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Conference Fieldtrip Guide:

Au and Ni mineralisation in Zimbabwean greenstone belts

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ZIMBABWE AND ITS GEOLOGICAL HISTORY - AN OVERVIEW

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Introduction

Zimbabwe lies in the southern part of Africa approximately between latitudes 15.5 and 22.5 degrees south and longitudes 25 and 30 degrees east; with an area of 390 760 sq km it is about 1.5 times the size of England, about 0.7 times the size of France and a little more than the size of Texas. Formerly known as (Southern) Rhodesia the country, prior to its attainment of sovereign independence in 1980, was a British colony. Completely land-locked, its international boundaries are partly controlled by natural features such as the mountains of its Eastern Highlands and major rivers such as the Zambezi in the NW, and the Shashe and Limpopo in the south. Although Zimbabwe lies entirely in the Tropics its average elevation is high and thus most of it enjoys temperatures appropriate to more temperate latitudes. More than 75% of the country lies above 650 m and some 66% above 1000 m; the highest point is the summit of Mount Nyangani (2592 m) in the E, and the lowest less than 250 m at the confluence of the Runde and Save rivers in the extreme SE. A marked ENE-trending plateau forms the wide central backbone of the country rising from about 1300 m is the SW to 1500 m and above in the NE. The highest parts of plateau forms the central watershed or, more precisely, the Zambezi-Limpopo divide. The country's capital and largest city is Harare (elev. 1470 m); its second largest city is Bulawayo (elev. 1350 m).

Much of Africa south of the Equator is made up of Archaean cratons surrounded by orogenic/mobile belts that range in age from late Archaean to early Palaeozoic. The belts include the Ubendian (2000-1800 Ma) the Kibaran (1400-1100 Ma) and the Pan-African (950-450Ma); the cratonic nuclei include the Congo, Tanzania, Kaapvaal and Zimbabwe cratons. The Zimbabwe craton, a low-grade granite-greenstone terrain, forms the geological foundation of Zimbabwe and extends SW to underlie part of Botswana. To the south, separating it from the Kaapvaal craton of South Africa, is the high-grade terrain of the Limpopo Belt the rocks of which are also of Archaean age. These two southern cratons appear to have evolved separately and their juxtaposition with the poly-tectonic Limpopo Belt, however this might have been accomplished, seems to have taken place in the late Archaean at c. 2500-2600 Ma, or perhaps even earlier at c. 2800 Ma, with further major tectonism in the Limpopo Belt at c. 2000 Ma.

Stabilisation of the two regions into the areally extensive lithospheric blocks that constitute the two cratons was markedly diachronous. During the approximate timespan 3000 - 2700 Ma the Kaapvaal crton was sufficiently rigid to support the epicontinental cover sequences of the Pongola, Witwatersrand and Ventersdorp Supergroups. In contrast Zimbabwe in this timespan, and beyond to c. 2600 Ma, saw the development of typical granite-greenstone terrains and of the country's major greenstone belts. Widespread stability was not attained until about 2600 Ma, although a small region in the south of the country - the Tokwe segment - had probably existed as a stable minicraton from as long as perhaps c. 3500 Ma. By c. 2500 Ma the Zimbabwe craton and Northern Marginal Zone of the Limpopo Belt together behaved as a stable entity with the emplacement of the Great Dyke and its satellite intrusions. Since c. 2500 Ma ago the Zimbabwe craton has remained a coherent geological unit: it has fractured to different degrees and has been intruded by dykes and sills at various times but otherwise, internally, it has been unaffected by tectonism. On the other hand its margins have been the sites of mobile belts and orogeny, and marginal instability has been a factor controlling the development of the dominantly sedimentary Proterozoic to Phanerozoic basins that ring Zimbabwe and whose infillings in places extend well on to the craton.

The Archaean

This comprises the Zimbabwe craton and the Limpopo Belt. The granite-greenstone terrains of the craton have also been described as the 'Basement Complex' consisting of the 'Basement Granites' and the 'Basement Schists'; and the deformed volcano-sedimentary piles that make up the greenstone belts have often referred to as 'schist'or 'gold' belts. Several ages of greenstone belt development can be recognised. The youngest and most widespread volcano-sedimentary greenstone pile is about 2700 Ma old and constitutes the upper part of the Bulawayan Supergroup. In the south-central region, however, the lower part of the Bulawayan is c. 2800 Ma old; whereas in the north there is a development of Upper Bulawayan greenstones that are perhaps nearer c. 2650 Ma in age. The predominantly sedimentary Shamvaian Supergroup unconformably overlies the Upper Bulawayan and is locally developed in various parts of the craton. Pre-Bulawayan greenstones occur in the south-central region in places marginal to some of the major Bulawayan belts but also partly infolded with granitic gneisses. The oldest pre-Bulawayan greenstones are c. 3500 Ma old and constitute the Sebakwian Group of the Tokwe segment; others intermediate in age between Sebakwian and Bulawayan, and c. 2900 Ma old, make up the Belingwean Supergroup.

The granite terrains of the Zimbabwe craton constitute a complex array of granitoids and gneisses that ranges in age from c. 3500-2600 Ma. Detrital zircons from clastic sediments in two greenstone belt in the south extend the geological record for buoyant crust back to c. 3800 Ma, but no rocks of this age have as yet been found. The c. 3500 Ma tonalite-trondjhemitic gneisses of the Tokwe segment make up the oldest preserved granite terrain. In the late Archaean a number of loosely defined granitoid 'Suites' can be recognised. These are largely tonalitic-granodioritic in composition and comprise the c. 2900 Ma Chingezi, the c. 2700 Ma Sesombi and the possibly c. 2650 Ma Wedza Suites. These Suites are interpreted as the plutonic equivalents of the intermediate-silicic volcanism of the upper parts of the Belingwean and Bulawayan greenstone sequences. The last major Archaean igneous event in the Zimbabwe craton, and what might be looked upon as the last act in the late Archaean cratonisation saga, was the emplacement of the craton-wide, Chilimanzi Suite of largely post-tectonic and sill-like monzogranites at c. 2600 Ma.

At its simplest the Limpopo Belt consists of a Northern Marginal Zone (NMZ) the main part of which is developed in Zimbabwe with a small extension into Botswana, a Central Zone (CZ) partly within Zimbabwe but extending into Botswana and South Africa, and a Southern Marginal Zone (SMZ) restricted to South Africa. The NMZ and SMZ, at high metamorphic grade, can be regarded as representing rocks of lower parts of their respectively adjacent cratons; and the CZ as something different that contains a greater proportion of metasediments and paragneisses. The geological history of the Limpopo Belt is long and complex and far from being fully understood and, while the rocks are Archaean in age, tectonic events are not limited to the Archaean. The boundaries between the zones in the Limpopo Belt and between the belt and the adjacent cratons are tectonic. Porphyritic granites that relate in time to the Chilimanzi Suite of the craton occur in the NMZ, and NMZ rocks have been thrust northwards on to the Zimbabwe craton. When this overthrusting began is not clear, but these southern porphyritic granites are syn- and post-tectonic to this thrusting suggesting that most deformation is Archaean in age.

The Proterozoic

Emplaced at c. 2460 Ma into some kind of abortive rift system, the major igneous event manifest in the Great Dyke and its satellites afford a magnificent strain marker for the stabilisation of the Zimbabwe craton and for the beginning of the Proterozoic aeon. The Great Dyke is funnel-shaped in cross-section and in its present erosion plane, which is in the upper part of the funnel, it is not a true dyke, but a NNE-trending line of contiguous, elongate, layered intrusions, some 550 km long and up to 11 km wide, that almost bisects the craton. It is flanked to the east and west by true mafic dykes: the East and Umvimeela dykes respectively; these, together with the satellite at its south end, extend into the NMZ of the Limpopo Belt. The ultramafic rocks, which form the major, lower part of the layered sequences, represent the remains of high-level, open-system magma chambers but any volcanic or sedimentary surface manifestation have long since been lost to erosion.

