ECONOMIC GEOLOGY RESEARCH INSTITUTE

HUGH ALLSOPP LABORATORY

University of the Witwatersrand
Johannesburg

LITHOLOGICAL CONTRASTS AND CONSTRAINTS ON GOLD MINERALIZATION IN GRANITOIDS IN THE ZIMBABWE CRATON: STRUCTURAL CONTROLS AND IMPLICATIONS FOR EXPLORATION

S. KALBSKOPF and T. NUTT

INFORMATION CIRCULAR No. 370

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

LITHOLOGICAL CONTRASTS AND CONSTRAINTS ON GOLD MINERALISATION IN GRANITOIDS IN THE ZIMBABWE CRATON: STRUCTURAL CONTROLS AND IMPLICATIONS FOR EXPLORATION

by

S. KALBSKOPF[1] and T. NUTT[2*]

([1]S K International Geoconsultants, P.O. Box 6084, Pietersburg North, 0750, South Africa
[2]Tim Nutt & Associates, P. O. Box 296 Wellington, 7654, South Africa)
**** deceased***

ECONOMIC GEOLOGY RESEARCH INSTITUTE
INFORMATION CIRCULAR No.370

March, 2003

LITHOLOGICAL CONTRASTS AND CONSTRAINTS ON GOLD MINERALISATION IN GRANITOIDS IN THE ZIMBABWE CRATON: STRUCTURAL CONTROLS AND IMPLICATIONS FOR EXPLORATION

ABSTRACT

At least 24% of all Zimbabwean Archaean gold originates from granitoid rocks or greenstone xenoliths within granitoids. In terms of aerial yield, internal intrusives are twice as productive as the remainder of the greenstone succession and yield 4 times as much gold as marginal external granitoids. More than 98% of the output is attributed to tonalitic I-type granites and their gneissic derivatives and 96% of all gold obtains from mines <2 km from a greenstone belt margin. Two thirds of all deposits exhibit significant lithological control, and shear-hosted ore bodies exploiting competency contrast between xenoliths and granite are responsible for the bulk of the output. Of these sites, mafic wallrocks account for approximately 70% of all xenolith-related production. In most of the examples presented, significant gold deposition has occurred in mesothermal environments accompanying brittle-ductile tectonism within second-order structures associated with regional shears bounding the margins of greenstone belts, and where major fissures intersect or impinge internal granitoid bodies. The presence of xenoliths and wallrock heterogeneities induces P-T-X changes that enhance gold precipitation and determine the specific shape of payshoots. Mafic wallrocks allied to metavolcanic and ironformation inclusions, generate sulphidation reactions that effectively scavenge gold out of solution, giving rise to the bulk of the deposits. The concentration of gold deposits along the periphery of external granitoid massifs mirrors the abundance of favourable structures. These marginal shears originate due to the competence contrast with the neighbouring greenstones exploited during cratonic shifting. The abundance of gold reefs can also be explained by metamorphic devolatilisation of adjoining greenstones producing auriferous fluids that migrate into these proximal fissures.

In terms of exploration potential, the most prospective ground in granitoid terrane will lie immediately adjacent to a greenstone belt, in tonalitic granite with major tangential shears containing semi-digested mafic greenstone relics, and, where mafic dykes and felsite intrusions exploit pre-existing shears. Such conditions prevail at many localities along the relatively well-exposed, eastern margin of the Midlands and Bubi greenstone belts where the bulk of the known deposits occur. However, the partly obscured western margins of these terranes must be considered as promising once the shallow cover can be penetrated.

____________________oOo____________________

LITHOLOGICAL CONTRASTS AND CONSTRAINTS ON GOLD MINERALISATION IN GRANITOIDS IN THE ZIMBABWE CRATON: STRUCTURAL CONTROLS AND IMPLICATIONS FOR EXPLORATION

CONTENTS

oOo

Published by the Economic Geology Research Institute
(incorporating the Hugh Allsopp Laboratory)
School of Geosciences
University of the Witwatersrand
1 Jan Smuts Avenue
Johannesburg
South Africa

http://www.wits.ac.za/egru/research.htm

ISBN 186838-325-3

LITHOLOGICAL CONTRASTS AND CONSTRAINTS ON GOLD MINERALISATION IN GRANITOIDS IN THE ZIMBABWE CRATON: STRUCTURAL CONTROLS AND IMPLICATIONS FOR EXPLORATION

INTRODUCTION

While the bulk of the gold production from Zimbabwe's Archaean granite-greenstone terrane has emanated from the volcano-sedimentary pile, a significant percentage is derived from mines in granitoid bodies, both internal and external. Published data for mines exceeding 100 kg output, to the end of 1984 (Bartholomew, 1990), representing 96% of Zimbabwe's total gold production, indicates that 24% of Zimbabwe's gold has been derived from granitoid rocks (Table 1). Even discounting the contribution of the Globe and Phoenix Mine (the country's second largest producer), the proportion of granitoid gold still amounts to 21%, thus emphasising the importance of small mines in granitic terrane. In a country where smallworkers (traditionally <300 t.p.d.) have numerically dominated the gold mining industry, a study of these deposits still has direct economic relevance to the nation.

To qualify as a granitoid-hosted deposit, the orebody must meet the following criteria:

(1) it must directly abut a granitic lithology; one sidewall must be granitic except for reefs in xenoliths, see (2);
(2) the mineralisation may occur within a xenolith wholly surrounded by granitoid rocks; and
(3) it must be situated in Archaean terrane.

The aim of this paper is to revise some of the more important production statistics, to focus on the particular role of xenoliths in granitic rocks in localising gold mineralisation by highlighting new and known deposits, and to present a broad structural model. The latest statistics broadly concur with Mann's (1984) conclusions for the distribution of granitoid gold deposits, and 97,6% of the gold obtains from 96,2% of the mines in granitoids rocks of tonalitic affinity.

Production data for selected areas has been drawn mostly from Zimbabwe Geological Survey bulletins, supplemented by more recent information acquired by one of us (S.K.) from the Ministry of Mines and private work.

The term 'granite' is used in the broadest sense of the word to denote a felsic, medium- to coarse-grained igneous rock ranging in composition from adamellite, through monzonite to granodiorite, and including the more mafic end-member tonalite-trondhjemite suite. 'Granitoid' is a broad, all encompassing, term embracing the former categories, plus material with a dioritic composition and their gneissic equivalents as well as some felsites. Felsite is commonly used by the Zimbabwean mining fraternity as a colloquial designation for a fine-grained, massive, siliceous, felsic intrusion, but most of these bodies are fine-grained quartz or feldspar porphyries, but may represent altered granites in some areas.

IMPORTANCE OF GRANITOID GOLD

Table 1 lists the production from 212 mines (or groups of deposits) declaring >100 kg with a combined output of 353,3 t of gold until the end of 1984. This total represents 24% of the entire gold output of 1481,84 t for the Archaean craton. Even allowing for the fact that this also includes gold for mines in the 100-311 kg range, it still represents a huge increase in gold output compared to the figures for mines in the +311 kg range for the period ending in 1977 (Foster et al., 1986). While one reason for the discrepancy could be the inclusion of 40t of gold from the Globe and Phoenix Mine and 17t from Rezende Mine, it also illustrates the importance of smaller mines that were not included in Foster et al’s statistics.

Table 1: Gold output according to terrane (see also Fig. 1)

Terrane	Gold Production (kg)	% of Production	No. of Mines	%	Kg gold to 1977 (2)	% of Production
Chilimanzi Suite	4304.91	1.22	9	4.3	3161.51	2.4
Sesombi Suite	156 522.55	44.30	66	31.1	36 253.81	27.5
Penhalonga Diorite & Felsite	32 260.93	9.13	9	4.3	10 207.85	7.7
Rhodesdale Gneiss Terrane	85 009.89	24.06	62	29.2	53 318.37	40.5
Gneisses (inc.>2.8 Ga basement)	39 803.68	11.27	50	23.6	24 369.94	18.5
Mont D’Or Formation	30 907.29	8.75	14	6.6		
Uncertain [1]	4 522.81	1.28	2	0.9	4 432.53	3.4
Totals	353 332.06	100.00	212	100.0	131 744.01	100.0

1. Ayrshire and Inyanga North group
2. Only for mines exceeding 311 kg (Foster et al., 1986)

In contrast to earlier figures, output has been dominated by production from the tonalite-trondhjemite granitoid bodies of the Sesombi Suite (Fig.1) that have produced 44% of the gold. Since the Mazowe, Bindura and Penhalonga stocks are consistently prolific and permit bulk underground mining, the pre-eminence of Sesombi-associated gold is likely to continue.

The inclusion of the Mont D’Or Formation, south of Shurugwi, is debatable since Stowe (1968) indicated that this series was derived by granitisation of arenaceous sediments with minor pelites and greywackes. However, mapping by Cotterill (1979), Zimasco geologists (M. Tsomondo – pers. comm.) and the authors, suggests that metasediments and metavolcanics are minor components, representing greenstone belt remnants within a tonalite core. Because of the close spatial and genetic association with the Penhalonga quartz-diorite stock, data from the Old West-Redwing felsite has also been included.

Mann (1984) calculated that the combined production for all granitoid gold mines up to 1977 amounted to 124t (9% of the total from the craton), but his selection criteria were more rigorous in that they have not accounted for orebodies that are entirely enclosed within small greenstone inliers surrounded by a granitic host. However, these earlier figures compare more closely with data from the Yilgarn Block, Western Australia (Ho et al., 1990), where the proportion of gold emanating from granitoid-hosted mines amounts to 3%, with 5,4% derived from orebodies in felsic porphyries.

Since 1994 the contribution of the Freda Rebecca Mine (currently Zimbabwe’s largest producer at *c*. 3.3 t.p.a.) accounts for a steady 15 - 18% of the country’s annual output. In addition, several granitoid-hosted gold mines have major ore resources that could sustain mining for 5-10 years, given a favourable economic climate (Table 2).

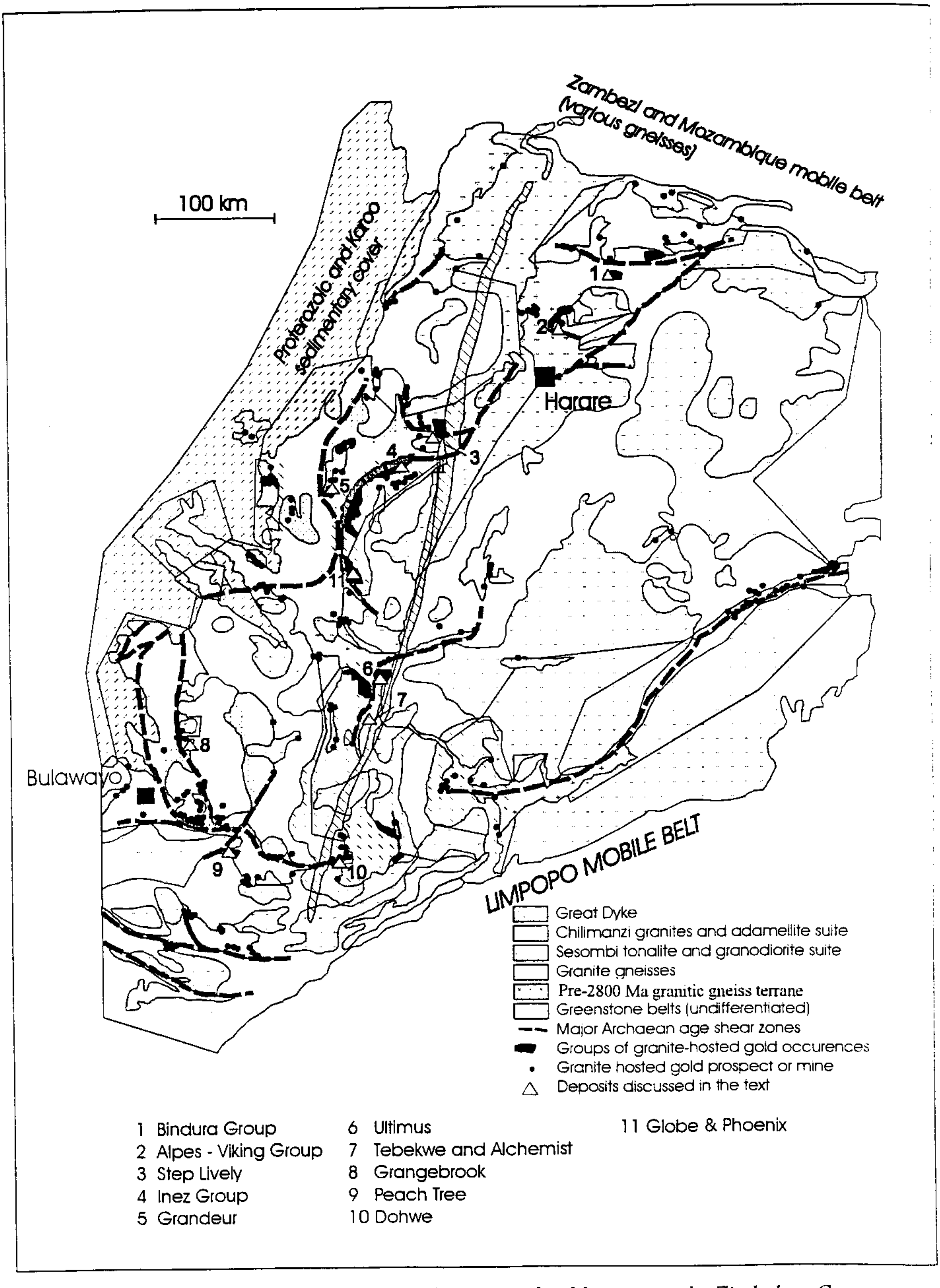

Figure 1: *Distribution of granitic rocks and associated gold mines on the Zimbabwe Craton (modified after Mann, 1984).*

