

**ECONOMIC GEOLOGY
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**THRUST DEFORMATION IN A
PRE-BUSHVELD SILL,
EASTERN TRANSVAAL**

M. HARLEY AND E.G. CHARLESWORTH

• INFORMATION CIRCULAR No. 237

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by

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June, 1991

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ABSTRACT

A tremolite-bearing metadolerite sill, intrusive into the Upper Monte Christo Formation, is exposed in a roadcutting in the eastern Transvaal, close to the Elandshoogte Gold Mine. A subhorizontal thrust fault is located along the footwall contact and steeper, westerly dipping, splays are present. The structure developed is consistent with ESE-directed thrust faulting of an initially en echelon set of sills. Bleaching of the wall-rocks occurs around the fault splays and sub-economic gold mineralisation is present in fault-related, carbonate-quartz veining.

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Published by the Economic Geology Research Unit
Department of Geology
University of the Witwatersrand
1 Jan Smuts Avenue, Johannesburg 2001
South Africa

ISBN 1 874856 28 1

THRUST DEFORMATION IN A PRE-BUSHVELD SILL, EASTERN TRANSVAAL

INTRODUCTION

The Transvaal Sequence in the eastern Transvaal hosts numerous sills and some workers estimate that up to 20% of the stratigraphic thickness consists of intrusives (Sharpe and Snyman, 1980). Age determinations of these sills and accompanying dykes are problematic because of the intense alteration and, in some cases, metamorphism displayed by the igneous lithologies. Pyroxenite, norite, and diabase are the predominant sill lithologies, with minor diorite sills being present (Zietsman, 1967; Sharpe, 1981; Cawthorn *et al.*, 1981) and it is commonly agreed that many of the sills of the eastern Transvaal are genetically related to the Bushveld Complex. Sharpe (1981) and Cawthorn *et al.* (1981) described the mineralogies and textures of a suite of metadolerite sills intrusive into the Transvaal stratigraphy in the eastern and central Transvaal. These sills, which have been affected by weak grades of metamorphism and deuteritic alteration, occur at various levels in the stratigraphy and are correlated with the Lydenburg-type sills described by Willemse (1959). Field relationships (Sharpe, 1981; Sharpe and Snyman, 1980) and the metamorphism evident within these sills have led workers (Sharpe, 1981; Cawthorn *et al.*, 1981) to suggest that these sills pre-date the emplacement of the Bushveld Complex. The occurrence of these sills throughout the Transvaal stratigraphy proves that they post-date sedimentation.

This paper describes previously unrecognised and undescribed deformation features associated with one such sill which have important implications for gold mineralisation within the Sabie-Pilgrim's Rest Goldfield.

GEOLOGY OF THE SUDWALA-ROSEHAUGH ROADCUTTING

A tremolite-bearing metadolerite sill is well-exposed in the road cuttings between Sudwala and Rosehaugh (Fig. 1). This locality is approximately 2,5 km east of the Elandshoogte Gold Mine, which comprises a typical flat reef deposit of the Sabie-Pilgrim's Rest Goldfield (Harley, in prep.). The sill occurs approximately 10m above the Middle Monte Christo unconformity (Clendenin, 1989) and 10 to 20m below the Elandshoogte Reef and is structurally overlain by megadomal stromatolitic dolomites and underlain by planar laminated boundstones containing abundant chert bands. Small fragments of "chert-in-shale breccia" are poorly preserved on the margins of the sill and a thin shale band is impersistently developed along the hangingwall contact. The sill, approximately 7m thick, consists of dark-green metadolerite and displays a pervasive alteration. Felted masses of tremolite replace pyroxenes, whilst the plagioclases are intensely sericitised within their cores, and along crystal cleavages. Chlorite is ubiquitously developed together with the sporadic occurrence of epidote and quartz as minor interstitial phases. Numerous quartz-carbonate-epidote veins are present within the sill. Epidote occurs as bright green prisms which project orthogonally from the vein margins into milky quartz, which predominates as the vein filling. Calcite occurs as rhombs or rounded masses within the veins, intergrown with quartz. The veins are invariably thin (7 to 12mm wide) and seldom exceed 20 mm in thickness. The veins also display lensoid forms which taper closed at their tips. Two dominant