Between the approximate timespan 2160-2000 Ma the mainly sedimentary and less abundant volcanic rocks of the Magondi Supergroup, comprising the Deweras, Lomagundi and Piriwiri Groups, were deposited on the NW side of the craton. Subsequent basin inversion and orogeny around 2000-1800 Ma produced the Magondi mobile belt which involved deformation and metamorphism of Magondi Supergroup rocks and the underlying basement. In the E the Magondi rocks occur both unconformable on the Archaean basement and thrust eastwards over this basement; metamorphic grade is low. To the N and NW, however, the metamorphic grade increases and Piriwiri rocks reach granulite facies. Partially hidden by later cover rocks the Magondi mobile belt now flanks the craton along the NW side. On the larger scale the metamorphic and magmatic events of the Magondi orogeny are part of the more widespread Palaeoproterozoic Ubendian orogeny of southern, central and eastern Africa. In Southern Africa the Magondi mobile belt has been correlated with the Okwa Basement Complex in Botswana and with the Kheis belt in South Africa on the western margin of the Kaapvaal craton.

In the south of Zimbabwe at c. 2000 Ma, and broadly synchronous with the Magondi orogeny, dextral movement occurred along the wide Triangle shear zone, a major zone of dislocation on the north side of the CZ of the Limpopo Belt. Meanwhile the craton and the NMZ at this approximate time, in a probable response to these various on-going marginal tectonic events, underwent extensive internal fracturing. This was accompanied by the widespread emplacement of the numerous mafic sills and dykes of the Mashonaland Igneous event.

The subsequent history covers the Neoproterozoic and embraces the development of the Zambezi and Mozambique mobile belts respectively positioned along the northern and eastern margins of the craton. These belts form part of the network of Pan-African mobile belts of south and central Africa. The Zambezi belt, which cuts across the earlier Magondi mobile belt at almost right angles, extends west into southern and central Zambia where, in the Copperbelt, it is separated from the Pan-African Lufillian arc to the north by the Mwembeshi Dislocation Zone. To the SW it links with the Damara belt in Namibia; eastwards it links with the N-S trending Mozambique belt. The latter straddles the Zimbabwe's eastern international boundary with Mozambique and only the western fringe occurs in Zimbabwe; the belt extends northwards as a major zone into Zambia, Tanzania and Uganda.

In Zimbabwe the Zambezi belt contains three broadly similar, metasedimentary, supracrustal sequences which were deposited on Archaean and Palaeoproterozoic sialic basement. From west to east these are the Makuti Group, the Guruve Metamorphic Complex and the Rushinga Metamorphic Suite. All these rocks were extensively deformed and metamorphosed between 850-500 Ma. In NE Zimbabwe there was large-scale, southward-directed thrusting of granulite terrain over the Rushinga Metamorphic Complex which itself reached granulite facies. In the west the Makuti Group shows evidence of south-directed thrust movements interpreted as reflecting southward movement of overlying nappes a likely remnant of which is the Urungwe Klippe, which has been tectonically emplaced over the Sijarira Group of essentially flat-lying, red-bed sediments. The Sijarira Group possibly represents a 'molasse' deposition in the foreland to the Zambezi orogeny. Within the belt sialic basement was affected both structurally and metamorphically to different degrees. Southwards the northern part of the Great Dyke, and the Upper Bulawayan greenstones and the Magondi mobile belt rocks to the west, all show a Pan-African overprint in the form of huge, S-shaped, E-W trending cross folds that become more ENE-trending westwards.

The deformation and metamorphism of the Mozambique belt affects the dominantly sedimentary rocks of the Umkondo Group of the northerly-trending Gairesi basin which was developed on the east side of the craton mostly in Mozambique. Facies variations are consistent with a deepening of the basin eastwards and allow the recognition of eastern and western successions. Tectonism affected both and involved westerly thrusting of the eastern and western successions. The western succession extends west of the Mozambique belt as a near flat-lying cover sequence on the Archaean. The upper part the Umkondo Group contains some volcanics and the whole is intruded by the presumed coeval, thick mafic sills of the Umkondo Dolerites.

The depositional age of the various Neoproterozoic supracrustal sequences is not well constrained but westwards the Makuti Group may be correlated with the Katanga Group sedimentary rocks of southern Zambia which were probably deposited at around 870-820 Ma. Also the sediments of the Tengwe Group of the Urungwe Klippe include deformed tillites suggesting a possible correlation with, and a tectonic derivation from, the upper part of the Zambian Katangan succession. The two other Zambezi belt supracrustal sequences may also equate with the Katangan but palaeomagnetic and, albeit poorly constrained, geochronological evidence point to an age of around 1100 Ma for the Umkondo.

The Phanerozoic

Mineral ages of 550 Ma and 450 Ma from northern Zimbabwe show that Pan-African disturbances extended into the early Palaeozoic but the subsequent late Palaeozoic and Mesozoic history of Zimbabwe, like the rest of south and central Africa, was dominated by the widespread sedimentation and volcanism of the Karoo Supergroup. In Zimbabwe the deposition was in major basins in the north and south. The northern basins followed respectively the ENE and E trends of the Magondi and Zambezi mobile belts; while the southern basins followed the ENE trend of the Limpopo Belt as well as faults parallel to Great Dyke and Mozambique mobile belt. A NE-trending watershed, approximately parallel to the present-day Zimbabwe-Limpopo divide but located about 80 km to the south of it, separated the northern and southern deposities.

The Karoo history spans about 100 Ma during which the Gondwana super-continent, of which Zimbabwe was then a part, drifted northwards from high southern latitudes. Sedimentation began in uppermost Carboniferous times with glacial deposits and continued through the Permian and early Triassic with various clastic sediments and coal seams. In the later Triassic water-lain clastics were succeeded by aeolian sands; and sedimentation essentially closed in the early Jurassic with vast outpourings of basalts. The lavas and later Triassic Upper Karoo sediment transgress the Lower Karoo succession and in places lie directly on pre-Karoo basement far from the craton margins. In the south the basalts are overlain by rhyolite flows and ignimbrites; the southern area also has two wide and extensive mafic dyke swarms that are related to the rifting that accompanied the break-up of Gondwana at the end of Karoo times.

From the late Mesozoic the geological history of Zimbabwe is one largely of spasmodic uplift coupled with resultant erosion and deposition which has allowed the geomorphic evolution to be considered in terms of a number of major erosion cycles. While the Kalahari basin to the west in Botswana remained relatively static, the Eastern Highlands area of the Zimbabwe Craton was the site of repeated uplift which initiated a succession of such cycles that advanced up the river valleys. Continual scarp retreat from the valleys allowed the resultant encroaching land surfaces to extend far beyond river courses in a succession of pediplains. The altitude of the erosion surface decreases with distance eastwards across Mozambique to the Indian Ocean coastline; and more gently westwards across Zimbabwe to Botswana.

During the late Jurassic to early Cretaceous thin sandy sediments were deposited in a restricted inland basin west of the present central watershed. In the SE a much thicker clastic sequence was laid down and extended S and E into Mozambique; further sedimentation occurred in the Zambezi valley below the Escarpment in the extreme NE. During Miocene and Pliocene times the aeolian sands of the Kalahari System, which cover a large area of tropical Africa south of the equator west of Zimbabwe, were deposited over much of the western half of the country; some of these sands were redeposited by river action in Pliocene times.

Mineral Deposits

The exploitation of Zimbabwe's mineral wealth has long been a vital factor in its economy, indeed the search for gold was the major reason for the country's original colonisation. Most of Zimbabwe's economic mineralisation is of Precambrian age. The Archaean greenstone belts, especially those of the Bulawayan, host deposits of gold, nickel, iron and limestone; chrysotile asbestos is developed in certain of the late Archaean ultramafic intrusions. Major chromitite deposits are found in Sebakwian ultramafic rocks and in the Great Dyke, and the latter is also becoming a major source of platinum and related metals. Copper occurs in the Deweras Group and to a lesser extent in the Piriwiri and Umkondo Groups. Mineralised pegmatites occur in the late Archaean (Be-Li and emeralds), associated with c. 2600 Ma Chilimanzi Suite granites, and later (Sn and mica) at c. 1100 and c. 500 Ma.