Table 2: Geological summary of granitoid-hosted mines discussed in the text

NAME	Host Rock	Style -Structure	Alteration	Mineralogy[1]	Resource 10^6 tonnes @ g/t	Output Kg g/t	Setting
Freda Rebecca	Diorite (Granodiorite)	Disseminations in low angle shears	Sericitic, silica, carbonate, chloritic, potassic	**py,** po, sch, *apy, (gersdorffite)*	15.9 @ 2.6	33 305 1.88	Mafic phase
Mazowe	Granodiorite, dacite porphyry, (mafic greenstone)	Low angle shear-hosted sulphidic quartz veins	Sericitic, pyritic, Chloritic, carbonate	**py, cp, apy,** sch, sph, gn, *mo, Bi, bt; (Bite, co)*	1.2 @ 13.9	39 100 8.63	Mafic phase
Eureka	Granodiorite	Sheeted quartz veins	(Silicification, potassic)	**mo, sch,** *(cp, po)*	10.5 @ 2.9	1 747 1.44	Intra-belt granite Marginal shears
Viking	Adamellite (mafic greenstone)	Shear-hosted disseminated sulphides & quartz stringers	Actinolite, calc-silicate, biotite	**py,** po, *ch, sch*	<0.2 @ 5.0	184 4.51	Hangingwall of mafic xenolith
Alpes	Adamellite (mafic greenstone)	Quartz vein on sheared contact	Chloritic	**py,** po, *(gn, Au)*		453 26.2	Hangingwall of mafic xenolith
LWD	Granodiorite (mafic schist)	Shear-hosted quartz vein	Actinolite, potassic, sericitic	**py,** po, sch, *gn, (Au, mo, fluorite)*		4.60	Footwall mafic xenolith
Step Lively	Granodiorite, serpentinite (diabase)	Shear-hosted quartz vein oblique to ultramafic xenolith along dyke margin	Potassic? Chloritic, (carbonate)	**Bi,** bt, *py, sch, (mo, po, bn, Au)*	<0.03 @ 10.0	638 7.19	Xenolith
Inez	Amphibolite - ultramafic schist in tonalite gneiss	Quartz vein + minor stockwork in xenolith and along buck quartz vein	Carbonate, silicification, (sericitic)	sb, py, *cpy Au, (tet, gn)*		4045 12.5	In xenolith
Inez East	Ultramafic (schist)	Shear hosted quartz vein and breccia	Silicification, carbonate	**chr, mal, di,** cpy, *bn, py, cu, covellite, cc, (sb, Au)*	0.05 @ 5.5	245 8.05	In xenolith
Brompton	Felsite, tonalite gneiss (amphibolite)	Thrust stacked quartz veins	Sericitic, carbonate (propylitic?)	**Py, sb** gn, sph, sch, *apy*	>0.10 @ 6.0	7750 9.10	In felsite dyke

Table 2: (contd.)

Redwing - Old West	Porphyritic rhyolite in quartz-diorite	Disseminated sulphides in fractures & quartz veinlets	Potassic	Py, gn, sch, sph, apy, covellite, marcasite	>5.0 @ 3.6?	24970 4.0	Felsite sill
Alchemist	Adamellite, amphibolite	Mineralised quartz on hangingwall of buck quartz	Chloritic	**Mal**, chr, *cpy*, *py*	0.07 @ 4.5	78 5.40	Greenstone margin
Dohwe	Tonalite, serpentinite	Laminated quartz vein along buck quartz	Sericitic	*(Mal, az)*		1 5.0?	Greenstone margin
Tebekwe	"Felsite", mafic greenstone, schist, serpentinite, granite	Quartz veins along lithological boundaries	Carbonate, sericitic, silicification	**Py, gn, sph**, cpy, apy, po, sch, *(co)*	0.60 @ 5.5	20 635 9.18	Greenstone margin
Ultimus	Granite stock in argillite & amphibolite	Stockwork next to regional shear	Sericite	**Py**, *gn*	1.22 @ 1.0	148 3.70	Intra-belt granite
Grangebrook	Granite in andesitic greenstone	Quartz vein	Sericitic	**Py**, cpy, gn, sph, mal, sch, *(cc, tet)*	0.10 @ 5.1	290 5.69	Intra-belt granite
Lone Star	Granodiorite	Quartz veins & stacked fracture zones (±stockwork)	Chloritic, carbonate, (tourmaline)	**Py**, gn, sph, sch, cpy, *po*, *apy*	3.0 @ 1.97	22 6.95	Intra-belt granite
RAN	Granodiorite, meta-greywacke	Quartz veins bounding porphyroid dykes	Potassic, tourmaline, silicification	**sch**, **py**, mo, *cpy (Bi)* in granodiorite; **py, cpy,** po, gn, sch,*apy*, *mo*, *(co, sb,)* in metagreywacke	1.5 @ 3.5 0.43% Cu	2302 6.62	Orthogonal shear
Bindura Kop	Granodiorite, metagreywacke	Tourmaline-quartz ± amphibole rock with mineralised quartz gash veins	Tourmaline, Silicification	Py, cpy, apy		35 1.95	Orthogonal shear
Globe and Phoenix	Talc-carbonate schist magnesite rock, Tonalitic gneiss (diabase, keratophyre dykes)	Quartz veins in conjugate shears sub-parallel & orthogonal to gneiss– serpentinite contacts die out in talcose schist	Propylitisation, carbonate, Sericite, fuchsite, silicification	**Gn, py, sb, gn, tet,** js, Au, apy, *cpy*, *sph*, *bournonite*, *(gersdorffite)*	3.73 @ 2.6	124 660 24.90	Greenstone margin, orthogonal reefs
Phoenix Prince (Prince of Wales)	Diorite (granite, metagreywacke)	Diss. sulphides in conjugate shears and quartz veinlets	Potassic	**Py, apy, sch**, po. *gn (gersdorffite, calaverite)*	1.41 @ 0.96	15 403 4.88	In mafic phase

Table 2: (contd.)

Acres/New Year	Tonalite, diorite	Quartz vein – dilational jogs in tonalite	Carbonate, sericite	Py,gn, Au, *(cpy, sph, mo)*	0.07 @ 10.5	2200 12.27	In mafic phase
Rose of Gold	Tonalitic gneiss, diabase	Quartz veins pinch out in diabase	Chloritic	**Py, cpy**		105 5.27	Xenolith/dyke
Sabi Vlei	Tonalitic gneiss, amphibolite, serpentinite	Quartz vein & breccia pinches in mafic bands. 1 contact vein	Carbonate sericite	Py, cpy, gn, sph, *Au*		325? 4.26	Orthogonal and greenstone margin
Sabi	Mylonitic schist in gneiss	En-echelon quartz veins along buck quartz dykes in mylonite	Carbonate sericite silicification	**Py**, *Gn*	5.0 @ 5.5	±7400? 5.2?	
Grandeur	Granodiorite	Quartz veins and mineralised reidel fractures in sericitised granodiorite only	propylitic, sericite, carbonate fluorite	**Py**, mo, *(gn, bt,)*	0.7 @ 2.6	470 4.72	Altered phase
Peach Tree	Granite/tonalite	Quartz veins and disseminated sulphides in stockwork	Chloritic (carbonate)	**Py,** mo, po, cpy, *sch*	1.0 @ 1.40	356 0.44	(Xenoliths)

Mineralogy – apy = arsenopyrite; az = azurite; bt = bismuthinite; Bi = bismuth; bite = bismuth tellurides; bn = bornite; cc = chalcocite; chr = chrysocolla; co = cobaltite cpy = chalcopyrite; cu = cuprite, di = dioptase; Au = visible gold; gn = galena; jm = jamesonite; mal = malachite; mo = molybdenite; py = pyrite; po = pyrrhotite; sb = stibnite; sch = scheelite; sph = sphalerite; tet = tetrahedrite/tennantite;

Abundant and common = **py**
Uncommon = py
Rare = *py*
Trace = *(py)*

Production from granite-hosted gold mines from 1985-2000 amounts to *c.* 92t, which accounts for approximately 29% of Zimbabwe's gold yield in this period. Hence, granitoid gold is supplying an increasing share of the national output. In terms of areal yield (Table 3), internal granitoid intrusions are the most prolific, but this is biased by the huge outputs from the Mazowe, Bindura and Penhalonga stocks.

Table 3: Gold yield[1]

Terrane	kg/km^2
Entire Zimbabwe Craton	11.06
Greenstone belts (excl. internal granites)	41.56
Internal granitoids	87.80
External granitoids	3.43
External granitoids >4 km from greenstone margins	0.04

[1] These data are based on approximate outputs to 2000 from **all** mines.

Average yields for the marginal external zones fall in the range 15-26 kg/km^2, although this figure is much higher in the Rhodesdale Gneiss and Mont D'Or Formation, and considerably lower elsewhere. This increased productivity may be due, in part, to the proximity of major craton-scale shear zones to granite-greenstone contacts.

AGE DATA

Limited age data obtained by Pitfield and Campbell (1994) for lodes concordant to an early deformational event in the Midlands greenstone belt, reveal that the main phase of gold deposition was at 2668 ± 64 Ma, which correlates broadly with the Sesombi Suite intrusions, coeval with E-W and NW-SE compression and sinistral transpressional events. For lodes crosscutting major structures, an early Proterozoic Sm-Nd age of 2401± 0.07 Ma is associated with local D_2 NNE-SSW compression combined with sporadic magmatism along reactivated Archaean shear zones. However, 2500-2660 Ma Rb-Sr dates for the Mazowe and Bindura granodiorites (Frei, 1995) indicate some reworking during the Chilimanzi thermal event, which probably acted as a heat engine for mineralisation in the southern part of the Bindura stock.

Table 4: Typical granitoid age ranges

Chilimanzi Suite	2601 ±15 Ma
Bindura Granodiorite	2617-2680 Ma
Mazowe Granodiorite	2640-2664 Ma
Sesombi Suite	2667-2680 Ma
Litchfield Gneiss	± 2690 Ma
Chingezi tonalite gneiss (Mberengwa)	2800-2875 Ma
Rhodesdale Gneiss	2976-2990 Ma
Shabani Gneiss	3088-3640 Ma
Mont D'Or Tonalite	3345-3670 Ma
Tokwe Gneiss	3475-3600 Ma

The figures provided in Table 4 are derived from Jelsma et al. (1996) and include data derived from U-Pb, Pb-Pb, Sm-Nd and Sr-Rb methods; thus some of the dates may refer to model ages. Nevertheless, there is sufficient clustering of data to bracket most of the units with a fair degree of confidence.

GEOLOGICAL SETTING

Mann (1984) noted that 64% of all granitoid deposits were associated with xenoliths or the margins of greenstone belts, while the present study found that 49% of the +100 kg deposits demonstrate a degree of lithological control, and these properties account for 56,4% (198,97t) of the total gold output. Anhaeusser (1976) and Mann (1984) both drew attention to the concentration of significant gold deposits occurring within close proximity to the margins of greenstone belts where semi-digested mafic inclusions and remnants are more abundant. Our research shows that 96% of the gold produced derives from 93% of the mines <2km from a greenstone belt margin. The present study of selected regions, where mapping has been updated, corroborates these findings. Gold production figures, provided in Table 5, are based on records to the end of 2000.

Table 5: Gold production from mines <2 km from selected greenstone belt margins

Area	% Production	% Mines	%Au litho[1]
Mazowe - Alpes	92.3	80.0	49.2
Kwekwe	92.9[2]	69.0	92.3[2]
Filabusi	99.7	94.7	67.0
Bulawayo East	99.3	78.2	93.5

[1] % Gold production from all granitoid-hosted mines with control imposed by lithological variation
[2] Excludes output from the Globe and Phoenix Mine, which would boost this figure to >99%

Adjacent to the larger greenstone belts the bulk of the gold is derived from lodes near-parallel to the granite-greenstone boundary. In the Rhodesdale Gneiss, this accounts for 70.6% of all output, while in the Mazowe-Alpes region, the figure rises to 99,2%.

