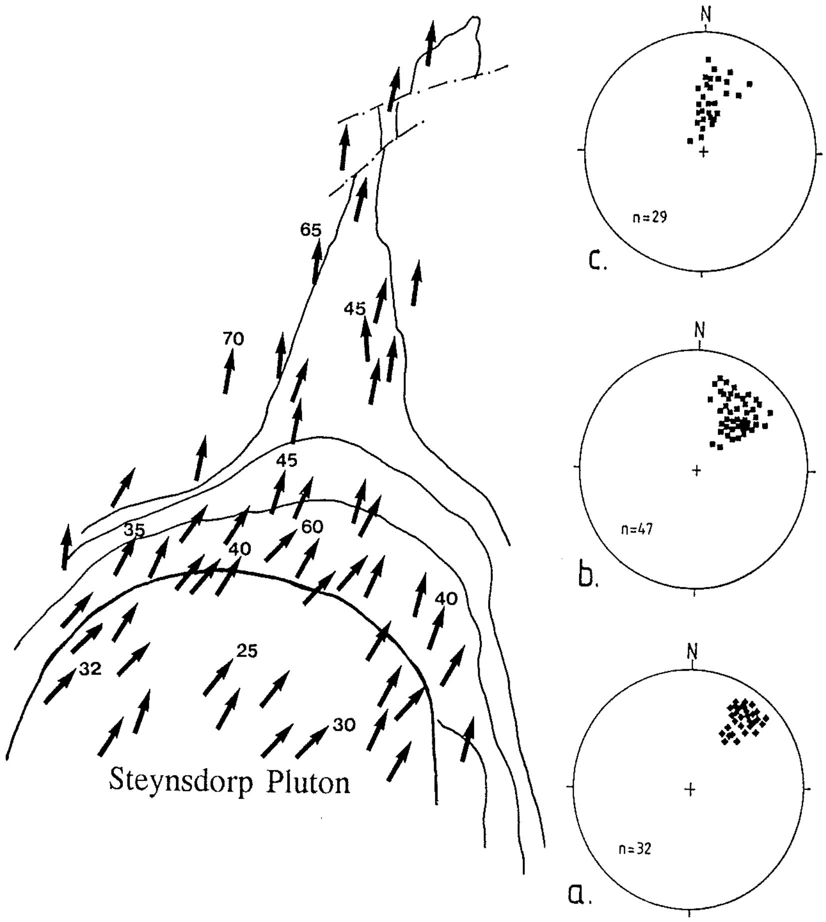


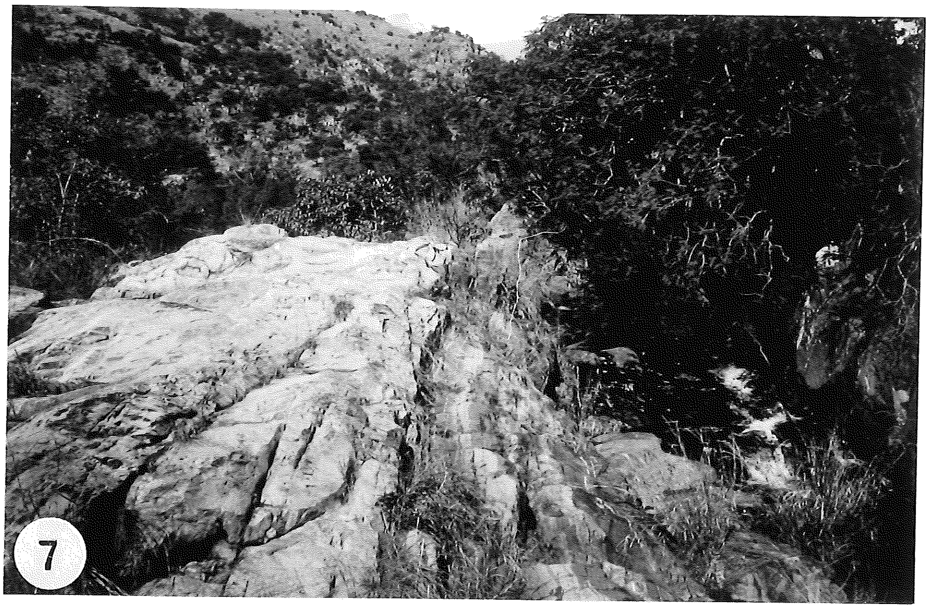
Figure 6: Pattern of mineral stretching lineations within the Steynsdorp anticline.
a-c: Lower hemisphere equal area projection of mineral stretching lineations within (a) the Steynsdorp pluton, (b) the Theespruit Formation, and (c) the upper Komati and Hooggenoeg Formations.