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THE GEOLOGY AND MINERALISATION OF TROJAN NICKEL MINE, BINDURA AREA, ZIMBABWE.

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The intention of this excursion in the Trojan area is to demonstrate that:
- a large number of layer or near-layer parallel shear zones exist in the greenstone sequence.
- these shear zones pre-date doming of the nearby granite-gneiss terrains, and thus the formation of the typical keel-shape of the Bindura Greenstone belt.
- these shear zones have accommodated stratigraphic doubling and thickening.
- the geometry of the Ni deposits at Trojan is a direct result of the shearing process.
- a large number of observations indicate that the evolution of the ore bodies is the result of hydrothermal alteration with fluids chanelled along the layer-parallel shear zones.

"There is abundant evidence at Trojan that the massive sulphides have been remobilised and may even have been generated during metamorphism and deformation." (L. Chimimba, 1987).

" The orebodies (of volcanic-type nickel deposits in West Australia) have an essentially tabular form elongate subparallel to the penetrative linear fabrics in host rocks (where present) and/or to the trend and plunge of regional and parasitic folds." (Barrett et al., 1977; Econ. Geol. 72, 1193-1223).

" Considerable modification, and possibly generation, of sulfide ores occurred in metasomatic reaction zones developed at the contact of the host ultramafic unit, with footwall rocks in some ores, particularly those from dynamic style environments." (Barrett et al., 1977; Econ. Geol. 72, 1193-1223)

Introduction

Deformation-metamorphic scheme of the Bindura segment of the Shamva-Bindura Greenstone Belt:

D_1

-formation of penetrative, layer-parallel fabric (350/70) and an associated mineral elongation lineation (260/25).
-formation of layer-parallel mylonites specifically in siliceous tuffs, cherts, carbonaceous shales and quartzo-feldspathic chlorite-sericite schists. These rocks commonly contain s-c fabrics, c-axis fabrics, ribbon grains, asymmetric pressure shadows, etc. Sense of movement was probably sinistral-hangingwall-down.
- metamorphic assemblages include hbl-plag, bi-hbl-plag, crd-gnt (?)

D_{1b}

-progressive D1 deformation results in the formation of constrictional and sheath folds within the mylonitic units. Especially in tuffs and graphitic shales this is accompanied by the development of an axial planar crenulation cleavage (S1b). Fold axes directions are highly variable within the dominant foliation plane.

D_2

- mostly static metamorphic overprint. Growth of unoriented hbl-gnt aggregates in felsic schists, unoriented tremolite-actinolite in ultramafics and sericite-chlorite in felsites.
- In places overgrowths are oriented in a steeply NE plunging lineation.
- the margin of the batholith to the south develops a prominent mylonite zone with a down-dip, steeply NE-plunging lination, which records a normal sense of movement. S2 parallels S1.
- quartz-veins are emplaced that contain saline fluid inclusions.
- deformation and metamorphism is associated with doming of the Chinamora Batholith and coeval folding of the greenstone belt in its keel-shaped geometry.

D_3

-brittle-ductile faulting paralleled by the development of numerous slickensided zones. Most of the brittle-ductile faults have propagated along earlier ductile shear zones. Lineations are generally near-horizontal and the sense of movement is sinistral.
-brecciation and infiltration by sulphides of competent units: particularly cherts.
-quartz-calcite veining is prominent.

Mineralisation

Most observations described in this section are a summary of Chimimba (1987)

All ore consists of pyrrhotite-pentlandite with lesser chalcopyrite-pyrite. Three ore-types can be distinguished (Chimimba, 1987):

- massive ore (60-90% sulphides; 10% Ni)

- near-massive ore (30-40% sulphides; 4% Ni)

- disseminated ore (cut off = < 0.4% Ni; average 0.6% Ni)

In all ore types the average Ni/Cu ratio is ~15, and Ni/Co ratio is ~45. Cobalt correlates well with Ni distribution profiles. Copper shows a more irratic distribution pattern and peaks in cherts immediately adjacent to massive ore.

Massive ore occurs along the footwall of "Main" ore body, "Hanging wall orebody and "Cardiff South" orebody. Near massive ore occurs as linear bodies in the "Main" and "Hanging wall" ore bodies. Disseminated ore is pervasive and makes up ~95% of reserves. The contacts between massive, near-massive and disseminated ore are sharp and parallel the pervasive foliation. These contacts are associated with sudden drops in Ni content. Massive and near-massive ores are separated from overlying disseminated ores by a thin pyroxenitic selvage low in Ni.

Massive and near massive ores are restricted to the footwall (= assumed stratigraphic bottom) of the orebodies with the exception of "Footwall no 2" orebody, and they always occurs in direct contact with a Si-rich unit, which is either quartz-feldspar schist or "chert". The use of the word chert is strickly speaking incorrect. The rocks in question are silicified schists with up to 50% sericite-chlorite. They are mylonitic with a strong layering and fine grain size (< 50μm) giving them a dark, "cherty" appearance. (In the "Hanging wall" orebody massive ore is only present in the extreme west where it conformably overlies "chert". When the "chert" stops the massive ore stops).

The nickel content in the disseminated ore decreases from hanging wall to footwall (from assumed stratigraphic top to bottom) with the exception of "Footwall no 2" orebody. Primary characteristics of mineralisation are largely obscured by later deformation and remobilisation of the sulphides.

Massive ore

Mode of occurrence:
- banded or spotted massive sulphide with a minor proportion of wall rock fragments (10-40%) occurs as layers conformable with the principle tectonic layering
- massive sulphide zones in breccias that break up pervasive tectonic layering
- injection veins in adjacent chert and quartz-feldspar schist
- massive sulphide veins along shears in metabasalt

Matrix grains in massive sulphide consist of pyrrhotite with minor chalcopyrite and pyrite. Pentlandite occurs mainly as clasts and exsolution lamellea in pyrrhotite or as small grains along the boundaries of larger pyrrothite crystals. Elongated pentlandite grain aggregates parallel to the wall rock contact are common within a matrix of pyrrhotite. The proportion of chalcopyrite is highest in the contact zone. Chalcopyrite contents increase and pentlandite decreases towards the apex of injection veins. Massive ore is depleted in magnetite.

Near massive ore

Near-massive ore is densly disseminated sulphide in an ultramafic host, commonly taking the form of numerous wall-rock blocks containing disseminated ore "floating" in a matrix of sulphide, giving near-massive ore a brecciated appearance.

Pyrrhotite-pentlandite banding parallel to S1 is common with brittle pentlandite grain aggregates embedded in a matrix of pyrrhotite. Chalcopyrite occurs in the matrix as small elongated aggregates parallel to S1. Pyrite occurs as subhedral grains. Magnetite is common in near massive ore with some localities being very rich in magnetite.

Disseminated ore

Disseminated sulphide is common in talc-carbonate schist, schistose serpentinite and massive serpentinite and commonly occurs as oriented (// S1) matrix grains closely intergrown with metamorphic alteration products. Chromite and magnetite are common asseccories. In talc carbonate schists millerite (NiS) and arsenites (hydrothermally introduced ?) are common.

Structural setting of the orebodies

Throughout the Trojan region almost every lithological contact between ultramafic units and surrounding lithologies displays a degree of shearing. Most contacts are associated with silicified, carbonaceous sericite-chlorite schists, graphitic "cherts" or quartzo-feldspathic-amphibolite-garnet bearing schist ("porphyry"), which preserve a multitute of non-coaxial deformation features. An anastomosing network of cherts and silicified schists can be mapped around and within the ultramafic bodies that host the nickel. The "Main", "Footwall" and "Cardiff South" ore bodies are all surrounded by chert and quartzofeldspathic schist units. The "Main" orebody is situated along two anastomosing branches that outline a broad synclinal feature.