Virtually all the mines fall into the category of shear-hosted deposits with only a few obvious examples of stockworks, such as the Ultimus, Grandeur, and Edge O'Beyond Mine, west of Commoner Mine.

A close examination reveals that while a favourable structural framework on all scales is extremely important (Pitfield and Campbell, 1994) major granitoid gold deposits occur primarily in 7 settings:

1. **Deposits along boundaries of greenstone inclusions and large buck quartz veins where there is distinct competency contrast**

At least 63,5% of the +100 kg deposits exhibiting some kind of lithological control (104 mines) are associated with either lenticular or tabular xenoliths parallel, or at an acute angle to the strike of the orebody. At least 70% of the time, these inclusions are mafic or ultramafic, usually amphibolite or chlorite schist, and these mines have yielded 69,3% of the gold (Fig. 2). In his survey, Mann (1984) found that for mines in the 100-1000 kg range, 55% of the production was derived from orebodies with mafic wallrocks, while for deposits producing more than one tonne of gold, this figure rises to 80%. Hence, reefs associated with mafic wallrocks are superior targets.

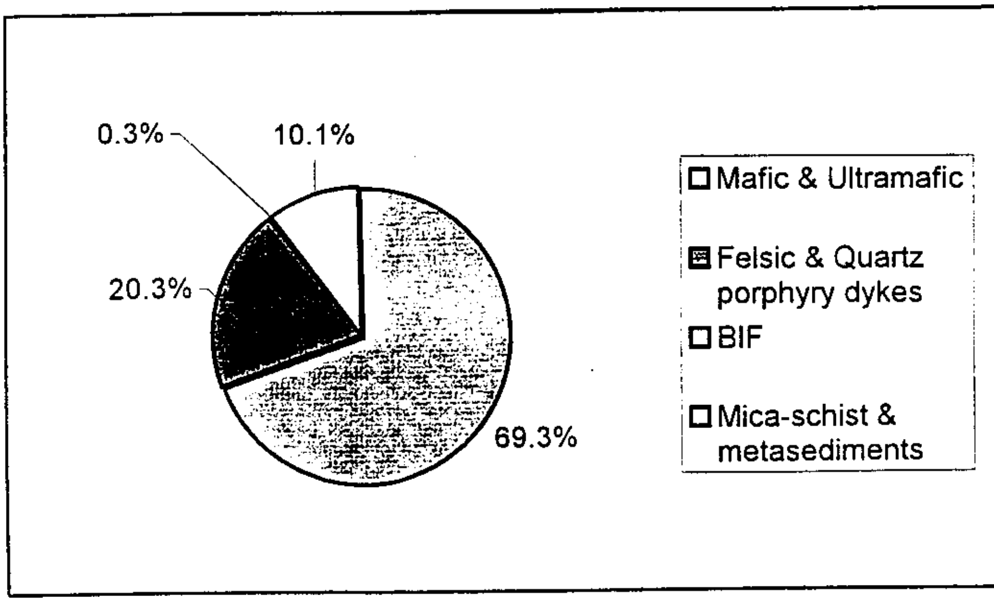

Figure 2: The influence of xenolith lithology on gold production.

Typical examples are found in the ***Alpes Goldfield***, some 20 km north of Harare (Fig. 3), and include mines such as the Viking, Dave's Luck, LWD Mine and Puzzle group on the western periphery of the Chinamora Complex (Baldock and Kalbskopf, 1991). The common E-W fissure orientation is possibly related to boundary-parallel shears associated with large-scale folding and intrusion of the Chinamora Complex accompanied by de-coupling on the granite-greenstone contact (Snowden and Bickle, 1976). Except for Dave's Luck, virtually all the deposits are based on quartz veins in ductile shears on the northern flanks of tabular metabasalt xenoliths dipping 23° to 80° N and NNE (e.g., Viking Mine, Fig. 4) Both southward-directed thrusting and strike-slip shearing are invoked.

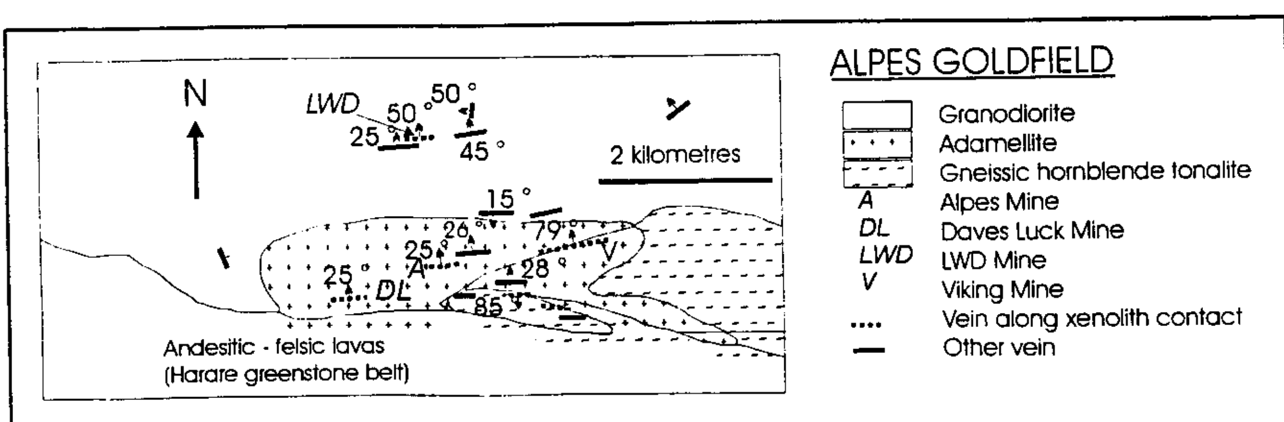

Figure 3: Simplified plan of the Alpes Goldfield, Harare District

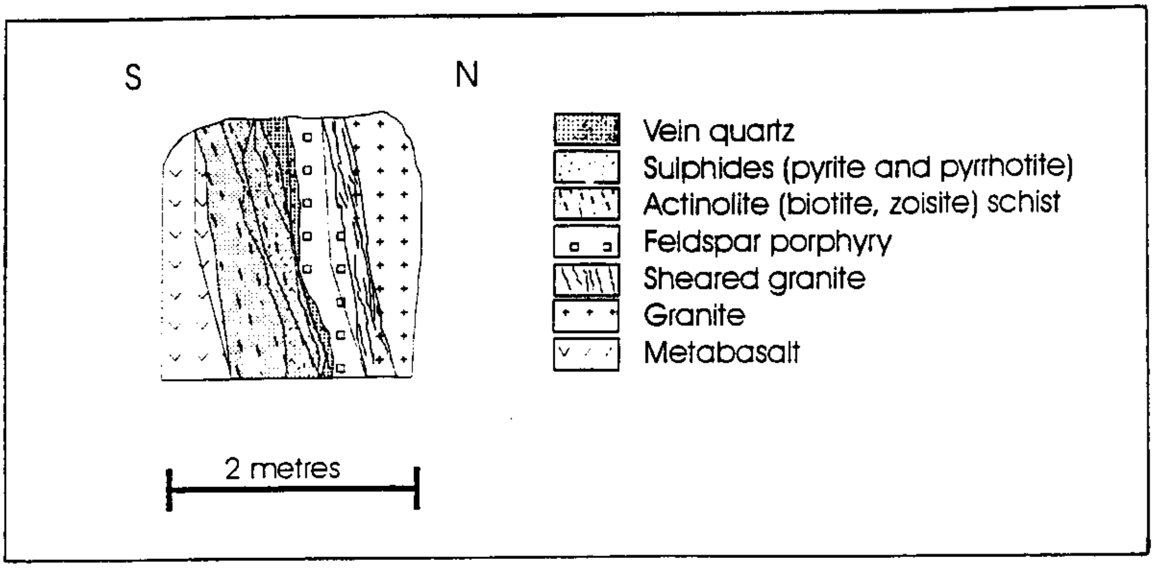

Figure 4: Schematic sketch (looking west) of drive face, Viking Mine.

The ***Step Lively Mine*** lies within a tongue of massive granodiorite in the southern arm of the Chegutu greenstone belt. The ore body consists of a shear-hosted, lenticular quartz vein paralleling a narrow, pre-mineralisation diabase dyke that cuts through a 5-15m wide, serpentine/talc schist inclusion at an acute angle (Fig.5). Where the shear transgresses from serpentinite into granodiorite country rock there is an immediate change in the character of the lode from a very lenticular form to a more consistent band with a regular, well-defined hangingwall and a patchily developed stockwork along the granite footwall.

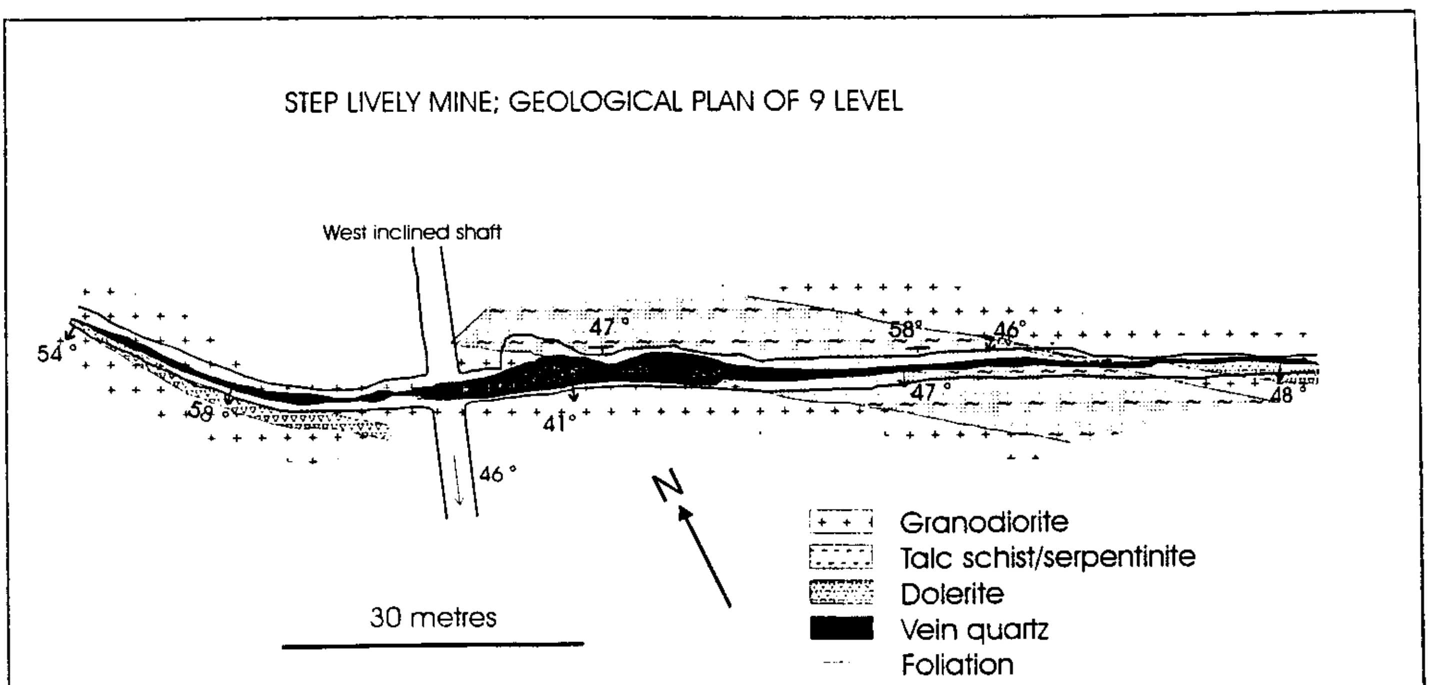

Figure 5: Geological plan of 9 Level, Step Lively Mine, Chegutu greenstone belt (see Fig.1).

The ***Rose of Gold Mine***, 8 km southeast of Kwekwe, exploited two parallel shear-hosted quartz veins 0,5-2,5m wide, dipping 72°-78° NW. Kinematic indicators point to oblique sinistral motion during thrusting from the NNW and payshoots plunge at ± 65 - 255°, parallel to some slickensides and the intersection of the shear with near-vertical diabase dykes. Where the heavily mineralised lode transgresses into these older subparallel dykes, the quartz tapers out and is replaced by barren chlorite schist with calcite stringers, although quartz still continues where the shear exploits the permeability and competency contrast along the contact of diabase and gneiss. Similar effects were noted at the ***Sabi Vlei Mine,*** Zvishavane, where the main lode is a thin quartz vein, locally encased in a narrow mylonite envelope, showing a transition to a mineralised quartz breccia caused by later brittle fracturing of the Shabani tonalitic gneiss. Where the reef cuts orthogonal bands of amphibolite and mafic gneiss, the rock exhibits a more ductile response to stress and the reef channel becomes a near-barren, 2m-wide chlorite schist band with carbonate stringers. However, the West Parallel reef is a lenticular quartz vein dipping 55°W along the contact of gneiss and ultramafics.