evidence of any compositional banding. Cross-cutting relationships between tonalitic/ trondhjemitic gneisses and greenstone lithologies were not observed, nor were high-strain fabrics recorded that might be indicative of shearing or a tectonic contact relationship. However, in the northeastern parts of the pluton a locally developed, compositionally distinct, granitic phase of the Steynsdorp pluton is clearly intrusive into the greenstones. It has prized off and incorporated greenstone xenoliths with granitic apophyses interfingering for up to 150m into greenstone lithologies. The mainly quartz-plagioclase-K-feldspar-bearing granitic phase also displays a foliation parallel to the gneissosity of the Steynsdorp pluton and adjacent greenstone lithologies.

Figure 7: *Contact relationship between tonalitic gneisses of the Steynsdorp pluton (left) and banded amphibolitic lithologies of the Theespruit Formation (right), looking southwest.*

Figure 8: *Large-scale isoclinal fold developed within the Theespruit Formation and manifest in the field by two merging limbs of greyish chert. Photograph is taken from within the isoclinal fold closure, looking northeast.*

Figure 9: *Small-scale isoclinal folds developed in isoclinal fold closure shown in Figure 8. Minor folds show moderate northeasterly to northerly plunges.*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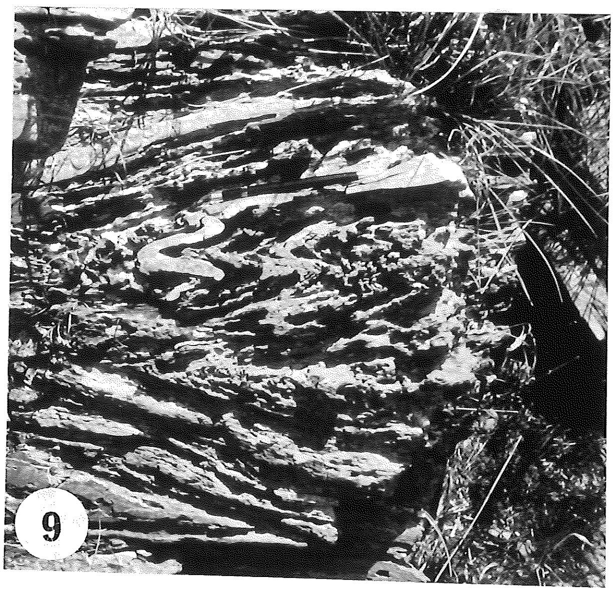
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Onverwacht Group lithologies

The Steynsdorp anticline comprises mainly rocks of the Theespruit, Komati and Hooggenoeg Formations.

Foliations and folding

Rocks of the Theespruit Formation in the Steynsdorp anticline are characterized by an intensely developed schistosity, S_1, which is generally subparallel to the lithologies and layering, S_0, within the sequence (the terms S_0, S_1,...S_n only denote the relative age relationships of planar fabrics within the Steynsdorp anticline as they were investigated in this study). The foliation and lithologies show moderate-to-steep dips which occur parallel to the contact and internal gneissosity of the Steynsdorp pluton (Fig. 3). S_1 is most prominently developed in felsic as well as ultramafic schists and, to a lesser extent, in massive amphibolitic units. The subparallelism between the foliation in the Theespruit Formation and the gneissosity in the Steynsdorp pluton is expressed in stereographic projections by the almost identical distribution of poles to S_1 and the gneissosity (Fig. 3b).