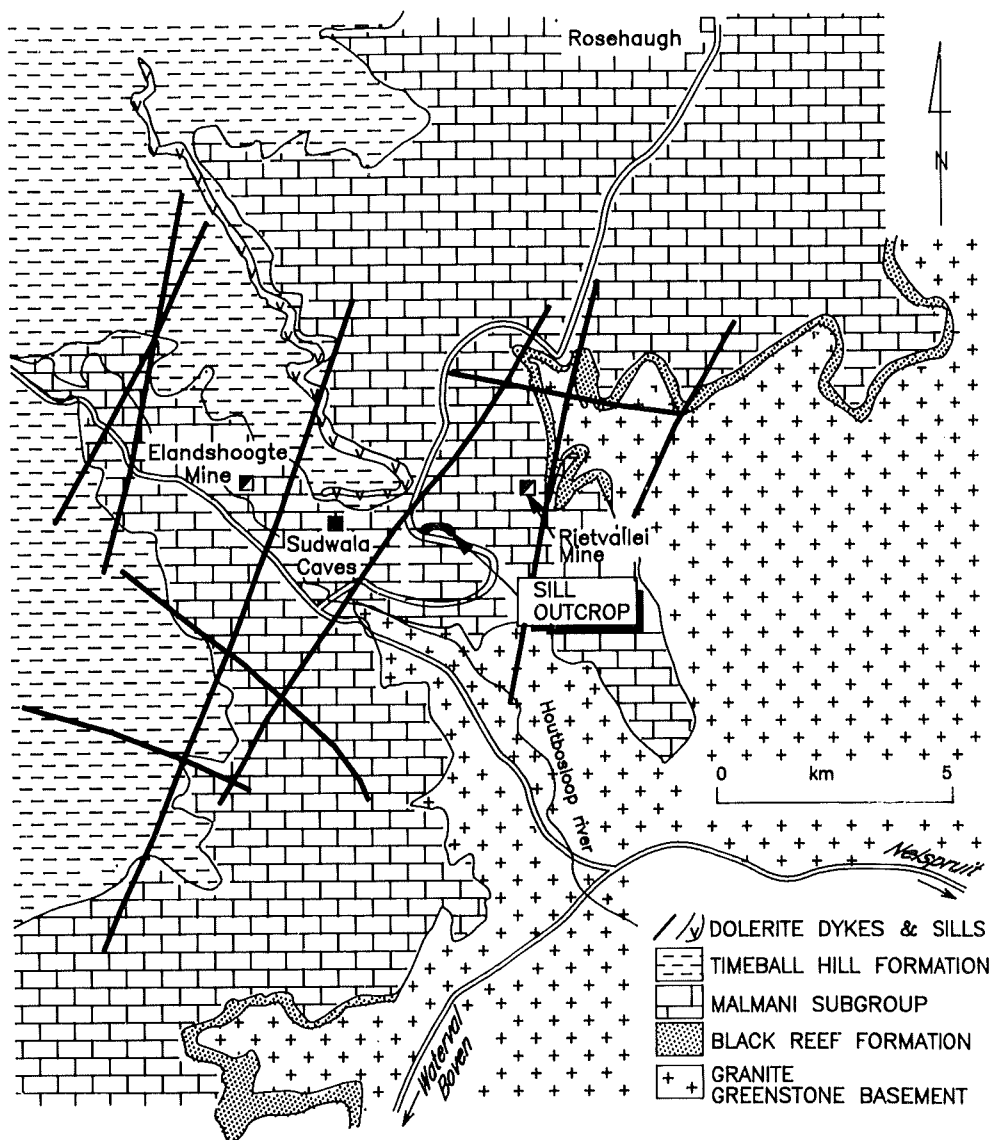


Figure 1: Locality plan showing the position of the sill relative to the Sudwala Caves and Elandshoogte Mine.

orientation trends of the veins are developed, one subhorizontal, lying subparallel to the sill margins and a second, steeply orientated set, which intersects the first set at a high angle. The high-angle veins have variable strikes which range from 330° to 040° . The relationships between the veins are complex. In some instances, steep veins appear to cross-cut subhorizontal veins and the reverse relationships are also observed at some localities along the exposure. Elsewhere, the subhorizontal and steeply orientated veins appear to be mutually continuous and contemporaneous. The interpretation of the vein relationships suggests that there is more than one generation of vein development.

STRUCTURE OF THE SILL

The sill is well-exposed on a curve in the road such that both a north-trending strike-section and an east-trending profile are visible; thus it is possible to construct a three-dimensional model of the structures within the sill.

North-trending strike-section

The strike-section is well-exposed over about 100 m, and a detailed map, showing 5m of the footwall contact, is presented as Figure 2. The hangingwall and footwall contacts of the sill are parallel with bedding in the country rocks. The hangingwall contact is not readily accessible for investigation, in contrast to the footwall which is well-exposed immediately above a band of talc-carbonate schist, which ranges from 40cm to 1m in thickness. This lithology is derived from contact metamorphism of siliceous dolomite. Large flakes of talc are present, some of which impart a banded appearance to the rock, possibly representing an original bedding. The talc-carbonate band shows complex internal structures (Fig. 2). On a