2. Reefs confined to larger enclaves of mafic-ultramafic rocks surrounded by granitoids

When xenoliths are relatively large and are oriented normal to the direction of shortening (maximum compressive stress), fissures preferentially exploit weaknesses within the greenstone inclusions, rather than the granitoid country rock. The ***Kingdom Mine*** 20 km east of Mazowe was based on a narrow mineralised quartz vein that transgresses from the footwall to the hangingwall of a much wider buck quartz body which is hosted entirely within a shallow-dipping felsic greenstone inclusion (Kalbskopf, 2002; Ferguson and Wilson, 1964). A similar scenario exists at the ***Inez Complex***, in the Rhodesdale Gneiss terrane, where mineralisation is largely associated with an east-striking, 3 km-long, 50 m-wide inlier of mafic-to-ultramafic composition dipping steeply southward (Wiles, 1957; Pitfield and Campbell, 1994).

At the ***Inez Mine***, the original orebody was localised, in part, along the sheared footwall boundary of amphibolite, while the main reef is a younger, laminated, quartz band that runs within and towards the hangingwall of a 2-12 m-wide buck quartz body. Some of the footwall mineralisation comprises a 1-2 m-wide stockwork that forms in carbonate-quartz-fuchsite rock traversed by pale-grey quartz veins carrying visible gold, stibnite and pyrite. The ***Inez East*** section (Fig.6) centres on the Copper Reef that consists of long lenses of pink opaque quartz superimposed on, and grading into, an indurated grey breccia derived from re-cemented, fractured and intensely silicified schist. Local thickening of the quartz vein is due to increased dilation associated with open, Z-shaped inflections, which are also sites of intensified brecciation.

3. Mineralisation within felsic intrusions in granitic rocks

The Brompton group of mines, 15 km south of Kadoma, is related to a thrust–induced lineament that parallels the regional Munyati Deformation Zone (Pitfield and Campbell, 1994). The ***Brompton Mine*** within the Rhodesdale Gneiss Terrane produced gold from a laminated quartz vein that is mostly confined within the margins of a 2-5 m-thick felsite dyke, which is more competent than the surrounding gneisses and exhibits a greater tendency to fracture during shearing. The dyke also follows the contact of a tabular amphibolite

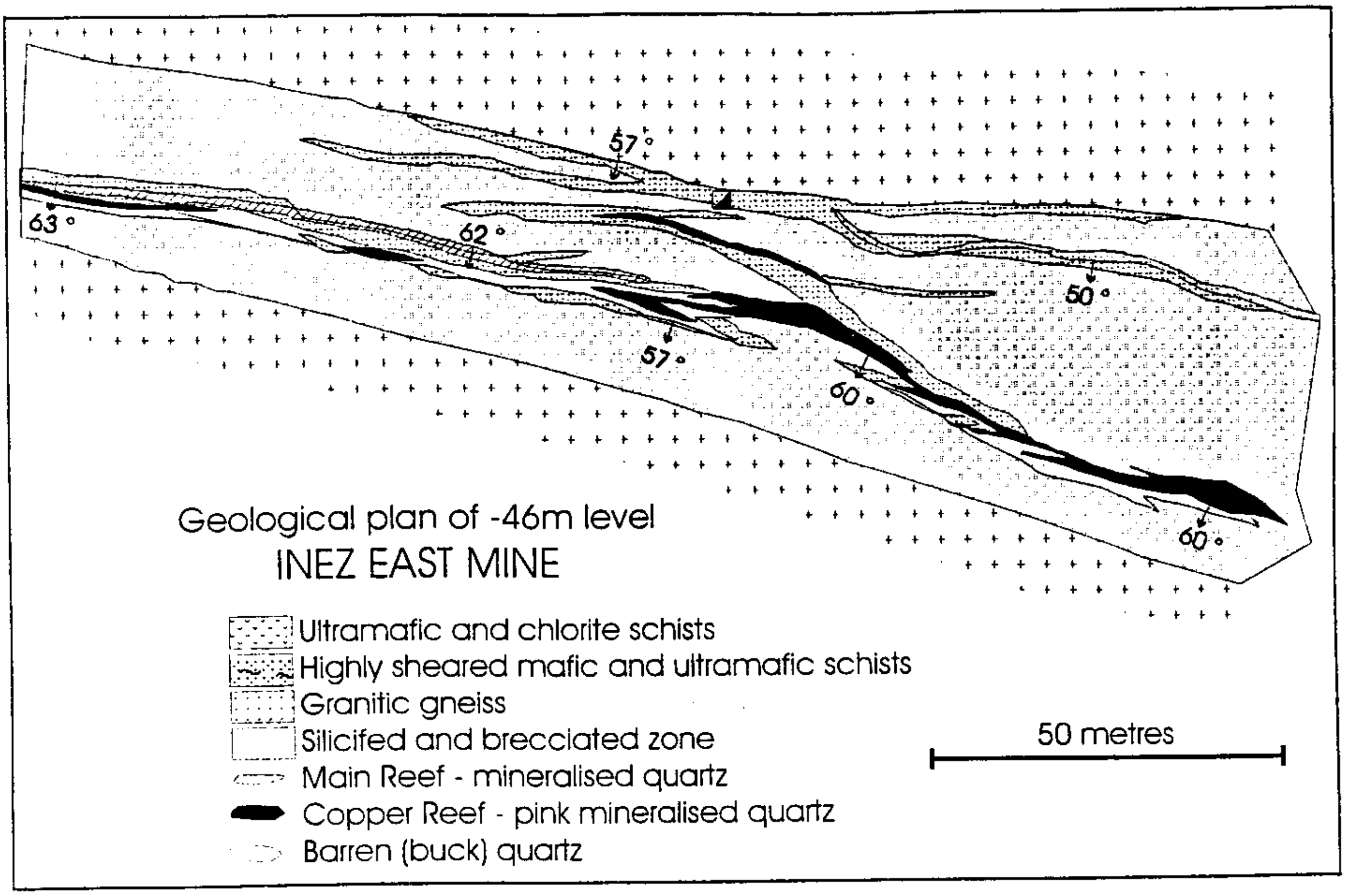

Figure 6: Plan of -46 m Level geology, Inez East Mine, Rhodesdale Gneiss Terrane (Fig. 1).

inclusion for some of its length, exploiting a pre-existing plane of weakness. Quartz veins favour thrust stacks and ore shoots are preferentially developed on Z-shaped flexures (Pitfield and Campbell, 1994).

The ***Redwing-Old West Complex*** near Mutare also demonstrates preferential mineralisation of a gently dipping, intrusive porphyritic rhyolite sill in granodiorite, in which mineralisation is concentrated along fracture cleavage planes related to thrust stacks (Schmidt-Mumm et al., 1994) In addition, sulphides focus in dilational veins selectively associated with intensely deformed rhyolite, as opposed to granodiorite, where shears die out, and where mineralisation focuses in more isolated sulphidic quartz veins (Harrison, 1979).

4. Orebodies along greenstone belt margins

The ***Alchemist*** lode, south of Shurugwi, forms the boundary between massive adamellite in the hangingwall and a tongue of mafic schist in the footwall to the NW, which dips upwards of 75° SE. The greenstone-granite contact is marked by a glassy- to buck-quartz vein 1-5 m wide, but economic ore is limited to 20-100 cm of heavily mineralised, brecciated quartz bounding the hangingwall. The ore zone exhibits a gradual transition to less mineralised, fractured white quartz towards the footwall. At the ***Dowhe 10-12 Claims***, west of Mberengwa, gold mineralisation is associated with broad, right-stepping, near vertical, *en echelon* quartz lenses injected within shear zones along and within the 50-500 m-wide Gurumba Tumba serpentine body that intrudes banded and massive tonalite (Fig. 7). Mining concentrated on laminated mylonitic quartz along the hangingwall margin of a 10 m-wide massive, pale-grey, buck-quartz outcrop. The occurrence is allied to the Germania and adjacent Golden Vein mines that occur along strike, and several other reefs, such as the

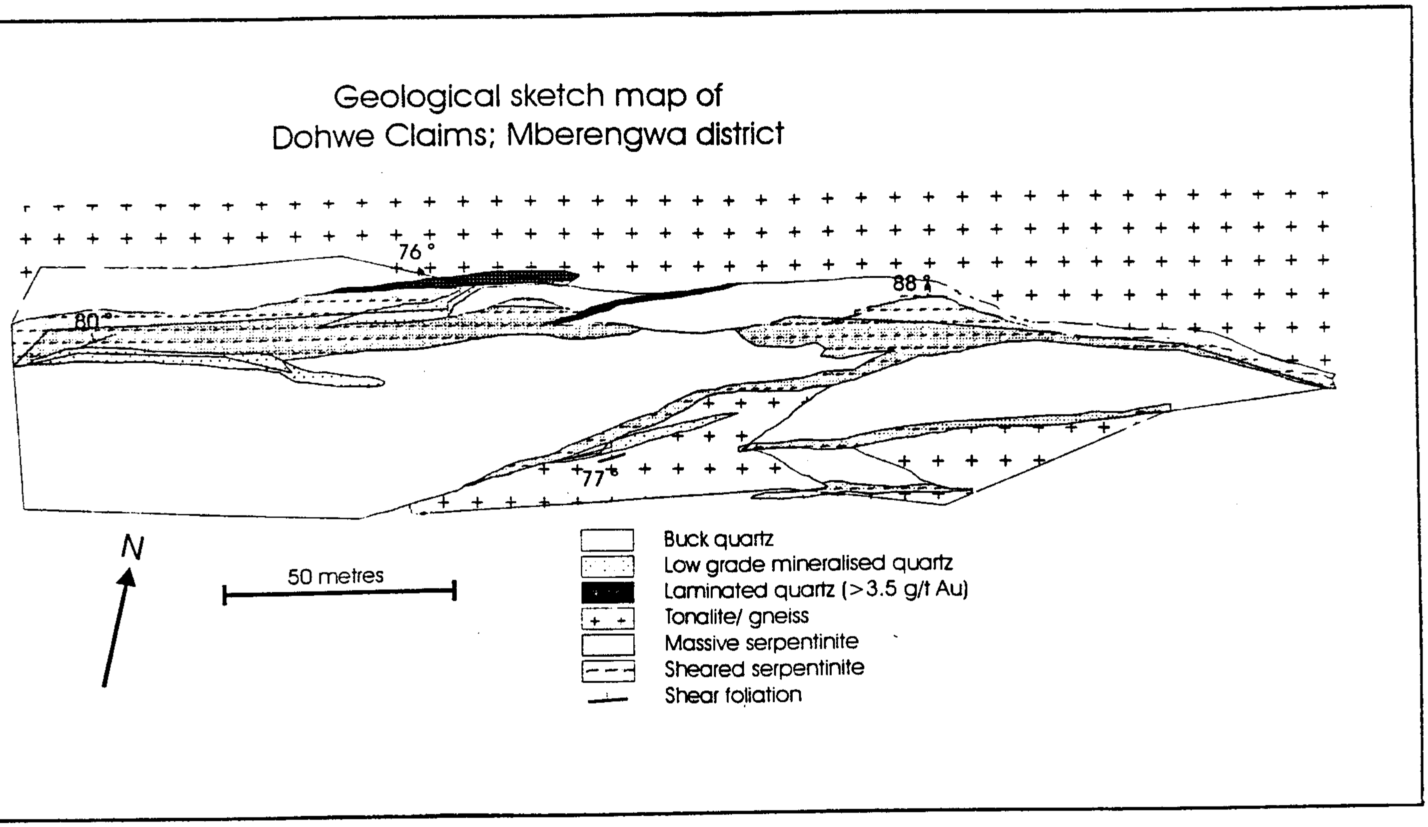

Figure 7: Geological sketch map of the Dohwe Claims, west of the Belingwe greenstone belt, Mberengwa District (Fig. 1).

Doune, Squeak, Dorabell and Druid, occur in a similar setting along the contacts of this complex (Worst, 1956).

The ***Tebekwe Mine*** in the Mont D'Or granite is not strictly on a greenstone margin, but a number of the lodes exhibit obvious lithological control associated with the contacts of granitoids with chlorite schist and ultramafic rocks. The main host is a brittle, fine-grained massive siliceous rock (termed "felsite" by the miners) composed of quartz, sericite, minor oligoclase, carbonates and chlorite, originally derived from the Mont D'Or tonalite pluton. The Tebekwe shear system comprises at least 5 major northerly trending, subvertical, quartz-carbonate shear veins with at least 4 left-stepping, *en-echelon,* right lateral fissures branching off the Tebekwe Reef (Fig. 8). Generally, the reefs form a series of northward and upward converging quartz-filled fissures against the 80°, westerly dipping Tebekwe Reef. The West Parallel Reef is best developed where it runs along the contact of the "felsite" and ultramafic rocks, but changes into a calcite-rich shear within the ultramafic schist. The northern extremity of the Tebekwe lode also pinches out where the fissure transgresses the ultramafic-felsite contact. The area east of the Tebekwe Reef has always been regarded as unfavourable for economic gold veins due to its proximity to a younger granite (Stowe, 1968). However, the 1997, discovery of the Billy Reef east of the main shaft posed some contradictions. Apart from the anomalous orthogonal strike direction of 075°, the SSE-dipping vein has been followed almost into the younger granite. The vein takes advantage of the junction of hangingwall mafic greenstone and footwall felsite over much of its course, but where the footwall changes to unaltered grey granite the quartz and gold content diminish, even though strong shearing and propylitic alteration is still evident.