S_1 is axial planar to large-scale isoclinal folds within the Theespruit Formation and is manifest in the field by isoclinal fold closures which are best observed in prominent, laterally continuous chert horizons (Fig. 8). The hinge zones of these large-scale folds are typically characterized by the development of small-scale isoclinal folds showing 'M'-type symmetries (Fig. 9). Folds show moderate northeasterly to northerly plunges, parallel to the regionally developed mineral lineation (see below) as well as the overall plunge of the Steynsdorp anticline. The axial planes of isoclinal folds are, together with the foliation, conformably wrapped around the Steynsdorp pluton (Fig. 3c). Isoclinal folding is also indicated by the occurrence of stratigraphically inverted sequences,and structural duplication of at least parts of the Theespruit Formation is interpreted to be responsible for the unusually thick development of the felsic units within the succession and which exceeds 350m in the hinge of the Steynsdorp pluton.

Open refolding of S_1 on a metre-scale is developed in felsic schists and mafic-to-ultramafic units of the Theespruit Formation on the northeastern flank of the Steynsdorp pluton (Fig. 10). Folds show 'S'-symmetries and shallow to moderate northeasterly plunges and the folding is locally associated with minor low-angle thrust-faults that verge onto the Steynsdorp pluton (Fig. 10).

The contact between the Theespruit Formation and the overlying Komati Formation is marked by the occurrence of intensely chloritized and carbonatized predominantly ultramafic and mafic rocks, such as talc-carbonate schists and komatiitic metabasalts (Viljoen et al., 1969). This contact is also characterized by the transition from intensely schistose units of the Theespruit Formation, containing S_1, to more massive, only poorly foliated and lineated lithologies. Primary textures are clearly discernable within the Komati Formation and include pillow structures, spherulites and spinifex textures. A steeply inclined, northerly trending crenulation cleavage, S_2, has locally been superimposed onto ultramafic talc-carbonate schists of the Theespruit Formation (Fig. 3d). Axes of the crenulation folds plunge to the north, subparallel to the regional mineral lineation (see below).

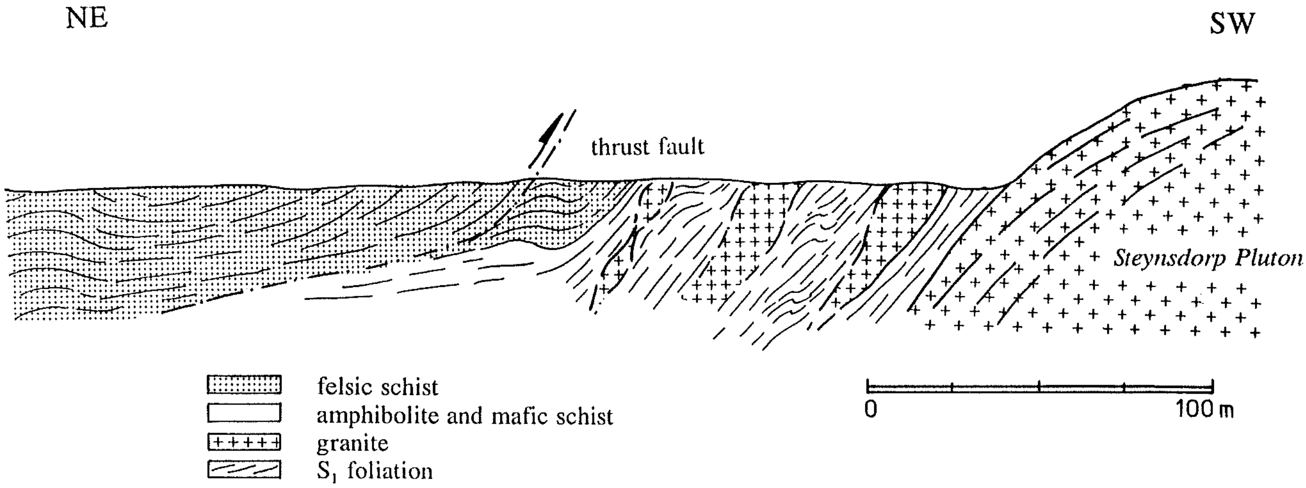

Figure 10: Open refolding of S_1 developed in felsic and mafic schists and amphibolites of the Theespruit Formation conformably overlying the northeasterly dipping contact and gneissosity of the Steynsdorp pluton. Folding is locally associated with minor thrust-faults verging towards the Steynsdorp pluton.

Felsic schists of the Theespruit Formation commonly display monoclinal, reverse kink bands on a cm- to dm-scale, which plunge predominantly to the north and northwest respectively. Mafic and ultramafic schists situated along the northwestern flank of the Steynsdorp pluton show metre-scale kinks and chevron folds. Although northerly plunges dominate, folding is irregular, resulting in a wide scatter of fold plunges.