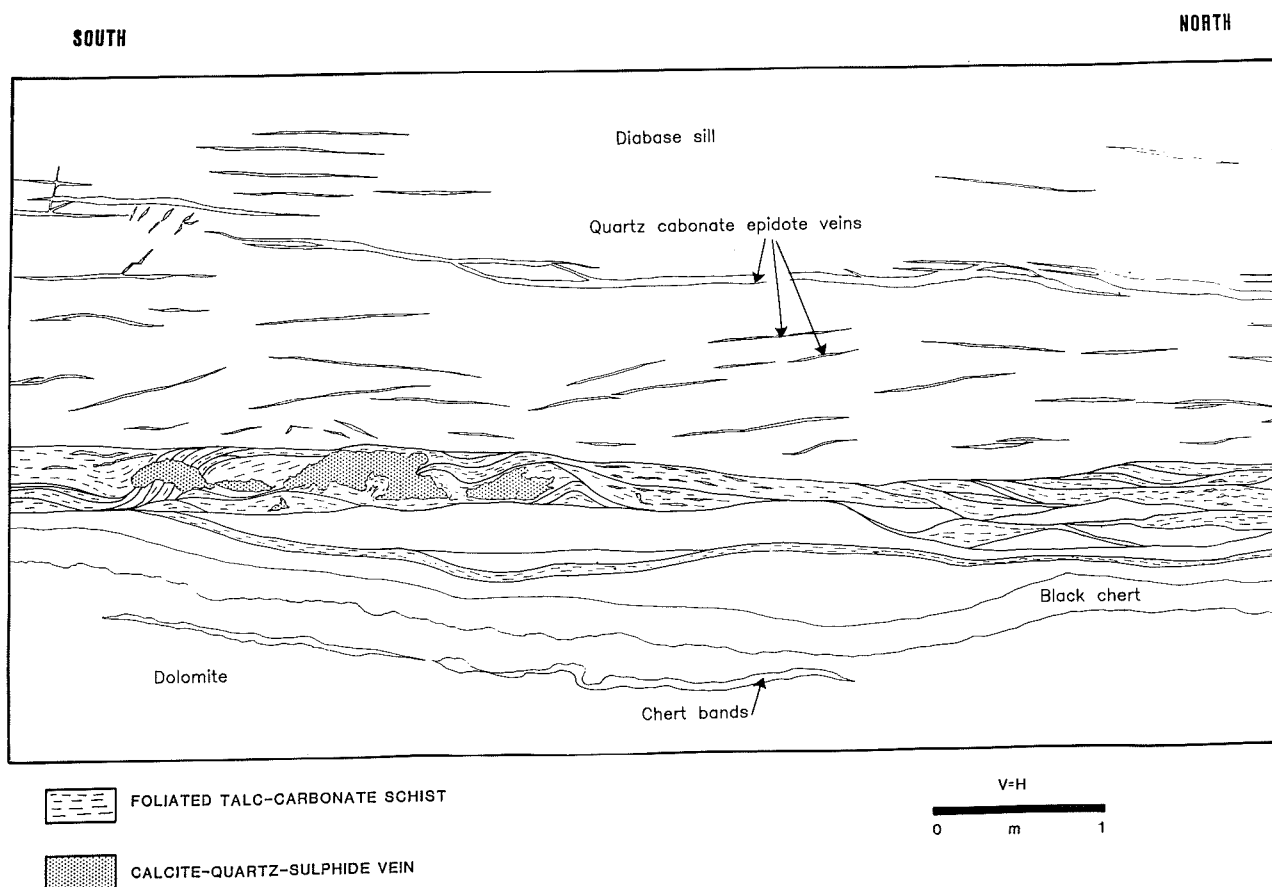


Figure 2: A strike section through the basal contact of the sill, showing some of the structures developed within the talc-carbonate metamorphic aureole.

large scale, well-foliated bands within the lithology anastomose around lithons of massive talc-carbonate rock. In this north-trending section, the lithons have a lensoid shape and range up to 2m in length. The thin, anastomosing foliated bands also converge to form a single foliated zone beneath the sill. Smaller-scale structures within the foliated bands are abundantly developed. The foliation is deformed into gentle, low-amplitude folds, and, in general, has an undulose form. Slickensides, present as shallow grooves, are developed on foliation surfaces. Narrow, transgressive faults also occur and often step off the foliation-parallel faults. Small duplex-like structures occur within the talc-carbonate rock. The sense of vergence of these structures is difficult to assess, but slickensides associated with the duplexes trend WNW (Fig. 3). The NW edges of the horses are attenuated into long tail-like features, while the SE edges of these structures are more blunted and rounded in form.

Small quartz veinlets, seldom longer than 5cm, and not exceeding 5mm in thickness occur interlayered within the foliation. These veinlets commonly show a highly contorted, ptymatically folded form (Fig. 4A).

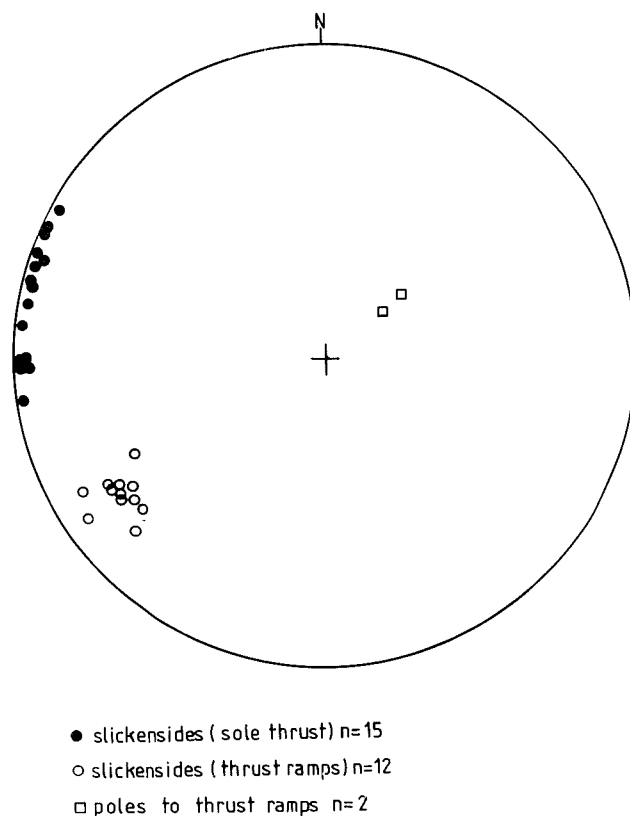


Figure 3: Lower hemisphere projection showing the orientation of slickensides and fault planes within the sill and the talc-carbonate layer.