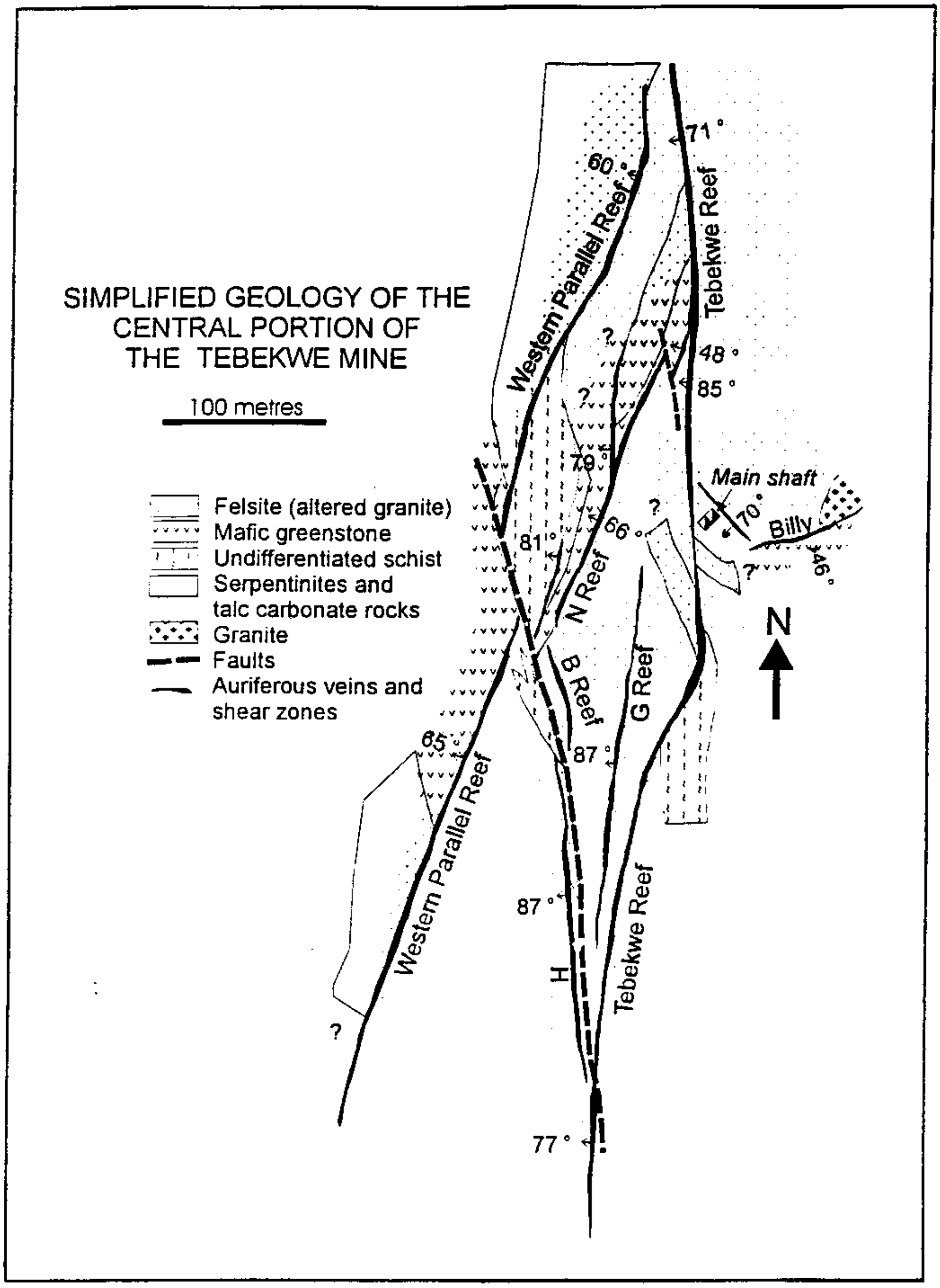

Figure 8: Simplified geological map of the central portion of the Tebekwe Mine ,located in the Mont D'Or tonalite pluton, southwest of Shurugwi (Fig. 1).

5. Mineralisation in small cupolas within greenstone belts

The ***Ultimus Mine*** is situated within a granite boss, approximately 100-500 m-wide and 2 km long, along the eastern flank towards the northern end of the 100-500 m-wide Surprise Fault northwest of Shurugwi (Fig. 1). The deposit is possibly associated with NNE-trending, second-order splays off this regional deformation zone and the granite contacts are sheared. Mineralisation is based on a quartz stockwork covering 5-10 ha of altered and mineralised granite over the southern lobe. Veins exhibit various orientations with the most prominent running around 060°-070° and containing traces of galena.

The ***Grangebrook Mine*** occurs in a broad shear zone that bisects a 0,5 x 1,5 km granite *(sensu stricto)* body intruding andesitic greenstones of the Bubi greenstone belt. Dipping *c.* 65° ESE, the fissure is postulated to be a possible Reidel shear connecting the Bembezi and Gabriella deformation zones (Pitfield and Campbell, 1994). Kinematic indicators, such as S-C packages and the orientation of tension veinlets, reveal that thrusting was dominant. Within the greenstone the shear zone is poorly defined, but quartz veins develop extensively within granite. The advent of mylonitic greenstone remnants near the margin of the intrusion coincides with the diminution of the robust vein, and the quartz becomes unmineralised. In the southern section, the laminated quartz lode carries 3-20 g/t Au and lies along the footwall of a weakly mineralised buck-quartz vein (Fig. 9), while the altered pyritic halo carries 0,2-1,0 g/t Au up to 4 m either side of the vein.

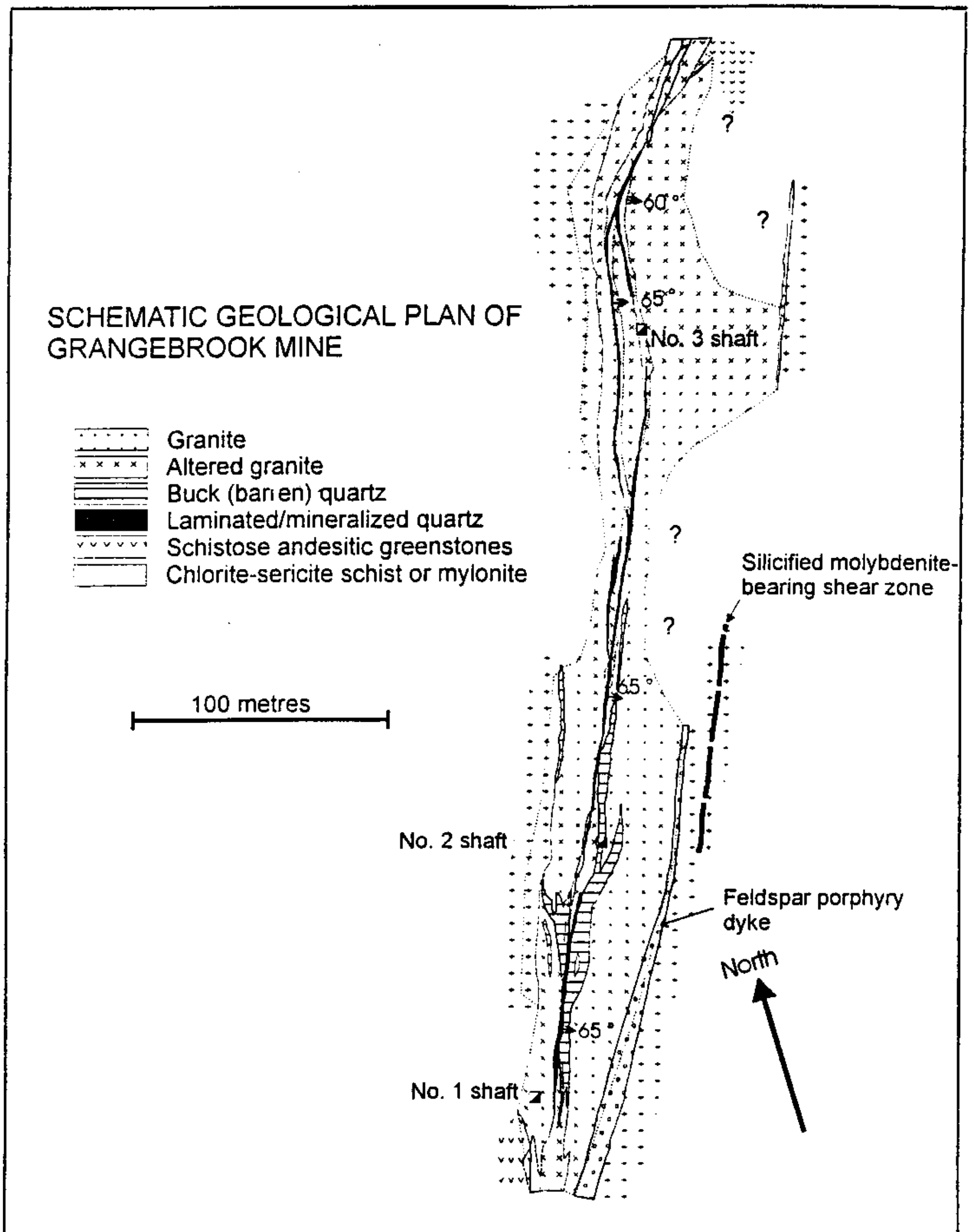

***Figure 9:** Schematic geological map of the Grangebrook Mine, Bubi greenstone belt, northeast of Bulawayo (Fig. 1).*

Lonestar Mine, 20 km southeast of Bulawayo (Fig. 1), is situated on the apex of a 10-12 ha, granodiorite stock that intrudes Bulawayan metasediments. The controlling N-dipping structures trend 070°, are paralleled by fold axes in the sediments to the east, and are probably related to regional thrusting (Garson, 1995). Significant mineralisation occurs over a strike of more than 350 m and a width of 50-80 m, but the bulk of the gold is confined to several grey cherty quartz veins, carrying 4 -7 g/t, which are 30-120 cm wide, dip 50-60° NNW, and are sheathed by 1-3 m of mineralised quartz-chlorite fractures. In addition, stacked mineralised lenses, 3-12 m thick, comprising closely spaced chlorite-silica-pyrite-filled fractures and incipient stockworks, dip 30-35° N and NNW. These average 1-3 g/t Au.

The ***Eureka Mine*** is located on a narrow tongue of gneiss that intrudes metasediments of the eastern edge of the Guruve greenstone belt. Mineralisation comprises stacked lenses of sparsely mineralised quartz veins with molybdenite and scheelite. Episodic brittle failure of the gneiss produced crack and seal veins and enhanced gold precipitation from highly saline, magmatic fluids (Kalbskopf, 1999; Höppner, 1994). The surrounding greenstones show ductile deformation and contain <3% of the resource.

6. Shears orthogonal to granite-greenstone contacts

While the Phoenix Prince Mine, Bindura (Fig.10), could fall into this category the nearby ***RAN Mine*** is a good example and is described in more detail by Kalbskopf (2002). The lode was rich in scheelite in the granodiorite, but a modest gold producer in the surrounding metagreywacke. The adjacent ***Bindura Kop*** tourmalinite orebody also transects the granodiorite-metasediment boundary and consists largely of a 5-15 m-wide zone of tourmaline plus quartz and minor amphibole containing ~ 0,5 g/t gold disseminated throughout. Significant mineralisation is confined to narrow concordant fractures and

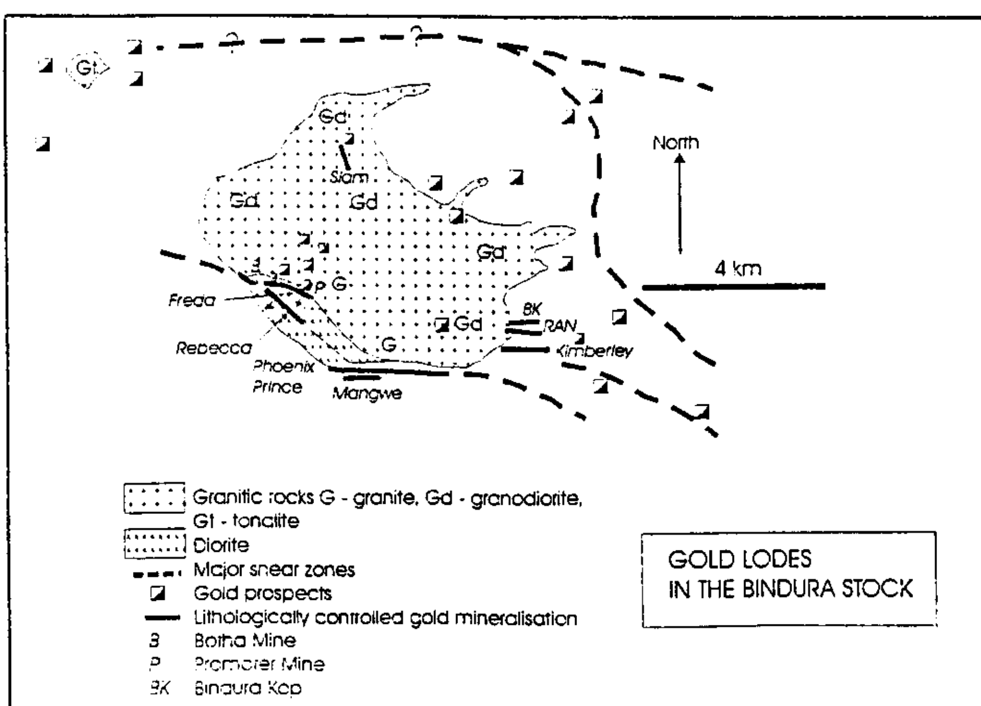

Figure 10: Gold lodes and shear zones in the vicinity of the Bindura stock, northeast of Harare (Fig.1).

sulphidic quartz tension gashes that form only outside the granodiorite stock.