Wall rock structures

The wall rock to the mineralized ultramafic units mainly consists of:
- high-Mg, pillowed metabasalts ("komatiitic basalts"), which locally contain spinifex textures, and which retrogress to talc-tremolite/actinolite-chlorite schists, easily confused with sheared ultramafic units.
- low-Mg, pillowed metabasalts ("tholeiitic basalts"), which are interbedded with massive gabrroic units, and which retrogress to chlorite-actinolite schists.
- interbedded graphitic schists, carbonaceous schists, sericite-chlorite schists, quartzofeldspathic schists with abundant biotite-hornblende-garnet and silicified equivalents of the above, together referred to as "cherts". "Cherts" occur as "dark cherts" with quartz and sericite in equal proportions and with minor sulphide veinlets or as "calcareous cherts" with alternation calcite and quartz layers.
- intrusive dolerite dykes.

Finite strains in the metabasalts are highly variable. Commonly up to 0.5 km long and several hundred metres wide lozenge-shaped blocks of weakly retrogressed, pillowed metabasalts with low internal strains (X/Z ratios range between 1-3) are surrounded by strongly foliated-lineated mafic schist zones that are generally 1-5 metres wide. The plane of maximum flatening (foliation plane) within lozenges is commonly at an angle to, but merges with the bounding schist zones. Where strains are virtually absent and primary layering, S0, can be estimated from pillow stacking, it appears that S0 is generally at a high angle to the bounding schist zones (typically S0 = 300/85 as S1 (schist zones) = 350/70).

Mafic schist zones laterally merge with sericite-chlorite-graphite schists and "cherts", which invariably occur at the boundaries with the ultramafic units. The felsic schists and "cherts" show ample evidence of strong deformation, although finite strain estimates can not be made due to a lack of strain markers. "Cherts" and silicified schists occur as an anastomasing network around and within the ultramafic. "Chert" horizons are not everywhere laterally continuous, but may occur as trails of boudinaged lenses embedded within a wider felsic schist zone together with lenses of quartzo-feldspathic schist and schistose meta-basalts (chlorite-actinolite schists). Deformation features commonly observed in the silicified schist and "chert" units include:
- a strong penetrative foliation defined by oriented mica grains, quartz-calcite banding and aligned opaques.
- S-C fabics
- ribbon grains of quartz and calcite
- dynamic recrystallisation and grain size reduction textures leading to extremely fine grain sizes
- a strong, asymmetric lattice preferred orientation of quartz in "cherts"
- intense folding, which is limited to the schist zones and includes highly disharmonic constrictional and sheath folding.
- foliation truncations
- asymmetric pressure shadows

All these features as well as the macroscopic geometries of the schist zones are consistent with shear zones accomodating significant amounts of strain.

Wall rock and especially "cherts" contain minor amounts of disseminated ore, usually as veinlets or elongated grain (aggregates) parallel to the pervasive foliation, or as later brittle fracture fillings. The order of abundance of sulphides in "cherts" is: pyrrotite, chalcopyrite, pyrite, pentlandite. It is common for pyrrhotite to be crystallographically aligned.

Host rock structures and structures in massive sulphides

The ultramafic host consists of variably sheared, serpentinized dunite and peridotite (MgO = 36-39 wt%). Pyroxinitic to gabbroic layers occur towards the stratigraphic top, or as thin selvages at the stratigraphic base of an ultramafic unit. The primary grainsize of dunites and pyroxinites is generally less than 3 mm, and massive serpentinites preserve cumulate-like textures. Pillows and spinifex textures have not been observed within the ultramafic host rocks, but are common in the high-Mg metabasalts, which are intimately associated with the ore host rocks.

The ultramafics are commonly sheared to form serpentinite-talc schists, talc-tremolite schists and talc-chlorite-tremolite schists. The latter may have originated from incorporated lenses of high-Mg metabasalt.

Sulphides in disseminated ore are generally intergrown with metamorphic alteration products that led to serpinitisation. In places these aggregates are poorly oriented, but in most locations sulphide grains and grain aggregates are elongated parallel to the main foliation.

Identical deformation features are well preserved in the massive and near massive ores. They are foliated with the foliation defined by:
- preferred orientation of silicate fragments in a sulphide matrix.
- preferred orientation of silicate inclusions within single pyrrhotite grains.
- orientation of pentlandite bands and trails of pentlandite "clasts".
- matrix pyrrhotite grainshape fabric
- cleavage orientation in matrix pyrrhotite grains
- optical preferred orientation of matrix pyrrhotite grains

Granoblastic polygonal recovery textures of matrix pyrrhotite grains (size: 0.05-0.3 mm) is common. These grains are crystallographically aligned and preserve shape fabrics and oriented silicate inclusions that parallel S1.

The extreme ductility of the massive sulphides is illustrated by:
- strong mineral fabrics.

- the presence of rounded quartz-calcite clasts that probably resulted from boudinaged and strongly deformed metamorphic veins.
- boudin trains of layered "chert", with individual boudins up to 10 m apart. (In the simplified case of simple shear, boudin blocks of 1 m length being stretched to 10 m requires a gamma of ~15 (meaning a 5 m wide shear zone would have accommodated at least 75 m of strain after the mylonitic texture developed in the "cherts")).

Contacts

The contact between massive banded ores and "cherts"/tuffs parallels the axial planar cleavage of minor F1b folds (shear folds), and embayments or piercement structures along this contact are common, resulting in an irregular, cuspate interface. Piercement as injection veins takes place along discrete sinistral fracture zones or faults characterized by slickensides. Massive ore locally occurs within footwall shear zones within metabasalts 150 m away from the nearest ultramafic body. To a lesser extent piercement occurs along the axial planes of F1b-folds.

Advanced stages of sulphide piercement result in brecciation textures with wall-rock fragments embedded in massive ore. In fact, all types of massive and near massive ores are breccias, meaning that a sulphide matrix envelops wall rock fragments. Clasts vary from angular wall rock fragments to rounded vein quartz-calcite fragments to sulphide clasts usually pentlandite in a matrix of pyrrothite. Wall rock fragments contain a penetrative foliation (S1; locally defined by oriented sulphides) that is folded in F1b folds.

The interface between ultramafic units and massive or near-massive ore is generally planar and not affected by later brecciation and sulphide infiltration. Ni values sharply change accross these boundaries. These observations and the fact that massive and near-massive sulphides are highly strained and contain numerous foliated wall-rock fragments indicate that the contact between ultramafic host and massive and near-massive sulphides is a tectonic contact separating lithologies of low ductility contrast.

Timing of sulphide mobilisation relative to deformation

Textural evidence suggests that sulphides were mobile during each stage in the structural-metamorphic evolution of the area, even though most obvious deformation features originated relatively late (post-D1b).

In massive serpentinites, sulphides are intergrown with unoriented laths of metamorphic talc, tremolite and antigorite. In places, sulphides are intergrown with antigorite in patches that resemble serpentinised olivine. Associated chromite spinels have metamorphic, high-Ni (~ 0.75% Ni) ferrite-chromite rims (with silicate inclusions). These textures suggest that Ni may have been liberated during initial serpentinitisation of olivine. Magnetite is a possible by-product of this process. Metamorphism and serpinitisation coincided with the development of the penetrative regional foliation and network of mylonite zones (at P-T's of 3-4 kbar and 490-520°C), and many of the Ni-sulphides in disseminated ores and massive ores are aligned parallel to S1. During progressive F1b folding of the mylonites, massive sulphide veins formed parallel to their axial planes.

The static metamorphic overprint during D2 is most clearly expressed in quartz-feldspar schists, where a strong biotite foliation is overgrown by unoriented patches of garnet and radial hornblende (at P-T's of 3-4 kbar and 530-550°C). Some of this hornblende is intergrown with sulphides, indicating that sulphides were mobile during D2.

Strong deformation resulting in the most dominant textures in the massive and near-massive sulphide veins post-date D2. This timing is obvious when considering that blocks of strongly foliated and folded wall rock fragments occur in a matrix of sulphides, and sulphide piercement occurs into recrystallised quartzofeldspathic schist. Considering the sulphide deformation textures and the fact that piercement is clearly controlled by D3 brittle-ductile faults, major ductile sulphide mobilisation accompanied D3, when most wall rock lithologies deformed in a brittle fashion.

Models

The preferred model for the Trojan deposit is one in which gravity settling of sulphides in an ultramafic flow resulted in Ni concentrations towards the footwall of the flow, with massive sulphides forming in depressions. The Trojan deposits occur in several such flows. It is generally assumed that minor remobilisation accompanied later faulting and the emplacement of felsic and mafic intrusives.