Large, discontinuous bodies of coarsely crystalline carbonate-quartz vein material are developed within the foliated talc-carbonate rock. These bodies generally lie within the foliation, but clearly cross-cut it at certain localities. The vein material is predominantly a coarsely crystalline, twinned, glassy calcite, intergrown with white, milky quartz. Fine-grained chalcopyrite and pyrite are sporadically developed within the veins and along the vein margins. In some instances, crystalline masses of sulphide up to 5mm across are developed within the vein material. Analyses by M.J. Duane (unpublished data) show that the vein contains gold at levels up to 100ppb.

Figure 4A: Highly deformed quartz veinlets within foliated talc-carbonate schist, in the footwall of the sill.

4B: View of the sill pinching down to the west, beneath inclined planar laminated dolomite.

4C: Sheared, foliated dolomite situated immediately above the sill wedge (see Fig. 4B). Note the development of small, easterly verging folds.

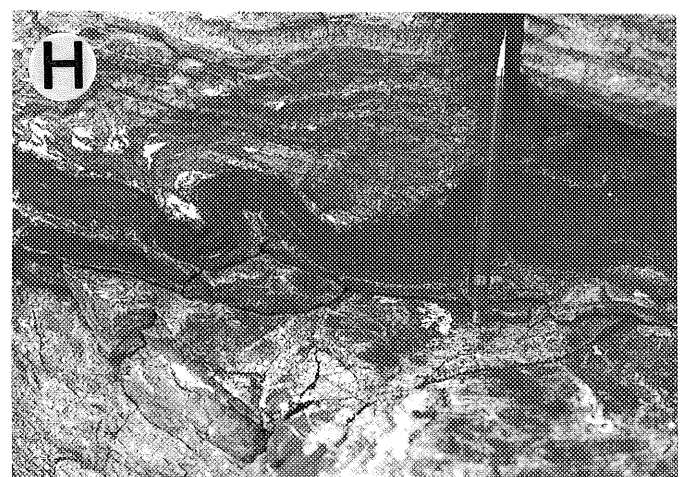
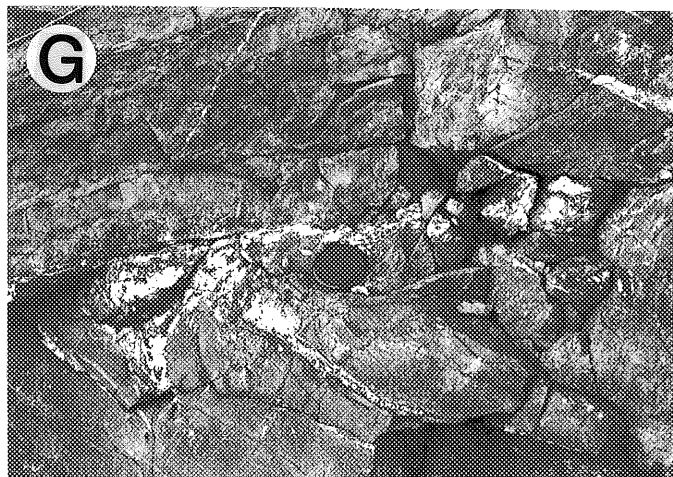
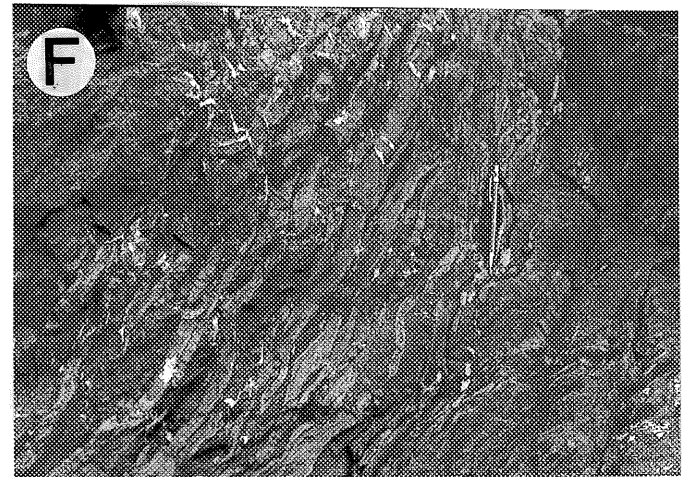
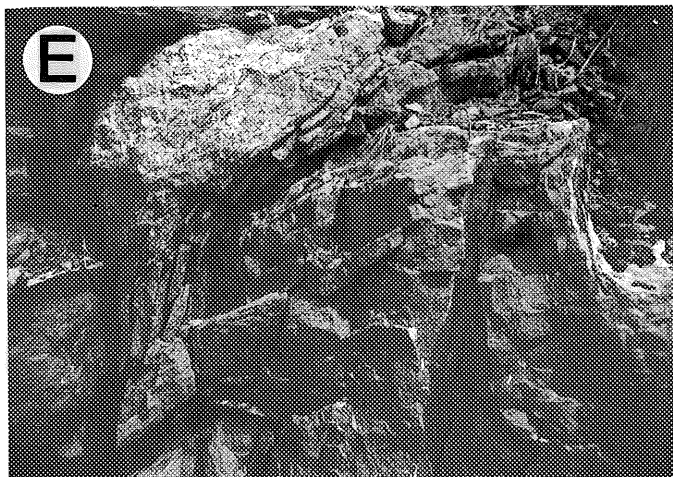
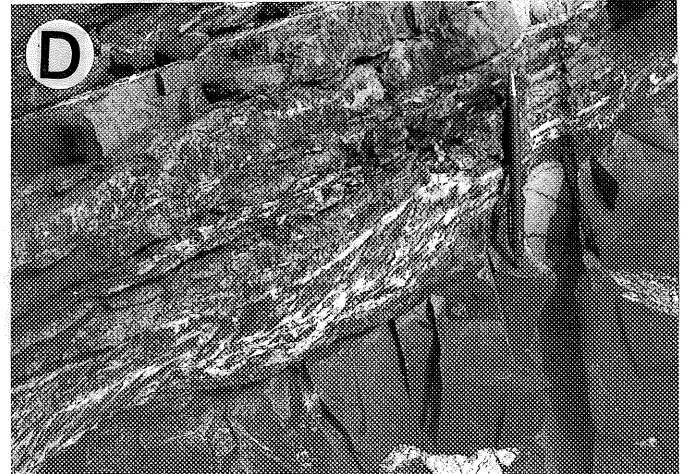
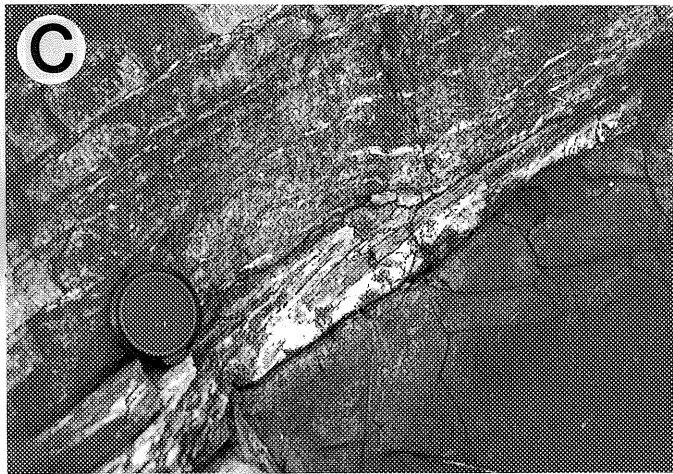
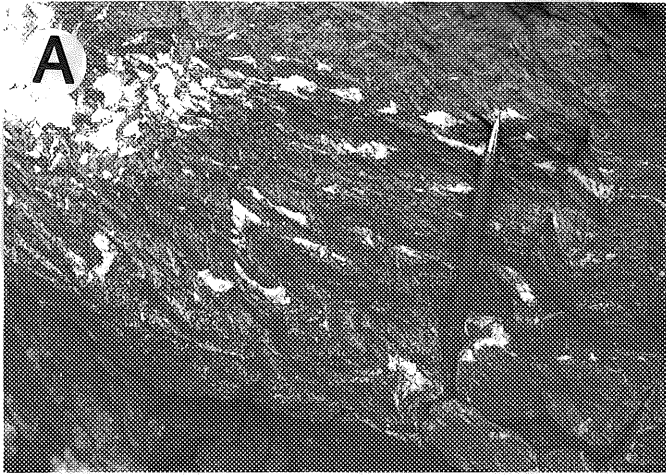
4D: Sheared dolomite, with development of an incipient cleavage, overlying the dolerite wedge.