While the lithological layering (S_o), and the foliation of the Komati and Theespruit Formations (S_1), are conformably wrapped around the eastern and western flank of the Steynsdorp pluton, folding north of the pluton is manifested as tight-to-close concentric folding (Figs. 3 and 3e), contrasting with the conical fold geometry outlined by the Steynsdorp pluton and its enveloping greenstone cover. Poles to S_0 of basaltic units of the Hooggenoeg Formation and parts of the Komati Formation outline a steep northerly plunging fold axis of the Steynsdorp anticline (Fig. 3e). The transition between the conical fold geometry in the south and concentric folding in the north is characterized by a drastic change in the curvature of the fold (Fig. 3) in order to accommodate the space problem created by the folding of greenstone lithologies of various competencies (i.e. the competent metabasaltic sequence of the Hooggenoeg Formation and the incompetent metaperidotitic units of the Komati Formation) around the Steynsdorp pluton as a competent core. This resulted in the development of a "hinge collapse zone" (Ramsay and Huber, 1987) north of the Steynsdorp pluton (Fig. 3, bold arrows). The collapsed hinge zone is occupied by markedly thickened and intensely folded rocks of the upper Komati Formation, which are only poorly developed on the flanks of the pluton further south. The thickening and accompanying folding and shearing of the altered rocks of the upper Komati Formation suggests a flow of the incompetent mafic and ultramafic units from the limbs into the hinge of the Steynsdorp anticline. Folds developed within rocks of the upper Komati Formation have predominantly northerly to northeasterly plunges and display, in places, a weakly developed, northerly trending axial planar cleavage (S_2), which parallels the crenulation cleavage developed in schists of the underlying Theespruit Formation (Fig. 3d).

Lineations

A prominently developed mineral lineation plunges moderately to the northwest and is parallel to the lineation recorded in the Steynsdorp pluton, although it shows progressively steeper plunges and a somewhat greater scatter to more northerly plunges in the hinge of the Steynsdorp anticline (Fig. 6b,c). The lineation is expressed as stretched quartz or quartz-feldspar mineral aggregates in felsic units of the Theespruit Formation, or by orientated hornblende and actinolite in amphibolitic units. The lineation is parallel or subparallel to the plunge of various generations and types of folds including: 1) isoclinal folds contained within the S_1 foliation of the Theespruit Formation; 2) folds defined by the refolding of S_1 on the northeastern flanks of the Steynsdorp pluton; 3) crenulation folds; 4) folds within the Komati Formation in the hinge of the Steynsdorp anticline; 5) the overall plunge of the Steynsdorp anticline; and 6) kink bands within the Theespruit Formation.

Strains within the Steynsdorp anticline

The orientation of the principal strains ($X \geq Y \geq Z$) was established by measurements of deformed elliptical objects, such as spherulites within units of the Komati Formation, and qualitatively approximated from the orientation of boudins and planar fabrics, such as pervasively developed schistosities, and mineral stretching lineations.

Assuming that the foliation of the Theespruit Formation, which is conformably wrapped around the Steynsdorp pluton, contains the XY-plane of the finite strain ellipsoid, a radially orientated shortening strain perpendicular to the contact between the Steynsdorp pluton and the overlying greenstone lithologies is suggested. This is also indicated by the boudinage of more competent lithological layers within the Theespruit Formation as well as quartz veins occurring in calc-silicate rocks and felsic schists. Intermediate boudin axes follow the convex interface between the granitoid gneisses of the Steynsdorp pluton and the greenstone cover and, as such, show a circumferential alignment around the pluton. Strain measurements on spherulites in the hinge of the Steynsdorp anticline, close to the contact between the Theespruit and Komati Formations, indicate that the rocks have undergone moderate to strong flattening-type strains, showing K-values ranging between 0.25 and 0.6 ($K=(X/Y-1)/(Y/Z-1)$; Flinn, 1962). The XY-plane of the deformed spherulites lies in the plane of the foliation and the long axes of spherulites plunge in a northerly direction at moderate angles, parallel to the weakly developed mineral lineation. The intensity of the fabrics developed in the Theespruit and lower Komati Formations decreases away from the contact with the Steynsdorp pluton, indicating decreasing strains outward from this contact.