The main argument supporting this model is the fact that the Ni-content of disseminated ore in the "footwall" and "Main" orebodies show a gradual increase in Ni content towards their footwall. It is also supported by the generally held notion that complicated interleaving of basalts ultramafics and sediments is a purely vulcano-sedimentary process in which most "cherts" are considered as primary chemical deposits. The obvious presence of deformation textures along lithological contacts has generally been viewed as insignificant.

Arguments against a simple gravity settling model include:
- Although Ni-content profiles in disseminated ore are gradual, sudden jumps in Ni-sulphide content when entering near-massive and massive ore, testify to some tectonic remobilisation.
- The Ni-content in most orebodies increases from hanging wall to footwall, or rather from top to bottom. The one conspicuous exception to this rule is "Foot wall no 2" ore body, just north of the summit of Cardiff Hill. The "Footwall no 2" orebody was mined to 3 level before becoming erratic. This body occurs in the hanging wall of an ultramafic lens, and its position has been explained by inferring a synclinal fold that overturns stratigraphy around the orebody. The existence of this fold structure is highly questionable, since nearby pillow basalts directly E and along strike of the assumed fold hinge do not show a change in younging directions (see figures provided by Chimimba and Ncube, 1987 and Alphandary, 1978). Therefore it appears that "Foot wall no 2" ore body is

anomalous to all other ore bodies, and Ni-sulphide enrichment profiles could be partly due to tectonic and hydrothermal process.
- The irregular nature of orebodies around Trojan (concentrated around Trojan Hill, even though similar ultramafic bodies are wide spread) suggest hydrothermal processes.
- The positioning of a pyroxinitic "blind spot' to the NW of the main orebody suggests that primary layering in the host serpentinite body trended NE-SW; at an angle to the E-W trend of the main massive ore zones. Similar relationships can be observed on surface in several ultramafic lenses.
- Deformation textures in "cherts" and schists are extremely strong, and have been associated with at least some displacement. Likewise, the deformation textures in the massive sulphides, including boudinaging, testify to significant displacements. Therefore, current geometries can not autometically be used to infer "depressions" to explain the positions of massive ore. It is quite probable that the current arrangement of lithologies bears no resemblance to the original stratigraphic stacking.
- It is a common observation that graphitic and sericite-chlorite schists become silicified and carbonaceous when they pass laterally from a stratigraphic position between meta-basalts to a position in close proximity or adjacent to ultramafic units. A very good example of this occurs south of Black Hill 3. Vise versa, massive and near-massive orebodies only occur in direct contact with a chert or silicified or carbonaceous quartzo-feldspathic schist unit. This strongly suggests that some hydrothermal fluid, channelled along discrete shear zones resulted in the simultaneous deposition of Si and Ca in felsic schists and sulphides in ultramafics.

Considering all observations in Trojan we suggest that although the ultramafic units of intrusive or possibly extrusive origin were enriched in Ni and probably sulphides as well, eventual concentration resulted from hydrohermal processes channeled along a network of low-angle shear zones. Tectonisation of the stratigraphic sequence led to an increase in permeability in the ultramafic rocks, and coeval metamorphism and serpentnisation liberated Ni from the host (olivine). etc.

Excursion stops in and around Trojan Mine

STOP 1. Underground visit to 23/3-25/1 level

- the contact between the "Main" ore body and host rock is well exposed, with layered massive sulphides adjacent to folded "chert" units. Nearby low-Mg metabasalts preserve pillows that young N-ward.

* *the nature of the orebody can be discussed.*
* *tchert bands are related with an increase in strain, strong folding and a remnant mineral elongation lineation.*
* *later sinistral fractures have developed along lithological contacts*
* *pillow lavas in adjacent greenstones show low strain and N-younging.*

STOP 2. Chert bands N of Trojan Hill

Chert bands within the greenstone belt (e.g. along the road section N of Trojan Hill)

* *Cherts and ultramafic schists alternate along shear zones*
* *Cherts are associated with the same foliation-lineation as the regional foliation that predates the metamorphic peak.*
* *Cherts occur in zones of increased strain and are associated with a number of features characteristic of mylonites. Many of these features are affected by later recrystallisation, iron-stone veining and chertification.*

STOP 3. Shear zones between Trojan and Caediff Hills

The contact between ultramafic schists, and cherts and graphitic schists between Trojan and Cardiff Hills.

* *here, beautiful disharmonic, constrictional folds are preserved on the contact, which demonstrates that the ultramafic is bounded by a shear zone.*
* *the ultramafics are truncated by later, lower grade sinistral strike-slip faults that must be post- peak metamorphic.*

STOP 4. Dunites and pyroxenites at Kingston Hill

Cumulate textured serpentinised dunites and pyroxinites around Kingston Hill.

* *Massive serpentinised cumulate textured dunites occur at the base of Kingston Hill*
* *Note the occurrence of Ni-carbonate staining, carbonate alteration and silicification and abundant magnetite growth.*
* *pyroxinites occur to the north of the dunites, and may be used to infer a younging direction in the ultramafic ore body.*

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Fig. 1 Map of the Bindura Greenstone Belt, showing the main lithologies and the orientation of L1 and L2 lineations. L2 is associated with doming of the Cinamora Batholith. Map is adjusted from Baglow, 1992.

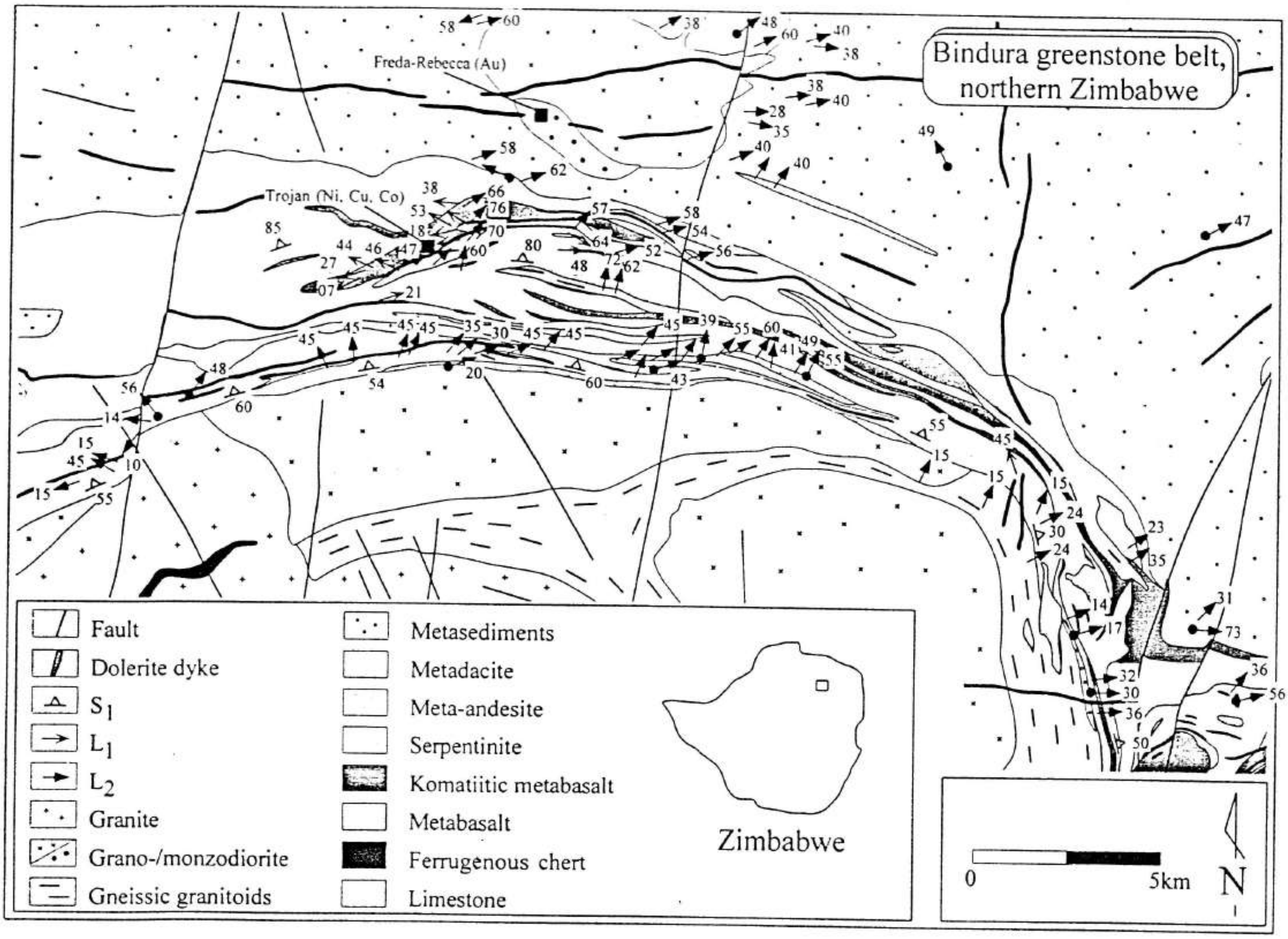


Fig. 2 Map of the area around Trojan Mine, displaying the distribution pattern of shear zones (including the "cherts").