4E: Asymmetric, Z-shaped folds in dolomite, immediately below a thrust fault overlain by dolerite.

4F: The steeply oriented shear-zone, consisting of bands of highly altered dolomite.

4G: Quartz-carbonate veining developed in dolerite immediately below a thrust fault separating dolomite from the underlying dolerite.

4H: Small folds within the talc-carbonate schist in the sill footwall. The fold is defined by a narrow shale band. Note also the slickensides beneath the folded layer.



East-trending profile

The dolerite sill is exposed over an east-trending profile extending approximately 90m. Figure 5 illustrates the well-exposed western half of the section, approximately 55m in length.

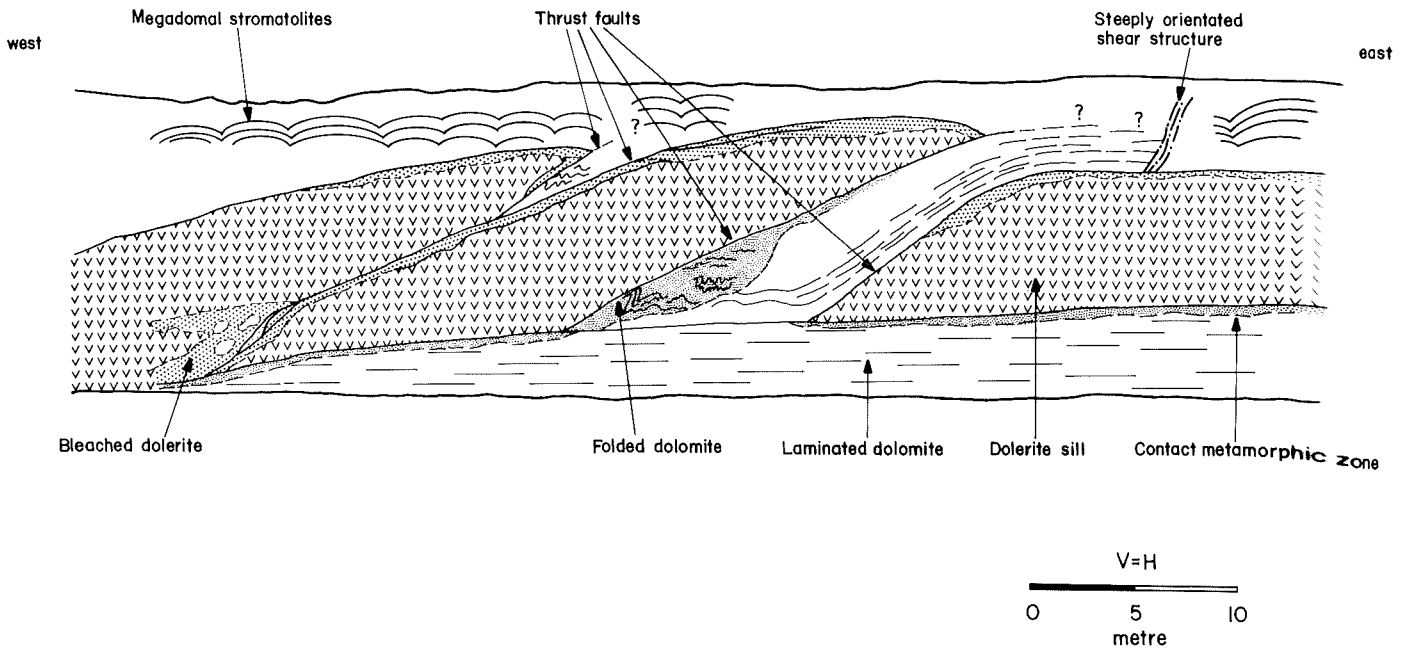


Figure 5: A profile through the deformed sill exposed in the road-cutting between Sudwala and Rosehaugh.

Four fault-bounded blocks can be recognised, forming a large imbricate structure. Three of the blocks consist of dolerite, while the fourth is composed of planar-laminated, cherty dolomite. The easternmost block (Fig. 5) is continuous with the sill described in the north-trending section (Fig. 2) and simply extends around the corner of the road. The sill pinches out, as a tapered wedge down to the west (Fig. 4B). Planar-laminated dolomite overlies the wedge, with its bedding similarly inclined. Moving to the west, off the wedge, bedding assumes a subhorizontal attitude across a monoclinial fold in the dolomite. Slickensides and small easterly verging folds (Fig. 4C), as well as zones of intense shearing (Fig. 4D) are present in a narrow thrust zone along the dolomite-sill contact and indicate transport up the wedge. In the centre of the mapped section a dolomite block occurs between the two dolerite units. Towards the centre of the dolomite block, bedding is concentrically folded. Initially, the folds are gently undulose and open in form, tightening to the west. The westernmost folds, which are immediately overridden by dolerite are highly asymmetric, overturned Z-shaped folds with extensive flexural slip along bedding planes (Fig. 4E). Narrow, curved, quartz veins occupy the hinge zones of many of the folds and the dolomite has been recrystallised and silicified to form a sugar-textured lithology within the block. The dolomite block has overridden the dolerite wedge and planar laminated dolomite has been transported up to the stratigraphic level now occupied by the megadomal dolomite. The laminated dolomite is separated from the megadomal unit by a steep shear zone which steps off the fault between the dolomite and the underlying dolerite. The shear is approximately 75cm wide, strikes north and dips between 70 and 80° to the west. The shear zone consists of bands of recrystallised, highly-altered dolomite (Fig.

4F). These bands have a sinuous form and range between 1 and 3cm thick. The bands are closely spaced and anastomose around blocks of planar-laminated dolomite. At the centre of the shear zone, the bands are closely spaced and form an almost continuous structure, with no little or no undeformed dolomite remaining between the bands. Towards the boundaries of the shear zone, bands are more widely spaced and are seen, in some cases, to pinch closed, with the form of lens-like bodies of altered, chertified dolomite. This resistant, partly chertified material stands out positively from the highly weathered dolomite at the top of the exposure. At this locality, the exact contact relationships in the vicinity of the steep shear zone are obscured by deep weathering and oxidation of the lithologies.

Carbonate-quartz veining is present along the fault separating the dolerite sill from the overlying, planar-laminated dolomite block (Fig. 4G). Curvilinear, easterly dipping gashes project from the vein into the overlying dolomite and underlying dolerite. The dolerite beneath the fault is bleached to a pale cream lithology, which oxidizes brick-red. This alteration extends up to 80cm beneath the fault. Coarse, euhedral pyrite is present within the bleached zone, as a 4cm-wide band, subparallel to the fault structure and situated about 30cm from it. A thick, talc-carbonate band is present beneath the dolerite blocks and shear bands, slickensides, and small folds (Fig. 4H) all indicate that extensive shearing has been localised within this lithology, which is the sole thrust for the entire imbricate complex. Beneath the dolomite block the sole thrust is situated within a narrow 5cm-wide carbonaceous shale band, overlain by carbonate vein material. The shale band does not bear any slickensides but is polished. The westernmost blocks of the imbricate complex consist entirely of dolerite sill material. They structurally overlie the intensely folded portion of the dolomite block and are separated from it by a westerly dipping fault. A narrow selvage of talc-carbonate schist is present and forms the shear, which dips west at 30°. A narrow westerly dipping fault separates the two dolerite blocks and steps off the sole thrust within the talc-carbonate rock beneath the dolerite. Intense bleaching of the dolerite is present around this inclined fault. Narrow quartz-carbonate veining and extensional quartz-fibre lineations are present within the fault zone and fine-grained disseminated pyrite is developed within the bleached rock. Small rafts of unaltered dolerite are sporadically preserved within the bleached halo around the fault. Lensoid fault-bounded blocks are present within the fault zone towards the western end of the exposure. Here, the alteration halo is particularly wide, and in places extends more than 2m from the fault.