The ***Globe and Phoenix*** lodes (Fig. 1) display both orthogonal and concordant alignments with the highly productive Phoenix Main Reef and Phoenix Parallel Reefs running along the contact of magnesite-fuchsite-magnetite rock (derived from altered serpentinite), and into the Rhodesdale orthogneiss in the hangingwall (Fig.11). Other parallel reefs and offshoots run along the ultramafic-magnesite rock boundary, often along mafic or lamprophyre dykes, where deformation focuses along lithological junctions (Porter and Foster, 1991). However, all quartz-carbonate veins die out where the shears enter serpentinite, and the strain is taken up by the altered ultramafic rocks where the shears may be up to 20 m wide. Within the carbonated ultramafic rocks, brecciation associated with stockworks post-dates ductile shearing and has been ascribed to high fluid pressures (Porter and Foster, 1991). In the gneiss, the reefs are discrete tabular bodies, enveloped by only narrow, weakly foliated and silicified zone aureoles, signifying a relatively un-reactive wallrock.

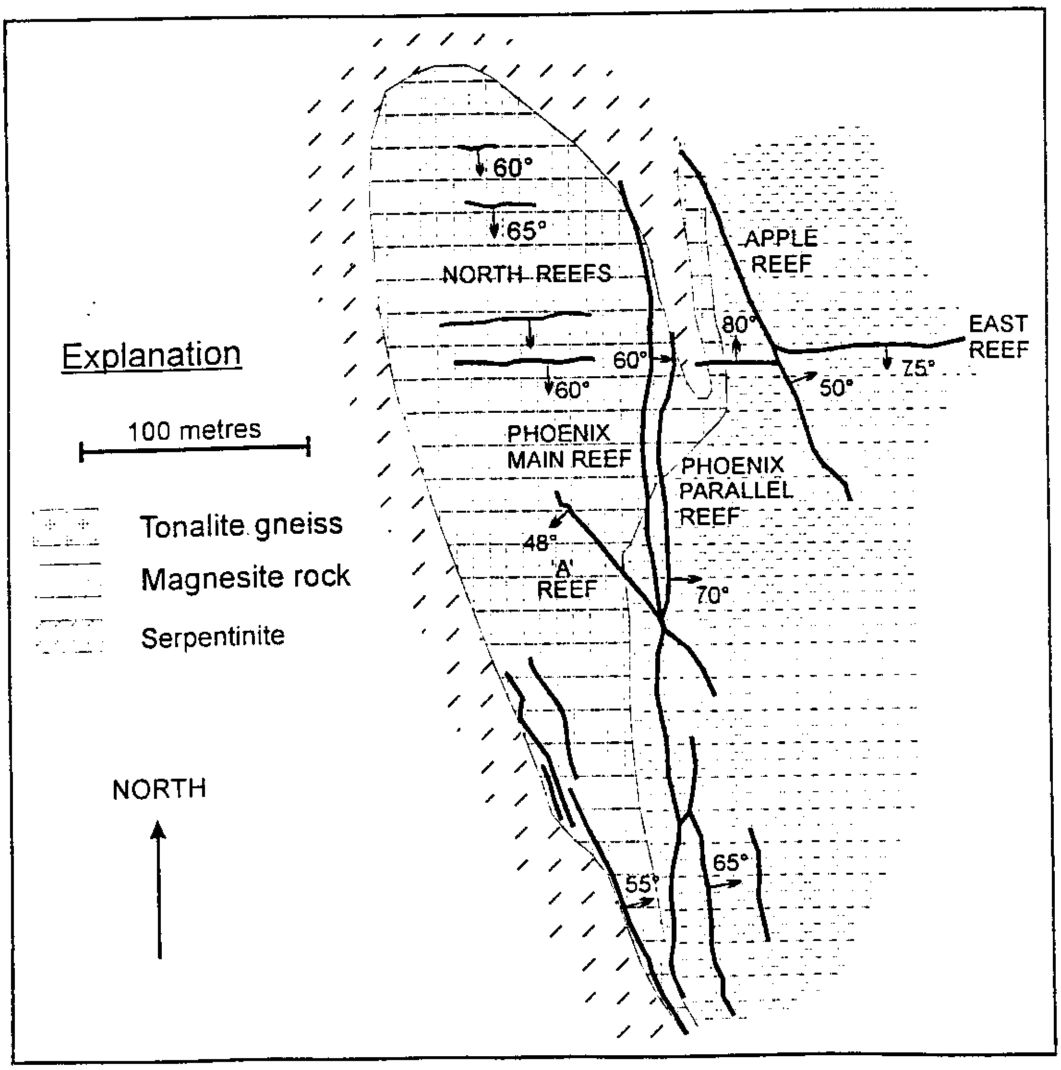

Figure 11: *Schematic plan of 6 Level, Globe and Phoenix Mine, Midlands greenstone belt (Fig.1). The Rhodesdale tonalitic orthogneiss forms the hangingwall (right) to the serpentinized magnesite body (left).*

7. Mafic and altered phases within granitoids

Various workers have drawn attention to the fact that gold deposits favour more mafic phases within a granitic stock and Foster et al. (1986) suggested that the ***Mazowe Complex*** fulfils this condition. Earlier, Tyndale-Biscoe (1933) had stressed the fact that the ***Phoenix Prince*** lodes developed in the diorite phase of the Bindura granitoid, as opposed to the contiguous granite. Payshoots on these same shears largely die out abruptly as the lode passes into metasediments, although small quantities of gold (106 kg @ 6,4 g/t) were extracted from poorly defined quartz stringer zones at the Asp and Earle mines on the eastern extremities, beyond the diorite (Kalbskopf, 2002).

A similar phenomenon has been documented at the ***Freda Rebecca Mine*** only 2 km to the northwest. Low grade ore (2.86 t Au @ 2,44 g/t recovery) was originally mined from open pits at the Botha and Promoter mines that are situated in granite and represent the extensions of the Freda Rebecca orebodies that dip 15-25° south. However, these shears are far more prolific within the diorite. Not only are sulphides more abundant in the more mafic diorite, but mineralisation focuses on brittle fractures and intensively developed C-shear planes that form preferentially in this lithology. The two, 6-30 m-thick, brittle-ductile shear zones strike over 600m, plunging approximately 18°SSE and eventually coalesce. Economic mineralisation terminates southwards where the shears enter metagreywacke (Kalbskopf, 2002).

A contrasting situation exists at the ***Acres/New Year Mine***, Esigodini, where the passage of a shear from the Essexvale Tonalite into more mafic diorite containing partly assimilated mafic xenoliths coincides with the absence of auriferous quartz. The main shoot terminates abruptly where the shear swings to the southeast (135°, Fig. 12) and the reef is replaced by a quartz-free, low-grade, carbonated-chlorite-schist band. The resumption of the usual ESE orientation heralds the New Year Shoot, averaging 20-40 g/t, but when the shear rotates clockwise to the southeast in quartz-diorite, the vein dies out again.

The ***Grandeur Mine***, 24 km southwest of Kadoma, lies in the southern portion of the Whitewaters tonalite pluton and is unusual in that the bulk of the gold mineralisation is largely confined to a finer-grained grey phase within a pinkish, porphyritic granodiorite (Fig. 13). The latter is characterised by pink microcline phenocrysts while the grey granodiorite comprises oligoclase phenocrysts in a fine-grained groundmass of biotite, hornblende and saussuritised feldspars. Gold concentrations are directly associated with pyritic joints and sulphidic quartz-calcite-chlorite ± epidote ± fluorite veinlets in vertical shears trending E-W and 300-330°. These fractures are oblique to inferred NNW sinistral shears bounding the grey granodiorite and a major NNE-trending quartz-chlorite-sericite schist band that cuts across the area. Significant gold is associated with greater fracture density and alteration giving rise to a few podiform, low-grade (1-2 g/t) bodies, with diffuse boundaries that measure up to 30m long. Brigden (1988) inferred that the altered grey granodiorite acted as a more competent unit than the pink granodiorite and was disposed to brittle failure.

A similar scenario exists at the ***Peach Tree Mine***, Filabusi, which is situated in a tonalitic phase of the Balmoral Granite cupola. The latter hosts 10 mines yielding 1243 kg gold, occurring mostly on the contaminated periphery of the intrusion. Nearly 98% of this total is derived from orebodies associated with greenstone inclusions. While the earliest workings at the Peach Tree Mine were based on high-grade quartz veins, the orebody is a stockwork of

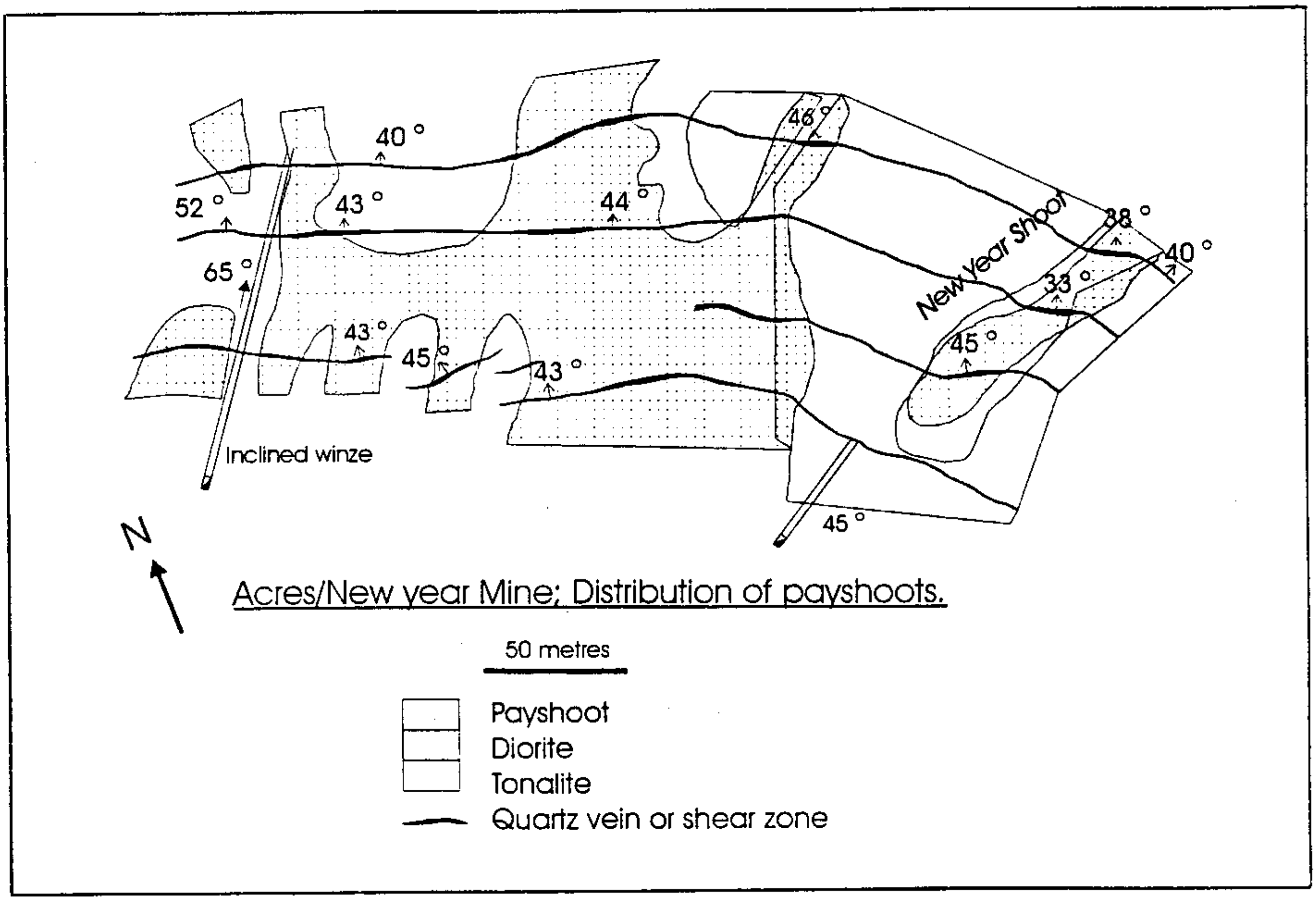

Figure 12: Distribution of payshoots in the Acres/New Year Mine in the Essexvale tonalite pluton, near Esigodini, southeast of Bulawayo.

quartz-filled fractures and mineralised chlorite-silica-calcite joints controlled by a subvertical NW-SE shear zone 6-20 m wide. Although elevated metal concentrations occur in quartz veinlets, gold is particularly related to pyrite and pyrrhotite that congregate around mafic relics and biotite-rich inclusions.