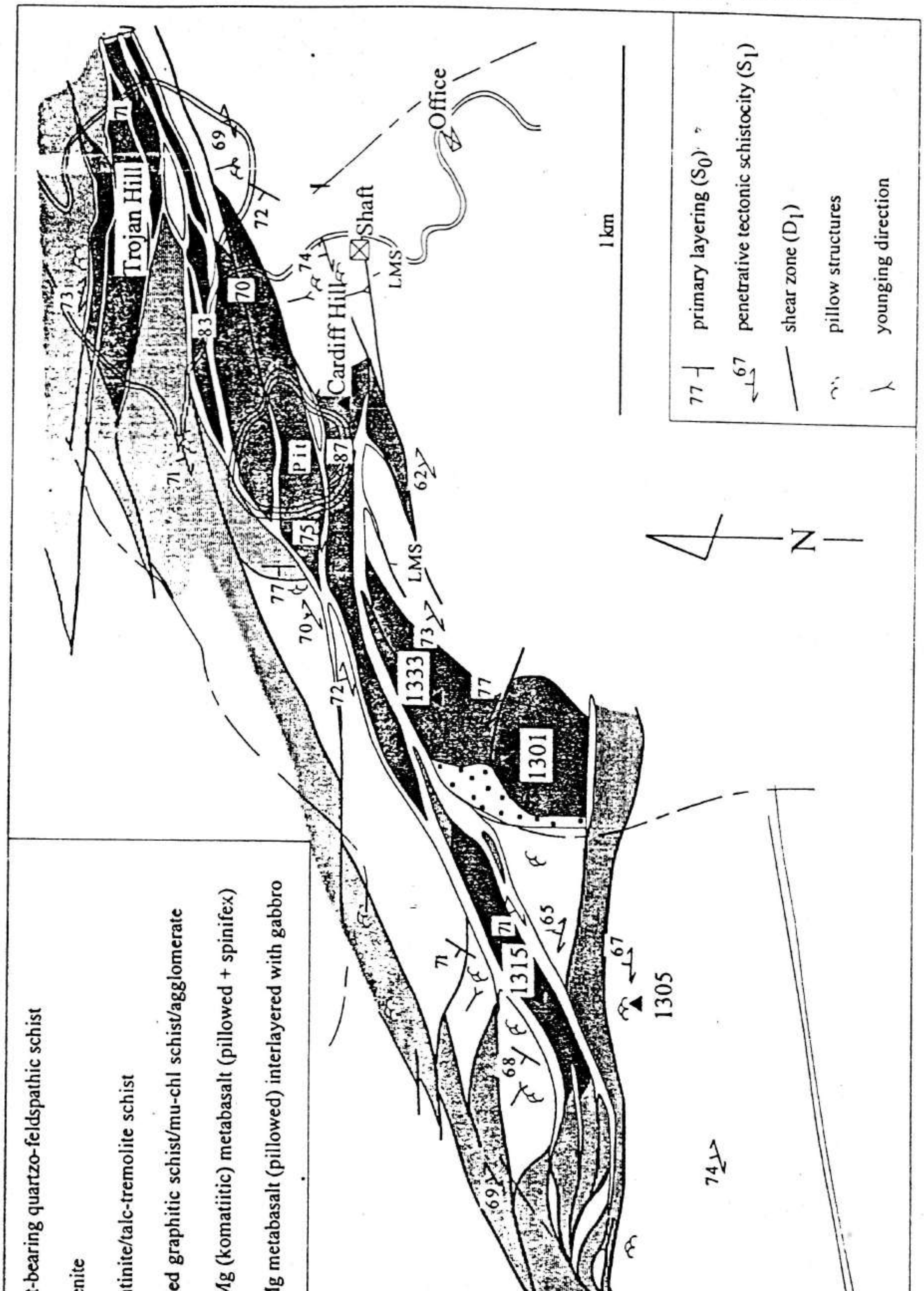


Fig. 3 Cross ection through Cardiff Hill showing the distribution pattern of the 'Main' and Hanging wall' ore bodies.