No clearly defined roof-thrust could be identified and, consequently, the structure cannot be described as a duplex. The fault separating the two dolerite blocks, in the western half of the mapped exposure, passes upwards into highly weathered dolomites and is lost. Similarly, the steeply dipping shear zone on the eastern end of the exposure is obscured by oxidation and weathering of the overburden.

DISCUSSION

The structure exposed within the roadcut is an easterly verging imbricate complex, involving a pre-Bushveld metadolerite sill. Structural indicators, such as the imbrication of the sill, duplex-like features in the sole-thrust, folds in the dolomite horse and the talc-carbonate lithology, together with the orientations of slickensides and quartz

fibre-growths within the shear zones show an ESE transport direction (Fig. 3) for the thrusts, with a minor ENE transport direction also indicated. Data from the nearby Elandshoogte Mine (Harley, in prep.) show identical transport directions from fault zones associated with the well-mineralised Elandshoogte Reef.

Fluids involved during deformation are evident by the carbonate quartz veining associated with the faulting and the bleaching of the dolerite around the faults. Subeconomic gold values are present within the fault-related veins exposed in the roadcut. In the Sabie-Pilgrims' Rest Goldfield several deposits are associated with dolerite sills and dykes (eg. Bourkes Luck Mine, Barnard, 1958; Astra Mine, Zietsman, 1967; Vaalhoek, Reinecke and Stein, 1929; Malidyke, Zietsman, 1967; part of Rietvallei Mine, Visser and Verwoerd, 1960; the Barrets-Berlyn Mine, Visser, 1956). Gold mineralisation associated with a faulted dolerite sill has been economically exploited within the Olifantsgeraampte and Mamre Mines south of Sabie (Tyler, 1989; Meyer et al., 1986; Visser and Verwoerd, 1960). These deposits characteristically contain abundant copper minerals and it is significant to note that the dominant sulphide mineralogy within the present study area is chalcopyrite and pyrite.

The style of alteration within the sill is also similar to that within Olifantsgeraampte Mine. Both show a bleaching of the dolerite as a symmetric halo around the veining. The bleached zone is characterised by replacement of the primary lithology by a fine-grained mass of sericite, carbonate, and quartz. Iron-rich minerals, mostly ilmenite within the sills, also show alteration and partial replacement by pyrite.

The occurrence of a dolomite block within the imbricate structure can be interpreted as resulting from at least two different scenarios (Fig. 6): (1) deformation of an echelon set of dolerite intrusives or (2) a stepped sole-thrust and out-of-phase thrust deformation. These two situations are briefly discussed:

- (1). En echelon sill emplacement has been described by Bussell (1989) and Nicholson and Pollard (1985). In the case of the outcrops along the Sudwala roadway, prior to thrusting (Fig. 6a, stage 1), the two en echelon sills would be separated laterally from each other by planar-laminated dolomite. During deformation, eastward-directed thrusting telescoped the structure. The dolerite sill to the west of the dolomite block underwent faulting and was thrust over the dolomite (Fig. 6a, stage 3). During this stage of the deformation, folds formed within the dolomite horse as it underwent lateral shortening and a vertical thickening. A point was reached at which it was easier to thrust the dolomite over the eastern sill rather than to continue folding the dolomite. This scenario predicts a fairly small total shortening across the structure, and an estimate of less than 15m of shortening is based on the mapping.
- (2). The second scenario is considerably more complex. A reconstruction of a possible sequence of events, the culmination of which will be the present day structure of the Sudwala duplex is shown in Fig. 6b. Initial thrusting occurred along a stepped sole thrust (Fig. 6b, stage 2), which cut upsection through dolomite to intersect the thrust plane located at the base of the sill. Thrusting placed folded planar-laminated dolomite on the level initially occupied by the sill, which now occurs as a broad antiformal fold. Out-of-phase thrusting has to be invoked to behead the antiformal fold as well as slicing