DISCUSSION

Localised Controls

The majority of the lodes display laminated- and/or ribbon-quartz formed by the crack-seal mechanism, characteristic of brittle- to brittle-ductile deformation. In zones of intense ductile cataclasis, such as the Sabi, Sabi Vlei Mine or the Munyati Shear Zone, gold-quartz mineralisation is always related to a later episode of dilation, often associated with trans-tension and younger brittle fracturing (Pitfield and Campbell, 1994).

Sulphide mineralisation is localised on the north side of all the xenoliths in the Alpes Goldfield, and the limitation of payshoots to areas underlain by mafic footwall rocks can probably be explained by sulphidation reactions. For the LWD, Alpes and Viking mines, it is concluded that southward-verging thrusts in the area cause strain to concentrate on the hangingwall of these inclusions, thus providing the prime sites for the passage of ore fluids and concomitant chemical and physical contrasts that aid gold deposition. Similar controls are evident at the Alchemist, Dohwe and Inez East mines where strain partitioning is evident to varying degrees. At the Alchemist Mine, a quartz vein has intruded along the zone of competence contrast between mafic schist and granite, with renewed cataclasis permitting Au

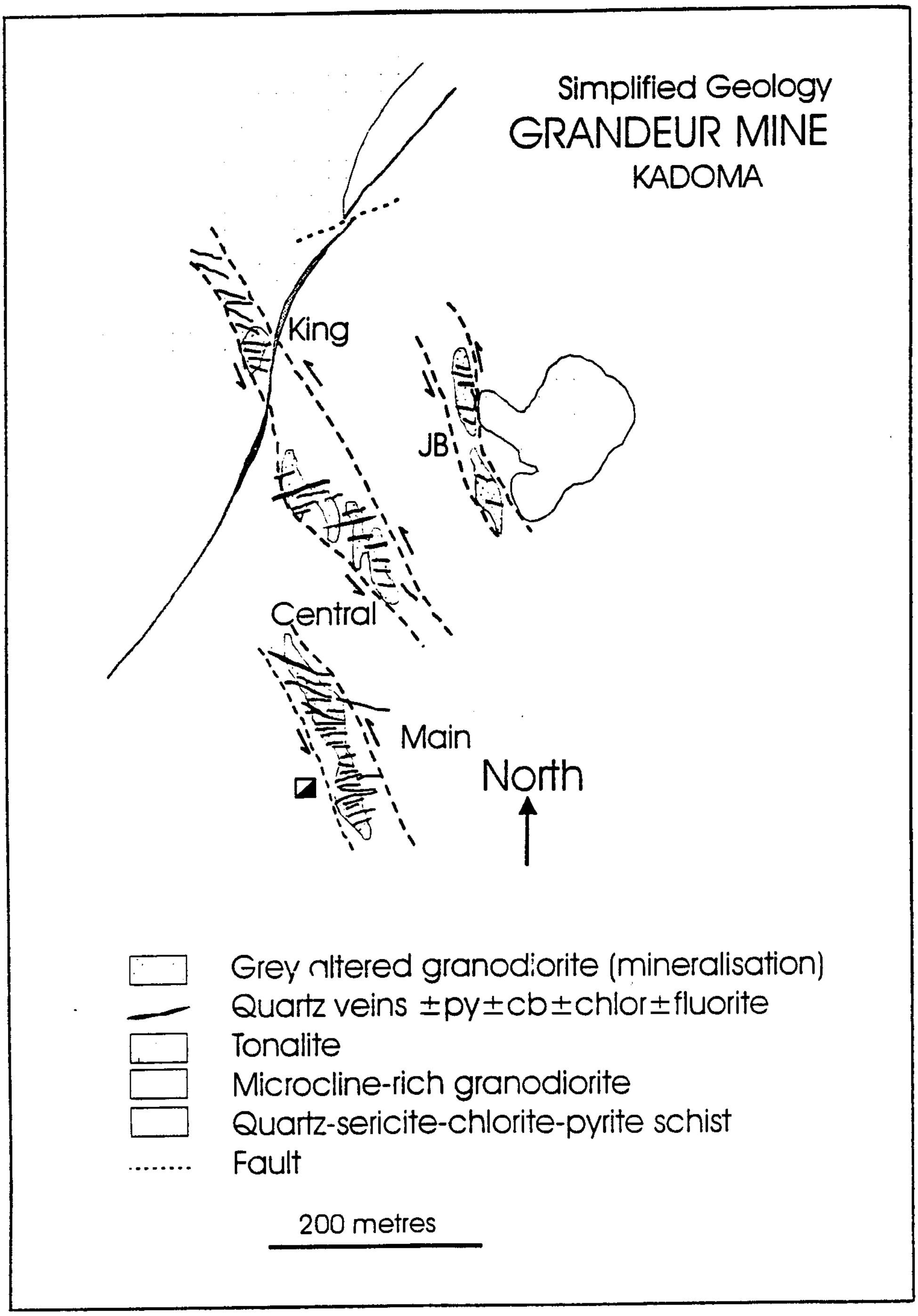

***Figure 13:** Simplified geology of the Grandeur Mine located in the southern portion of the Whitewaters tonalite pluton (locality 5 on Fig. 1), approximately 200 km southwest of Harare.*

Cu mineralisation to concentrate in the buck quartz, which acted as a massive buttress to the principal stress along an ENE axis. While the footwall schist absorbs much of the shear energy, the more rigid granite becomes amenable to fracturing, with the strain partitioning along the hangingwall and favouring mineralisation over a narrow zone along the SE margin of the vein. At the Dohwe Mine, the shears run at an acute angle to the buck vein, which acted as a resistant body. However, the shear appears to dissipate over a much broader zone within the ultramafic body and the dispersion of strain over a larger area due to plastic deformation probably explains why the quartz veins die out here.

Apart from the obvious ductility controls at the Globe and Phoenix Mine, the overall lode complex reflects early E-W fracturing, possibly associated with transpression at the point of maximum inflection of the NNW-trending, Taba Mali Deformation Zone (Pitfield and

Campbell, 1994). However, the dominant mechanism appears to be WSW-directed thrusting related to movement of the Rhodesdale terrane onto the Midlands greenstone belt.

At the Inez East Mine ground preparation, in the form of silicification, has played a vital role in the positioning of the Copper Reef, providing a brittle, dilatory host, in an otherwise unfavourable schist environment. By contrast, towards the footwall of the xenolith, much of the strain has been accommodated by plastic deformation in schist. Similar mechanisms may account for stockwork veins at the original Inez Mine, where competency contrasts along the buck quartz - schist boundaries and footwall gneiss with amphibolite promoted more brittle fracturing accompanied by auriferous quartz veins.

At the Step Lively Mine, the orientation of the principal compressive stress axis was along a SSE axis, at an obtuse angle to the xenolith, so that the shear was unable to propagate along the contact of the ultramafic body, but transgressed it an acute angle. As expected, the serpentinite exhibits typical plastic deformation. During repeated tectonism, simple shear caused this less resistant lithology to warp more readily than the granodiorite and fluids exploited this dilatory tendency, thereby leading to much broader vein widths. On account of its rigidity, granodiorite demonstrates the features of more brittle fracture. Where the shear abuts dolerite it took advantage of the obvious competence contrast, but strain was focussed over a much narrower width and so the reef is smaller.

The tendency for auriferous veins to form in the less mafic granitoid at Acres/New Year Mine is related to refraction of the shear at the transition to diorite, in which the granodiorite has acted as a more brittle host, permitting hydraulic brecciation along extensional fractures exploited by supra-lithostatic fluids. The disposition of broader veins, slickensides and S-C packages suggest that thrusting was important during quartz-vein formation, while S-C duplexes and right-stepping, *en-echelon* veins in the upper levels indicate that sinistral motion was significant. Refraction of the shear at the diorite/tonalite boundary is due to more plastic deformation in diorite and resultant formation of chlorite schist along the shear. These conditions inhibit extensional openings suitable for quartz vein development.

Low-strain domains in areas of bulk ductile strain locally fail in a brittle manner, triggering quartz deposition and can act as fluid conduits. Such conditions are satisfied by small granite bodies within sheared metasediments, as at the Ultimus, Eureka and Lone Star mines, although at the latter, the strain is focused along more discrete channels. These represent zones of low mean stress and differential stress that are consequentially tensile areas favourable for fluid migration (Mugumbate and Mupaya, 1999) that manifest as stockworks and multiple stacked fracture zones. These conditions probably apply to the Copper Reef at the Inez East deposit whose silicified envelope acts as a rigid body surrounded by more pliable chloritised serpentinite schist. The felsite dyke at Brompton Mine has also responded in a similar manner. Apart from satisfying the above criteria, the apices of small endo-granite intrusions are also the prime sites for magmatic assimilation of country rocks and loci for mixing of deep-seated fluids with meteoric water along fractures generated by diapirism. This provides ample opportunity for gold deposition and partially explains why the smaller intra-belt stocks contain the majority of endo-contact lodes (Mugumbate and Mupaya, 1999). The same phenomenon can also be explained by magmatic fluids affected by P-T-X changes due to adiabatic cooling (Mann, 1984) as well as redox reactions when encountering greenstone material.

Bliss (1970) speculated that the Grandeur granodiorite was a later intrusion while Brigden (1988) asserted that the grey 'reduced' granodiorite was the result of anatectic mixing of a fractionated granitic melt with greenstone near the apex of the pluton. While there also appears to be a gross structural control to much of the alteration, the localisation of auriferous quartz veins to grey granodiorite denotes a primary lithological constraint. However, the fact that some auriferous shears extend outside the grey granodiorite infers that alteration and mineralisation were not synchronous processes. Auriferous solutions appear to have invaded reidel, *en-echelon* fractures generated by regional NNE-trending shears exploiting possible competence contrast between the grey and pink granodiorites (P. Hastings – pers. comm., 2002).

General Considerations

In their discussion of the granodiorite-hosted Woodcutters deposit, Yilgarn Block, Western Australia, Phillips and Zhou (1999) maintained that fluids derived by metamorphic devolatilisation are typically aqueous, high $CO_2 \pm CH_4$, low salinity liquids that give rise to nearly all the largely "gold-only" deposits throughout the craton (Ho et al., 1990; Kerrich, 1989). Analogous mineralogical assemblages are present in the bulk of the mesothermal gold lodes in the Zimbabwe Craton inferring that these ore fluids are very similar. Limited fluid inclusion studies corroborate these findings (MMAJ, 1987, Schmidt-Mumm, 1994). Since metamorphic dewatering adequately accounts for the majority of mesothermal gold lodes, it also explains the proximity of deposits to the major greenstone belts within external granitoids, especially in the Midlands and Rhodesdale Gneiss Terrane. Considering that the major deformation zones are developed in close proximity to, and tangential to, terrane boundaries, it follows that auriferous solutions will be conveyed along these conduits to be deposited in proximal second- and third-order structures wherever sudden physico-chemical changes occur. Such fluctuations occur adjacent to granitoid-greenstone margins where there are often an abundance of semi-digested mafic greenstone remnants. These xenoliths are frequently arrayed with their long axes concordant with a regional fabric imposed by either diapiric pressure on the margin of the intrusion or thrusting and strike-slip tectonics caused by trans-cratonic deformation. Hence the bulk of the gold is contained in fractures that are aligned subparallel to the greenstone belt margins.

The granites are modelled as large rigid blocks with regional compression causing thrusting of the greenstones against these massifs, giving rise to stacked thrusts and splays proximal to the boundaries. Hence, the paucity of large deposits >2 km from the greenstone-granite contacts is then largely a reflection of the lack of favourable structures. Secondly, it mirrors the depletion of gold in solution due to reaction with favourable host rocks proximal to the greenstones as seen northeast of Zvishavane where, regional north- and NNW-trending mylonites and brittle-ductile shears extend many kilometres orthogonally from the greenstone belt. However, auriferous quartz (e.g., Sabi Mine) only occurs within 1,5 km of the nearest mafic/ultramafic massifs, also inferring that the latter could be the source of gold-bearing fluids.