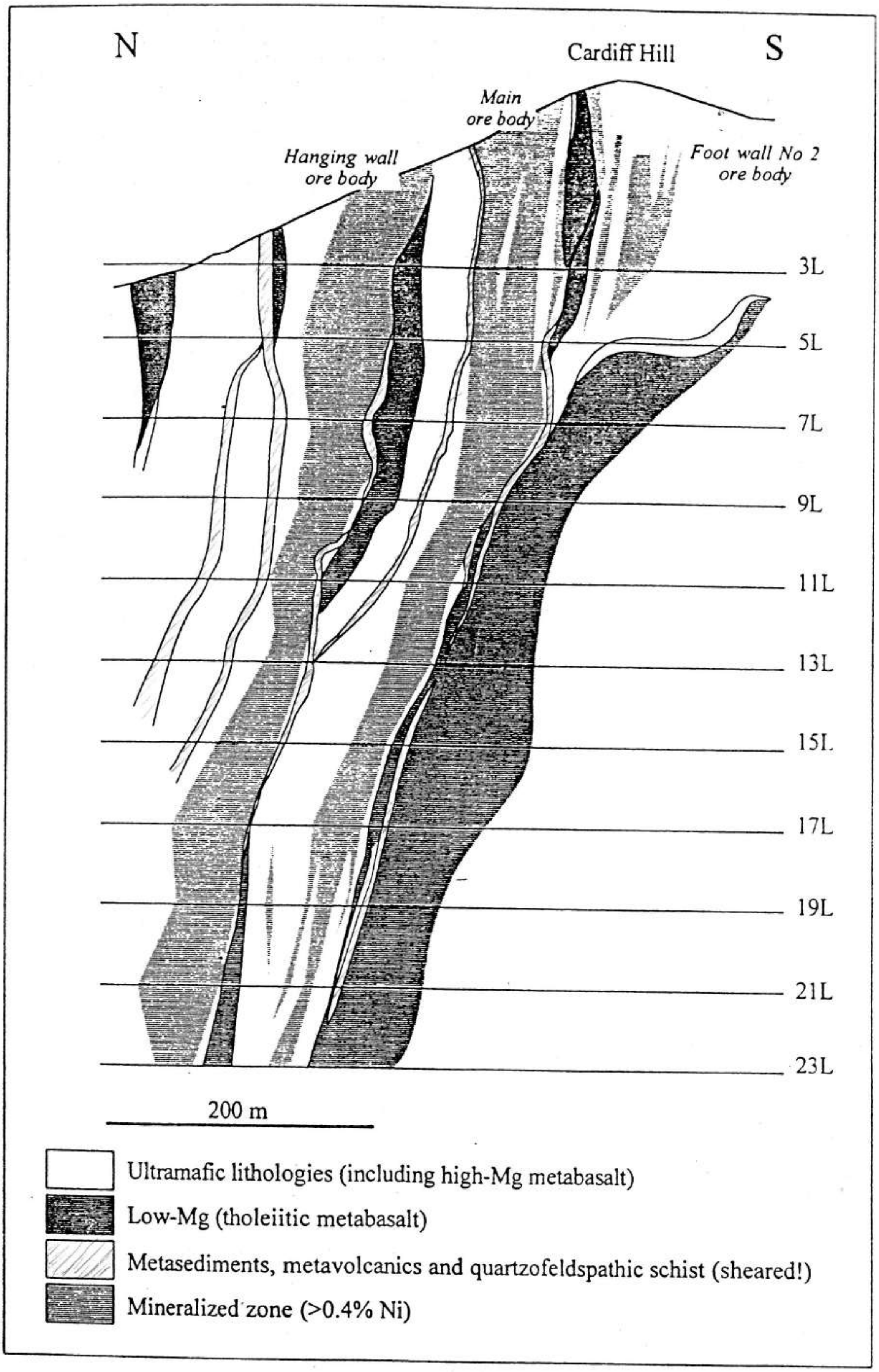
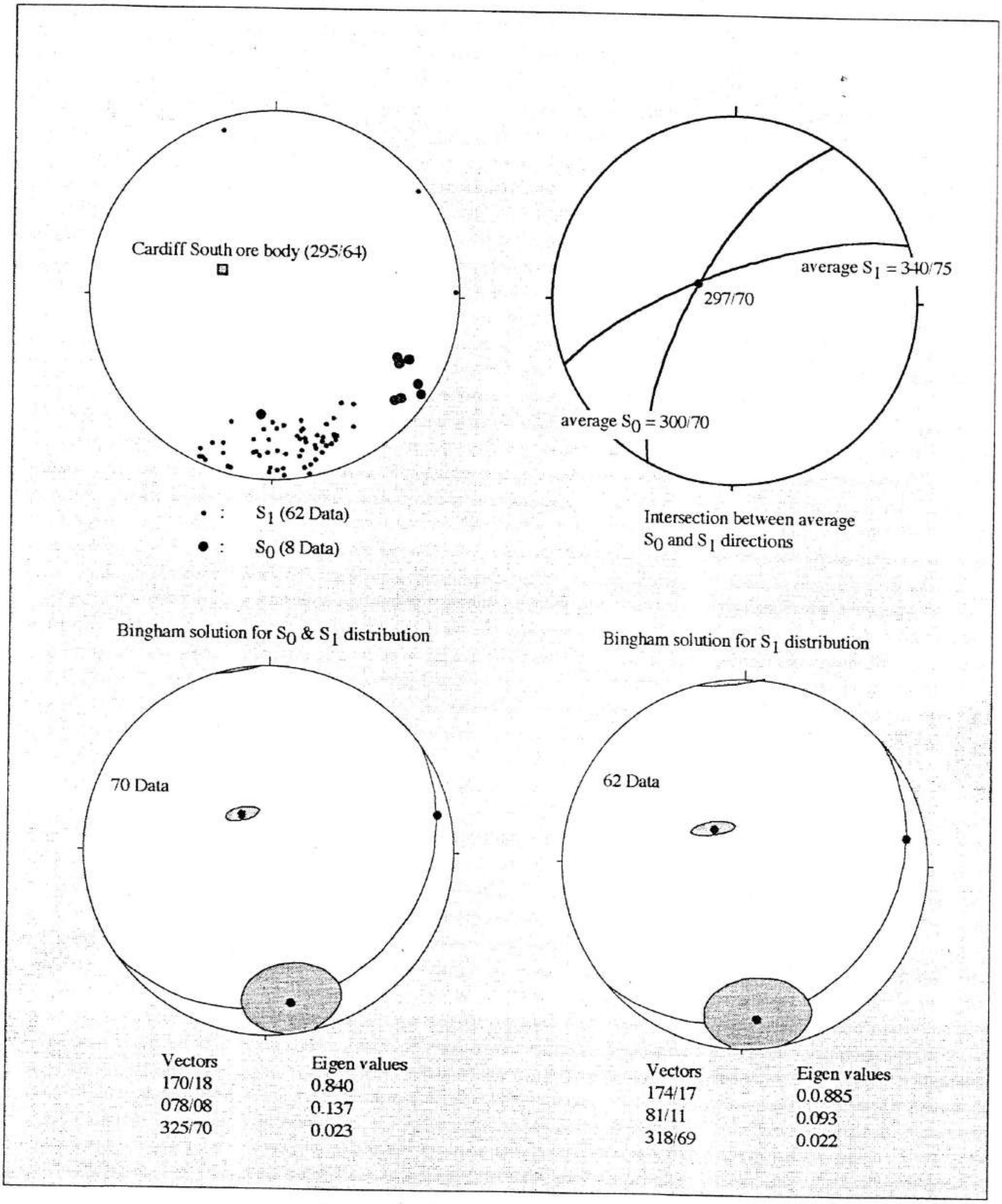


Fig. 4 Orientation data for the Trojan area. Note that the orebodies parallel the intersection lineation between S1 directions and between average S1 and S0.



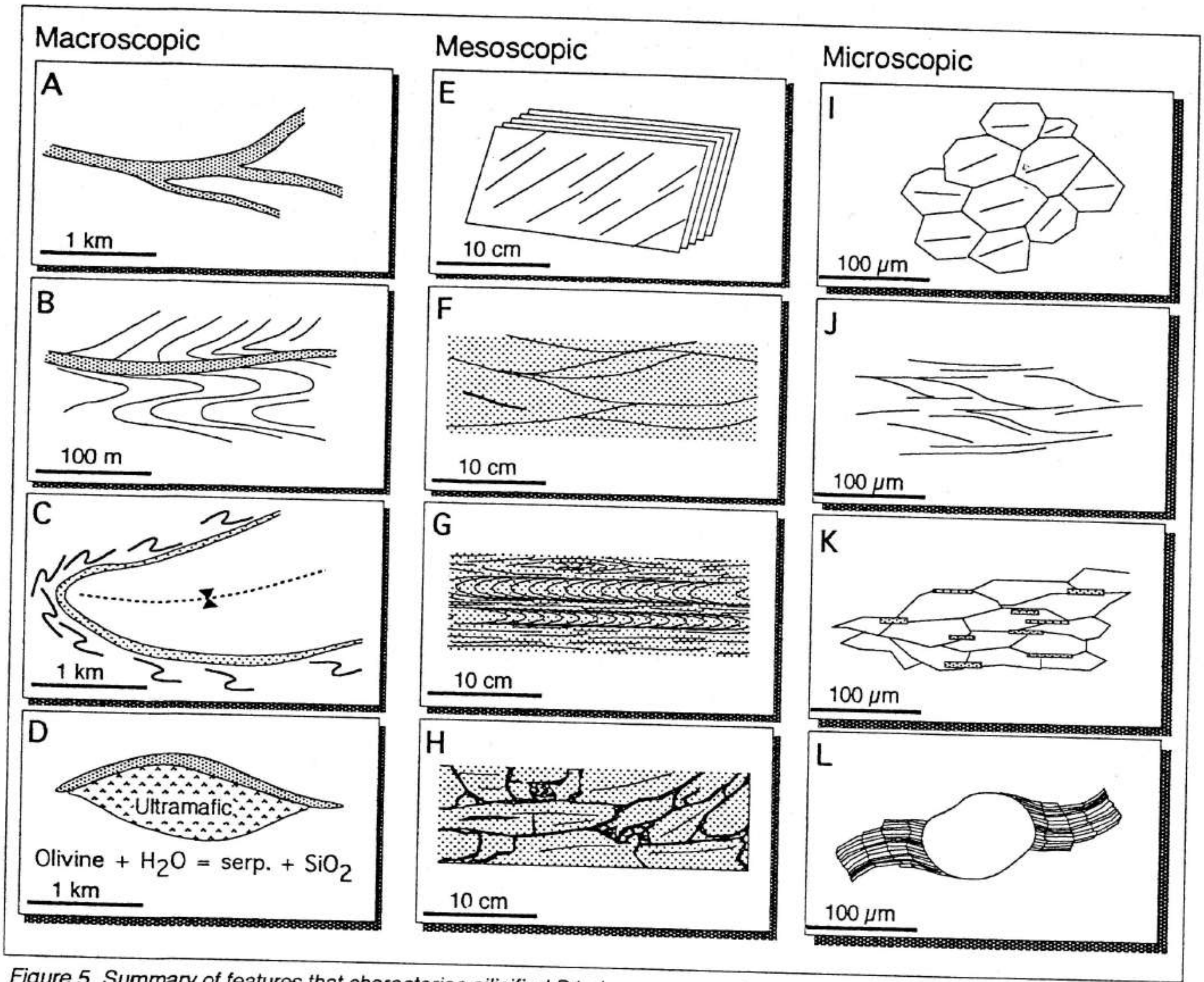


Figure 5. Summary of features that characterise silicified D1 shear zones and distinguish them from primary BIF or sedimentary chert horizons.