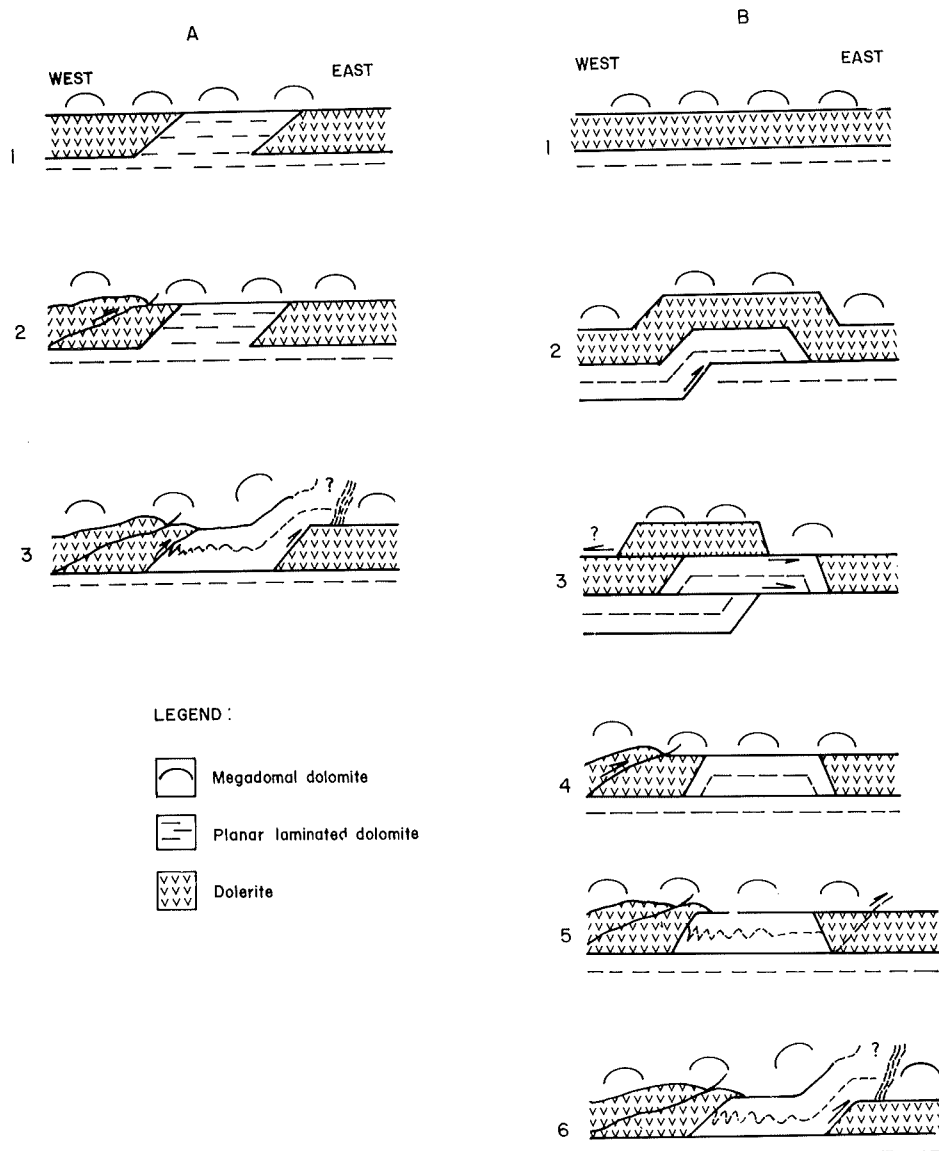


Figure 6: Cartoon, showing two possible mechanisms for producing the present day configuration of the sill.

through the folded planar laminated dolomite at the level of the sill footwall (Fig. 6b, stage 3), isolating it from the underlying dolomite unit. Continued thrusting of the composite sill-dolomite package would have displaced the antiformal fold which is not evident in the mapped section. Imbrication of the dolerite and dolomite occurred during this phase of deformation (Fig. 6b, stages 4, 5, and 6) to give rise to the present day configuration of the sill. This mechanism implies several 10's to 100's of metres of shortening, in contrast to scenario 1.

Comparison of the two proposed mechanisms, which admittedly, are not the only possibilities, suggests that the first, and simplest solution should be favoured. The amount of displacement required for the first mechanism is a lot less than that of the second, and field evidence also

favours small displacements along individual faults. The lack of a metamorphosed selvage beneath the dolomite horse is considered critical evidence to support scenario 1. Assuming that the dolerite sill was initially continuous presupposes that the contact metamorphic halo beneath it should also be continuous. The implied transport of the dolomite horse would place it above the contact-metamorphosed rock. Clearly this is not the case and an en echelon model of sill emplacement should be favoured. The cause of the thrusting is at present unresolved, but is clearly related to the contractional deformation accompanying mineralisation in the Sabie-Pilgrim's Rest Goldfield (Zietsman, 1967: Harley, in prep.). This has been suggested to be related to flexural slip and outward displacement of Transvaal Sequence lithologies accompanying emplacement of the Bushveld Igneous Complex (Harley, in prep.).

Important features of the Sudwala roadway exposure are summarised as follows:

- 1) gold mineralisation occurs within quartz-carbonate-sulphide veins associated with thrust deformation;
- 2) structural indicators show an eastwards directed transport direction, consistent with deformation in other, well-mineralised deposits within the goldfield;
- 3) mineralisation post-dates the emplacement of the sill, which is considered to pre-date the emplacement of the Bushveld Igneous Complex; and
- 4) a sill-related gold occurrence occurs in close stratigraphic and spatial proximity to a flat reef gold deposit at Elandshoogte Mine. Both occur within the upper Monte Christo Formation, laterally within 3km of each other.

ACKNOWLEDGEMENTS

The field work for this project was done as a part of the SA Geological Survey SAMINDABA project in the Eastern Transvaal and logistic support is gratefully acknowledged.

M. Hudson, Mrs. L. Whitfield and Mrs. J. Long provided valuable technical support in the production of this document. Discussion with G. Hery and P. Wipplinger also contributed to this publication.

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