IMPLICATIONS FOR EXPLORATION

In Archaean granitoid terranes, only narrow belts along greenstone belt margins are highly prospective, provided one or more of the following conditions are satisfied:

- major tangential shears are present;
- the belt is bounded or intruded by tonalitic granitoids;
- the granitoids contain semi-digested greenstone belt remnants;
- where mafic dykes and felsic intrusions predate mineralisation and exploit pre-existing shears;
- areas close to the margins of internal granitoids; and
- along the contact of mafic xenoliths.

While similar constraints apply to intra-belt stocks, the smaller cupolas and apices of intrusions are most prospective. Prospective territory includes the eastern Midlands, Zvishavane-Mberengwa and Bulawayo, regions that have already been intensively exploited. However, the potential for new discoveries rests on locating hidden mineralisation. If the tongue of gneiss between the Kwekwe Ultramafic Complex and the mafic greenstone massif to the west is thrust-defined on both sides, there is a reasonable chance of new gold deposits occurring <1.0 km W and SW of the Globe and Phoenix - Gaika trend and along strike from the known mineralisation. The western periphery of the Zimbabwe Craton, from Mafungabusi through Silobela towards Nyamandhlovu, must be regarded as a prime target because it is penetrated by major shears and Sesombi granitoids that are only partially exposed due to variable thicknesses of cover rocks.

Away from greenstone belts, major gold deposits are most likely to be confined to regional shear zones where re-hydration has occurred, or, where shears tap into buried greenstone and/or mafic rocks in greenschist - amphibolite facies terrane (Phillips and Zhou, 1999). Lithological boundaries affording a major ductility contrast will be prime sites. Such deposits may lie along the margins of the Limpopo Orogen and the Pan-African orogenic belts in northeast Zimbabwe.

Application to the Kaapvaal Craton

On the Kaapvaal Craton, south of the Zimbabwe Craton, the paucity of gold deposits in granitoids might reflect the infertile nature of the peraluminous granites, as in the environs of the Murchison greenstone belt where corundum-normative, S-type granitoids prevail (Vearncombe et al., 1992). External boundary shears along the northern margin, such as the Letaba Shear Zone, reflect extensive ductile deformation with little evidence of brittle-ductile tectonics or mafic xenoliths, and the marginal granitoids are barren. However, most of the internal plutons, located within the core of the central deformation zone proximal to the Antimony Line, contain some mineralisation. They are frequently carbonated and sheared, giving rise to Au (Sb) quartz veins (Duchen, Inyoni, Sutherland, Horseshoe) and stockworks (Malati Quarry), making them the best exploration targets.

The northern margin of the Giyani greenstone belt has been affected by pervasive ductile deformation (Sieber, 1991) and, while there are a few gold prospects in the gneissic granitoids, economic mineralisation is confined to large mafic xenoliths that host productive gold mines such as the New Union/Osprey (3,06 t Au) and Louis Moore (2,5 t Au) (Ward and Wilson, 1998). Further discoveries can be anticipated proximal to these amphibolite bodies and where second-order brittle-ductile shears are identified. The re-hydration zone south of the Limpopo Belt also hosts several small gold deposits with the largest, Doornhoek (0.4 Mt @ 3,07 g/t), confined to a ferruginous amphibolite relic in gneiss. Most of these deposits are associated with reactive banded iron formations in sheared amphibolite within a few metres of gneissic country rock. Such conditions are fulfilled by the Goudkop Mine on the western side of the Stella greenstone belt (Gemsbokpan 309). Quartz stockworks develop over several hundred metres strike along several zones, 2-10 m wide, on the boundary of magnetite-quartzite and silicified granite. Limonite after pyrite preferentially develops closer to the magnetite-quartzite contact while poorly mineralised quartz increases towards the granite.

The few examples from the Kaapvaal Craton seem to validate the model derived from the Zimbabwe Craton. The discovery of further auriferous bodies in the Kaapvaal granite-greenstone terrane will be enhanced by locating semi-brittle shears juxtaposed on Archaean schist remnants, particularly in Fe-rich horizons.

CONCLUSIONS

Kerrich (1989) noted that many mesothermal lodes occur near the brittle-ductile transition where the fault-valve model of Sibson et al. (1988) applies. This accounts for the frequency of laminated or ribbon quartz and the absence of economic quartz veins in regions of extensive ductile, high-temperature deformation, except where resistant bodies or late-stage brittle fracturing occurs. Fluid flow is enhanced in high-strain zones through crack propagation that takes advantage of lithological heterogeneities, such as banding and gneissic layering. Since this process is independent of scale, ductility contrasts along xenolith and greenstone belt margins will preferentially be exploited during deformation, and provide ideal fluid channels and mineralising sites.

ACKNOWLEDGEMENTS

The authors would like to thank Percy Hastings for information he provided relating to the geology of the Grandeur Mine.

REFERENCES

Anhaeusser, C.R. (1976). The nature and distribution of Archaean gold mineralization in southern Africa. Minerals Sci. Engng., **8** (1), 46-84.

Bliss, N.W. (1970). The geology of the country around Gatooma. Bull. Geol. Surv. Rhod., **64**, 240 pp.

Baldock, J.W. and Kalbskopf, S. P. (1991). The geology of the Harare greenstone belt. Bull. Geol. Surv. Zim., **94**, 213 pp.

Bartholomew,D.S. (1990). Gold deposits of Zimbabwe. Mineral Resources Series, Zim. Geol. Surv., **23**, 75 pp.

Brigden, J.F. (1988). Grandeur Prospect, Zimbabwe. Unpubl. Progress Rep. Chase Minerals, 88.136, 13 pp.

Cotterill, P. (1979). The Selukwe schist belt and its chromitite deposits, 229-245. *In:* Anhaeusser, C. R., Foster, R.P. and Stratten, T. (eds.), *A Symposium on Mineral Deposits and the Transportation and Deposition of Metals*. Spec. Publ. Geol. Soc. S. Afr., **5**, 295 pp.

Ferguson, J. C. and Wilson, T. H. (1964). The geology of the country around the Jumbo Mine, Mazoe District. Bull. Geol. Surv. Rhod., **33**, 137 pp.

Foster, R.P., Mann, A.G., Stowe, C.W. and Wilson, J.F. (1986). Archean gold mineralisation in Zimbabwe, 43-112. *In*: Anhaeusser, C.R. and Maske, S. (eds.), *Mineral Deposits*

of Southern Africa. I. Geol. Soc. S. Afr., 1020 pp.
Frei, R. (1995). A new Pb-dating technique for gold deposits; examples from Zimbabwe, 64-67. Ext. Abstr., Centennial Geocongress, Rand Afrikaans University, Johannesburg, Geol. Soc. S. Afr., I , 592 pp.
Garson, M.S. (1995). The geology of the Bulawayo greenstone belt and surrounding granitic terrain. Bull. Geol. Surv. Zim., **93**, 294 pp.
Harrison, N. M. (1979). The geology of the Redwing Mine, Penhalonga, Umtali District, Rhodesia, 55-60. *In:* Anhaeusser, C. R., Foster, R.P. and Stratten, T. *(eds.), A Symposium on Mineral Deposits and the Transportation and Deposition of Metals*. Spec. Publ. Geol. Soc. S. Afr., **5**, 295 pp.
Höppner, M. (1994). The Eureka gold deposit in northern Zimbabwe: an example of Archean gold-quartz shear zone mineralisation derived from magmatic fluids. *In:* Oberthür, T. (ed.), *The Metallogenesis of Selected Gold Deposits in Africa* (BGR. Hannover), Geol. Jb. **D 100**, 391-342.
Ho, S.E., Groves, D.I. and Bennett, J.M. (1990). *Gold Deposits of the Yilgarn Block, Western Australia: Nature, Genesis and Exploration Guides*. Univ. Western Australia. Publ. **20**, 360 pp.
Kalbskopf, S.P. (1999). Gold mining cycles in Zimbabwe: the Eureka and Step Lively Mines. J. Chamb. Mines Zim., **41** (2), 25-31.
Kalbskopf, S.P. (2002). The economic geology of the country around Bindura. Bull. Geol. Surv. Zim., **97** (2), 120 pp .
Jelsma, H.A., Vinyu, M.L., Valbracht, P.J., Davies, G.R., Wijbrans, J.R. and Verdurmen, A.T. (1996). Constraints on Archaean crustal evolution of the Zimbabwe Craton: a U-Pb zircon, Sm-Nd and Pb-Pb whole rock isotope study. Contrib. Mineral. Petrol.,**124**, 55-70.
Kerrich, R. (1989). Geodynamic setting and hydraulic regimes: shear zone hosted mesothermal gold deposits, 89-128. *In*: Bursnall, J.T., (ed.), *Mineralisation and Shear Zones – Short Course Notes*, Geol. Assoc. Canada, Vol. 6.
Mann, A.G. (1984). Gold mines in Archean granitic rocks in Zimbabwe, 553-568. *In*: Foster, R.P.(ed.), *GOLD'82: The Geology, Geochemistry and Genesis of Gold Deposits*. Spec. Publ. Geol. Soc. Zim., 1, Balkema, Rotterdam, 753 pp.
MMAJ (1987). Report on the first stage of cooperative mineral exploration programme with Zimbabwe, Midlands Province. Metal Mining Agency of Japan.
Mugumbate, F. and Mupaya, F.B. (1999). Gold mineralisation associated with competent bodies in ductile to brittle ductile shear zones: examples from the Zimbabwe Craton. Ann. Geol. Surv. Zim., **19**, 48-57.
Mukasa, S. B., Wilson, A. H. and Carlson, R.W. (1998). A multi-element geochronological study of the Great Dyke, Zimbabwe: significance of the reset and robust ages. Earth Planet. Sci. Lett., **164**, 353-369.
Phillips, G.N. and Zhou, T. (1999) Gold only deposits and Archean granite. SEG Newsletter **37**, 7-13.
Pitfield, P.J. and Cambpbell, S. G. (1994). Structural controls of gold mineralisation in the Zimbabwe Craton – exploration guidelines. Bull. Geol. Surv. Zim., **101,** 270 pp.
Porter, C.W. and Foster, R.P. (1991). Multi-phase brittle-ductile deformation and the role of Archean thrust tectonics in the evolution of the Globe and Phoenix gold deposit, Zimbabwe, 665-671. *In:* Ladeira, E.A. (ed.), *Brazil Gold ' 91*, Balkema, Rotterdam.
Schmidt-Mumm, A., Chenjerai, K.G., Blenkinsop, T.G., Oberthür, T., Vetter, U. & Chatora, D. (1994). The Redwing deposit, Mutare greenstone belt, Zimbabwe: geology, mineralogy, geochemistry and fluid inclusion studies. *In:* Oberthür, T., (ed.), *The*

Metallogenesis of Selected Gold Deposits in Africa (BGR. Hannover), Geol. Jb., **D100**, 423-475.
Sibson, R.H., Robert, F. and Poulsen, H. (1988). High angle faults, fluid pressure cycling and mesothermal gold-quartz deposits. Geology, **16**, 551-555.
Sieber, T. (1991). *Styles of hydrothermal alteration in Archaean rocks of the northern Kaapvaal Craton, South Africa, with implications for gold mineralisation.* Ph.D thesis (unpubl.), Rand Afrikaans University, Johannesburg.
Snowden, P.A. and Bickle, M.J. (1976). The Chinamora Batholith: diapiric intrusion or interference fold? J. Geol. Soc. London, **132**, 131-137.
Stowe, C.W. (1968). The geology of the country south and west of Selukwe. Bull. Geol. Surv. Zim., **59**, 209 pp.
Tyndale-Biscoe, R. (1933). The geology of the central part of the Mazoe Valley. Bull. Geol. Surv. Rhod., **22**, 120 pp.
Vearncombe, J. R., Barton, J.M., Cheshire, P.E., De Beer, J.H., Stettler, E.H. and Brandl, G. (1992). Geology, geophysics and mineralisation of the Murchison schist belt and surrounding granitoids. Mem. Geol. Surv. S. Afr., **81**, 139 pp.
Ward, J.H. and Wilson, M.G.C. (1998). Gold outside the Witwatersrand, 350-386. *In:* Wilson, M.G.C. and Anhaeusser, C.R. (eds.), *The Mineral Resources of South Africa*. Handbk. Council for Geoscience, **16**, 740 pp.
Wiles, J.W. (1957). The geology of the eastern portion of the Hartley gold belt- gold deposits and mines. Bull. Geol. Surv. Rhod., **44** (2), 180 pp.
Worst, B.G. (1956). The geology of the country between Belingwe and West Nicholson. Bull. Geol. Surv. Zim., **43**, 218 pp.

oOo