A superimposition of a regional strain is indicated by the development of an axial planar foliation and axial planar crenulation cleavage (Fig. 3d) in parts of the Theespruit Formation and within the hinge of the Steynsdorp anticline, as well as the occurrence of a mineral stretching lineation that is developed in both the Steynsdorp pluton and the overlying greenstone sequences (Fig. 6). The steeply inclined, northerly to northeasterly trend of the axial planar foliation and crenulation is consistent with the regional trend of large-scale, upright folding, that has affected the Barberton greenstone belt as a whole. Mineral stretching lineations within the Steynsdorp pluton and overlying greenstone units show consistently shallow northeasterly plunges suggesting a principal direction of extension in this direction.

DISCUSSION AND INTERPRETATION OF STRUCTURAL DATA

The Steynsdorp anticline can be subdivided into a dome-like, conical fold geometry in the south and including the Steynsdorp pluton and its overlying greenstone cover (Fig. 3a,b), and an upright, northerly trending concentric fold developed in the greenstone lithologies north of the Steynsdorp pluton (Fig. 3e).

Dome-like features, such as that exhibited by the Steynsdorp pluton, can be attributed to a variety of mechanisms including: 1) diapirism, for which Archaean greenstone belts provide an ideal scenario, showing denser ultramafic supracrustal rocks overlying lighter granitoids (Anhaeusser, 1973; Schwerdtner, 1981; Ramberg, 1981); 2) interference folding, resulting in dome-and-basin patterns (Ramsay, 1967; Thiessen and Means, 1980; Ramsay and Huber, 1987); and 3) non-cylindrical buckle folding (Dubey and Cobbold, 1977). A clear distinction between these features in the formation of dome-like structures is difficult and often controversial (Platt, 1980, 1981; Schwerdtner, 1981) and a combination of various mechanisms such as diapirism and coeval regional deformation is not uncommon (Brun et al., 1981; Bouhallier et al., 1993).

An origin of the Steynsdorp pluton due to doming is suggested by its half-dome like, conical shape which is mimicked by its internal structure (i.e. gneissosity and compositional banding). The role of doming of buoyant granitoid material for the resulting geometry of the Steynsdorp pluton is indicated by radially orientated flattening strains recorded within the Steynsdorp pluton as well as in the overlying greenstone cover, being perpendicular to the interface between the tonalitic gneisses and the greenstone lithologies. The superimposition of a regional deformation onto the dome-like pluton is, however, indicated by: 1) the unidirectional, northeasterly plunging mineral lineation pattern which is developed in both the Steynsdorp pluton as well as in the greenstone lithologies to the north (Fig. 6a-c); 2) the development of a crenulation cleavage, S_2, superimposed onto the S_1 foliation developed within the Theespruit Formation (Fig. 3d), the latter being conformably wrapped around the Steynsdorp pluton; 3) the open refolding of S_1 into shallow-to-moderate northeasterly plunging folds; 4) the concentric, upright folding of greenstone lithologies north of the Steynsdorp pluton and the northerly trend of the Steynsdorp anticline, which forms part of the northeasterly trending regional structural grain of the Barberton greenstone belt (Fig. 3e); and 5) the formation of a collapsed hinge zone north of the Steynsdorp pluton as a result of the structural incompatibility that emerged during regional-scale folding around the competent core of the Steynsdorp pluton (Fig. 3).

In the case of the Steynsdorp pluton, the following features need to be considered in any further discussion as to the origin of the pluton and its present disposition with respect to the greenstone cover. The Steynsdorp pluton is unique within the Barberton greenstone belt showing single-zircon ages of $\geq$3500 Ma (Kamo and Davis, 1994), as well as a uniquely developed, pervasive gneissosity and compositional banding.

Single zircon ages of >3500Ma for the Steynsdorp pluton pre-date those of other TTG's by 50 to 70 Ma and, similarly, old gneisses which show an analogous fabric development are only reported to occur as "tectonic slivers" of limited extent within volcanoclastic units of the Theespruit Formation (De Wit et al., 1983; Armstrong et al., 1990). The solid state origin of the gneissosity and the lack of cross-cutting relationships point, furthermore, to an emplacement of the Steynsdorp pluton in the solid state as opposed to a primary intrusive relationship as is frequently observed with other TTG's.

This poses the question as to the origin of the gneissosity of the Steynsdorp pluton and two alternative origins must be considered:

1) a development of the gneissosity and compositional banding during doming, as experimentally modelled for diapirs by Dixon (1975); or 2) the gneissosity reflecting an earlier deformation event that occurred prior to doming and the regional upright folding of the Barberton greenstone belt.

Fabric patterns in diapirs characteristically consist of subhorizontal planar and shallowly plunging, often radial lineation patterns in the crest of diapirs which assume progressively steeper to subvertical attitudes in the stems of diapiric structures (Dixon, 1975; Schwerdtner et al., 1978). Both linear and planar fabrics in the Steynsdorp pluton deviate from this orientation of fabrics formed during doming. As discussed above, mineral stretching lineations in the Steynsdorp pluton describe a unidirectional pattern which can, however, be attributed to the superimposition of a regional deformation. This regional, superimposed lineation may, in fact, have obliterated a pre-existing lineation pattern which formed during doming. However, planar structural elements, such as the gneissosity and compositional banding, show a circumferential orientation throughout the pluton and, as such, deviate from the complex fabric pattern observed by Dixon (1975) for gneissosities formed during doming.

The latter scenario, involving the doming of a pre-existing gneissosity, is suggested by the uniqueness of the fabric development that has not been observed in other TTG's, and is supported by single zircon ages of >3500 Ma (Kamo and Davis, 1994), which allow for a deformation phase prior to the deposition of most of the Onverwacht Group. The presence of an older, deformed granitoid basement formed prior to the development of the Barberton greenstone sequence has been proposed by De Wit et al. (1983) and Armstrong et al. (1990) on the basis of gneissose material found within the Theespruit Formation.

Taking the abovementioned factors into account, it appears that the gneisses of the Steyndorp pluton record a fabric-forming event that pre-dates the evolution of the bulk of the Barberton greenstone sequence and, as such, may bear similarities to rocks of the "Ancient Gneiss Complex" which outcrop to the southeast of the Barberton Mountain Land (Kröner and Tegtmeyer, 1994). However, numerous amphibolitic xenoliths occurring within the Steynsdorp pluton, and lacking any evidence of tectonic infolding as reported for amphibolites in the Ancient Gneiss Complex to the south (Kröner and Tegtmeyer, 1994), suggest that the tonalitic/ trondhjemitic gneisses intruded into a pre-existing mafic (presumably ensimatic) crust.

Although the Barberton greenstone belt is characterized by polyphase deformation, the dome-like shape of the Steynsdorp pluton, due to interference folding, appears to be unlikely, as most deformation phases are largely co-axial and dome-and-basin interference patterns have nowhere been described in the Barberton region. A component of non-cylindrical buckling that has possibly interfered with the buoyant doming of the granitoid gneisses of the Steynsdorp pluton cannot be ruled out. However, folding, expressed in greenstone lithologies north of the pluton, is essentially of a concentric geometrical style. It thus appears that the dome-like geometry of the Steynsdorp pluton is likely to be the result of a gravitationally induced instability which caused subsequent doming of lighter granitoid material underlying mafic and ultramafic supracrustals. Further support for this mechanism of emplacement is provided, in particular, by the circumferential flattening strains recorded around the pluton. However, a synkinematism of doming and regional deformation is suggested by the influence of the Steynsdorp pluton on the fold style during progressive deformation (i.e. conical fold geometries around the Steynsdorp pluton, concentric fold shapes, and the formation of a hinge collapse north of the pluton). It thus appears that the geometry, structural pattern and lithological character of the Steynsdorp pluton and its surrounding greenstone cover fits the description of a mantled gneiss dome, the latter having been defined by Eskola (1949) as a structure cored by older gneissic rocks and mantled by younger, metamorphic, supracrustal lithologies.

The significance and timing of the formation of the isoclinal folds contained within rocks of the Theespruit Formation is not clear. Isoclinal folding has been described by De Wit (1982) and De Wit et al. (1983) in the Theespruit Formation north of the Theespruit pluton. This folding was attributed to an early deformation phase of recumbent folding and low-angle thrusting, resulting in the duplication of greenstone lithologies. An early deformation recorded in these rocks is, indeed, supported by single zircon ages >3500 Ma for parts of the Theespruit Formation (Kröner, 1993). The large-scale isoclinal folding in the Theespruit rocks in the Steynsdorp area could, alternatively, be accounted for by the development of a rim syncline or complex rim synclinoria conformably wrapped around the Steynsdorp pluton during progressive doming. However, a clear distinction between either an early isoclinal fold phase, possibly associated with the early fabric development within the Steynsdorp pluton, or the development of rim synclinoria due to doming is not possible because of the subsequent superimposed strains produced during progressive doming of the Steynsdorp pluton and the coeval regional upright folding. The superimposition of these later strains is suggested by the northerly to northeasterly plunge of isoclinal folds parallel to the regionally developed mineral lineation, indicating a rotation of the fold axes into parallelism with the mineral stretching lineations during the subsequent deformation.

Relation between deformation and gold mineralization

The Steynsdorp Goldfield represents one of the few areas in the southern portion of the Barberton greenstone belt where gold mineralization was relatively well developed. The structural control and localization of small-scale gold occurrences in the form of gold-quartz veins and fractured chert horizons has been described by Viljoen et al. (1969) and was attributed to dilatant zones that developed during folding and faulting. However, the question remains as to what influenced the development of the Steynsdorp Goldfield as a whole in its relatively isolated position in the southern part of the Barberton greenstone belt.

Based on the structural evolution of the Steynsdorp anticline, as described in the sections above, the unique position of the Steynsdorp Goldfield is considered to have resulted from increased and focussed fluid flow into the hinge of the Steynsdorp anticline. The

Steynsdorp pluton appears to have acted as a competent or rigid body during the regional WNW-ESE-directed shortening of the Barberton greenstone belt during regional folding. This regional stress pattern has produced a pressure-shadow situation in the hinge area of the Steynsdorp anticline north of the Steynsdorp pluton. Reduced mean stresses in this pressure-shadow situation are likely to have localized fluid flow around the competent pluton and into the hinge zone of the Steynsdorp anticline (Stromgård, 1973; Ridley, 1993). This fluid flow may have been assisted by the compatibility and space problem created during folding in the hinge zone north of the pluton which can only be gradually compensated by the flow of incompetent upper Komati rocks into this zone.

CONCLUSIONS

The orientation and superimposition of linear and planar fabrics as well as strains observed within the Steynsdorp anticline are the result of synkinematic doming of tonalitic/trondhjemitic gneisses of the Steynsdorp pluton during a regional WNW-ESE directed, subhorizontal shortening episode. Doming of buoyant granitoid gneisses underlying mainly mafic-to-ultramafic greenstone sequences of the lower Onverwacht Group resulted in the dome-like, conical geometry and structure of the Steynsdorp pluton and its conformably overlying greenstone cover. Regional-scale folding of the greenstone succession north of the Steynsdorp pluton resulted in the development of the northerly trending, steep northerly plunging Steynsdorp anticline, which forms part of the regionally developed structural pattern of large-scale, upright, northeasterly trending folds within the Barberton greenstone belt. Coeval doming and regional folding, due to lateral shortening, is manifest by the superimposition of strains and the interference of linear and planar fabrics as well as the development of a large-scale collapsed hinge zone north of the Steynsdorp pluton.

Evidence of a deformation phase pre-dating the deposition of the bulk of the greenstone lithologies of the Onverwacht Group in the Barberton greenstone belt is supported by the presence of intense fabrics developed within the tonalitic/trondhjemitic gneisses of the Steynsdorp pluton, which have not been observed in younger TTG's to the northwest. The existence of an early gneissic granitoid basement is supported by the single zircon age for the pluton of 3509 +8/-7 Ma (Kamo and Davis, 1994) which pre-dates other TTG plutons of the area as well as most of the Onverwacht Group. However, the presence of numerous amphibolitic xenoliths found within the gneisses of the Steynsdorp pluton suggests that an earlier intrusive relationship existed between the granitoid rocks and an even older mafic volcanic crustal precursor.

As the geometry and structural evolution of the Steynsdorp pluton is that of a gneiss dome, it is suggested that the structure should be referred to as the Steynsdorp dome.

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