Macroscopic characteristics include: A) anastomosing and branching "chert" horizons; B) "chert" horizons that pass discordantly through folded country rock; C) fold vergences in "chert" horizons that are independent from the greenstone keels; D) preferential occurrence of "chert" horizons near serpentinised ultramafic units.

Mesoscopic characteristics include: E) a penetrative foliation with or without a penetrative lineation; F) anastomosing foliation domains (commonly Fe-oxide or Fe-sulphide seams); G) intrafolial folds, sheath folds and transposition fabrics; H) brecciated "chert" blocks infiltrated by Fe-oxide or Fe-sulphide seams.

Microscopic characteristics include: I) strong quartz c-axes fabrics; J) s-c fabrics; K) grain-shape fabrics; L) asymmetric pressure fringes around clasts (chert fragments, pyrite cubes, etc.).

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Gold Mineralization in the Harare-Shamva Greenstone Belt.

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Geological setting

The Harare-Shamva granite/greenstone terrain, located in the northern part of the Zimbabwe Craton, is characterized by a ca. 2.7 Ga bimodal mafic - felsic volcanic assemblage of the Bulawayan Supergroup is locally unconformably overlain by a ca. 2.67 Ga clastic Shamvaian Supergroup sedimentary sequence (Jelsma 1993; Vinyu 1994, Wilson et al, 1995; Jelsma et al, 1996). There is evidence from U-Pb zircon dating of felsic clasts in the Shamvaian Supergroup that the supracrustal succession was deposited onto a 3.34-2.8 Ga sialic basement (Doughety-Page, 1994) and has in turn been intruded by both syn- and post-kinematic granitoids of batholithic dimensions which are external to the greenstone belt (Jelsma et al., 1993). The stratigraphy of the area and the geological relationships of the various lithologies are summarized in Fig. 1.

Two main phases of granitoid intrusive activity can be distinguished in the area. The first phase overlaps and slightly post-dates the main cycle of greenstone belt volcanic and sedimentary activity. These granitoids were derived from remobilized older basement, and sequentially intruded as diapiric plutons during the main phase of deformation (Ramsay 1989; Jelsma et al., 1993). They form batholiths which control the present disposition and configuration of the greenstone belt. The second phase of late syn- to post- tectonic plutonic activity involved intrusion of a diverse composition of small plutons into both the greenstone belt assemblages, and the granite/gneiss terrain. The terminal phase of this post-tectonic cycle was intense, of craton-wide scale, and led to the stabilization of the Zimbabwe Craton around 2.6 Ga.

Within the post-tectonic group of intrusions, two suites are recognized on the basis of their geological setting. Following the criteria of Cassidy et al., 1989, those post-tectonic suites that intrude the supracrustal sequence are termed "internal" granitoids, while those which intrude the surrounding gneissic batholithic terrains are "external" granitoids. The ìinternalî suite of granitoids (sl) is characterized by a wide compositional spectrum varying from gabbro to granite (ss). A number of these ìinternalî granitoids host important lode gold deposits which are currently being exploited at Bindura and Mazowe (Fig. 1, see Table 1 for summary of their age attributes). There is no major difference in modal composition between the "internal" granitoids which host lode gold deposits and their barren "internal" and "external" contemporaneous counterparts.

Complex	Mineralized Structures	Age (Ma)	Ore Assemblages	Mineralization Age
Mazowe *(Jumbo granodiorite)*	shears and faults	2664+15 *(U-Pb zircon)**	Diss Py, ± Ap/Sch/Mo/Te	2659±13 *(Pb-Pb mineral Leach)* 2640, 2780 *(Sm-Nd TDM)#*
Bindura granodiorite	Shear Fractures	2649±6 *(U-Pb zircon)**	Diss/mass APy/Cpy/Sch/Mo	2647±9, 1936±26 (")
Bindura monzodiorite	Shear zone	2617+23/-24 *(Pb-Pb bulk rock)(*)* 2620-2640, 2780 *(Sm-Nd TDM)#*	Diss py/Ar	Not known
Glendale gabbro/tonalite	None	2618±6 *(U-Pb zircon)** 2620-2650 *(Sm-Nd TDM)#*	No known mineralization	Apparrently barren

Key to abbreviations
Diss=disseminated, Mass=massive, Py=pyrite, Cpy=chalcopyrite, Ap=arsenopyrite, Sch=scheelite, Mo=molybdenite, Te=tellurides.
* = Crystallization age
(*) = Hydrothermal age
\# = Mantle derivation or mixing age (calculated using individual analysis)

Table 1. Summary of the major attributes of studied post-tectonic intrusions from the Harare-Shamva greenstone belt, N Zimbabwe.

Characteristics of the major gold deposits

Four principal gold producing deposits occur in the region:- Arcturus, Shamva, Freda-Rebecca, and Mazowe (see Fig. 1 for summary indication of annual production figures). The ore bodies in the mines are related to east-west trending, moderate to steeply dipping shear zones and fractures within either the supracrustal rocks, or post-tectonic felsic plutons intrusive into the metasedimentary/metavolcanic succession. The subvertical structures that host the mineralization show evidence of brittle/ductile deformation, as shown by the presence of disseminated sulphides within zones of ductile shear and fissure filled veins. In individual deposits, the mineralization is found in fracture/shear zone sets that commonly intersect both along strike and in the vertical dimensions (see Fig. 2 & 3). Blind splays that normally diverge from the main fracture/shear zones are sometimes mineralized. Sense of movement on the shear zones is mostly oblique-reverse, with a small, but variable sinistral component (Jelsma et al., 1990, Campbell and Pitfield 1994). Although the primary shear zones which host the mineralization are normally traceable along strike only for short distances (<3kms), these often occur in complex sets which result in replication of deposits in a particular area (for example at Mazowe and Arcturus).

Gold is hosted by sulphides, mainly pyrite, but it is also found associated with pyrrhotite, arsenopyrite, chalcopyrite, and minor quantities of other sulphides (galena, molybdenite, stibnite, bismuth, bismuthinite and tellurides) and scheelite (Foster 1985; Foster et al., 1986; Jelsma et al., 1990; Campbell and Pitfield 1994; Oberthür et al., 1994). A small proportion of the gold from the Mazowe and Shamva deposits occurs in free milling form. Visible alteration around the deposits is marked where the deposits are located in mafic rocks, i.e. at the Arcturus, Shamva and the Freda-Rebecca (monzodiorite hosted) deposits. The most marked alteration styles include carbonation, silicification and potassic metasomatism.

Existing fluid inclusion data from the deposits indicate pressures during ore mineral deposition in the range of 0.1- 0.27 GPa, while temperatures varied from 250-450°C
(Jelsma et al, 1990; Höppner and Oberthür, 1994).

The Bindura Goldfields

The Bindura Group of mines, located 90 km north of Harare, are clustered around, or hosted within the internal Bindura monzodiorite-granodiorite intrusive complex, near the southern or eastern margins. There are three principal country-rock associations (Campbell and Pitfield 1994):

(1) deposits partially or completely hosted by the monzodiorite phase on the SW side of the stock, where the bulk of the gold production has been derived (Freda, Phoneix and Prince of Wales;
(2) deposits hosted by the granodiorite phase (Rebecca);
(3) deposits largely hosted by the Shamvaian Supergroup metasediments (RAN/Kimberly).

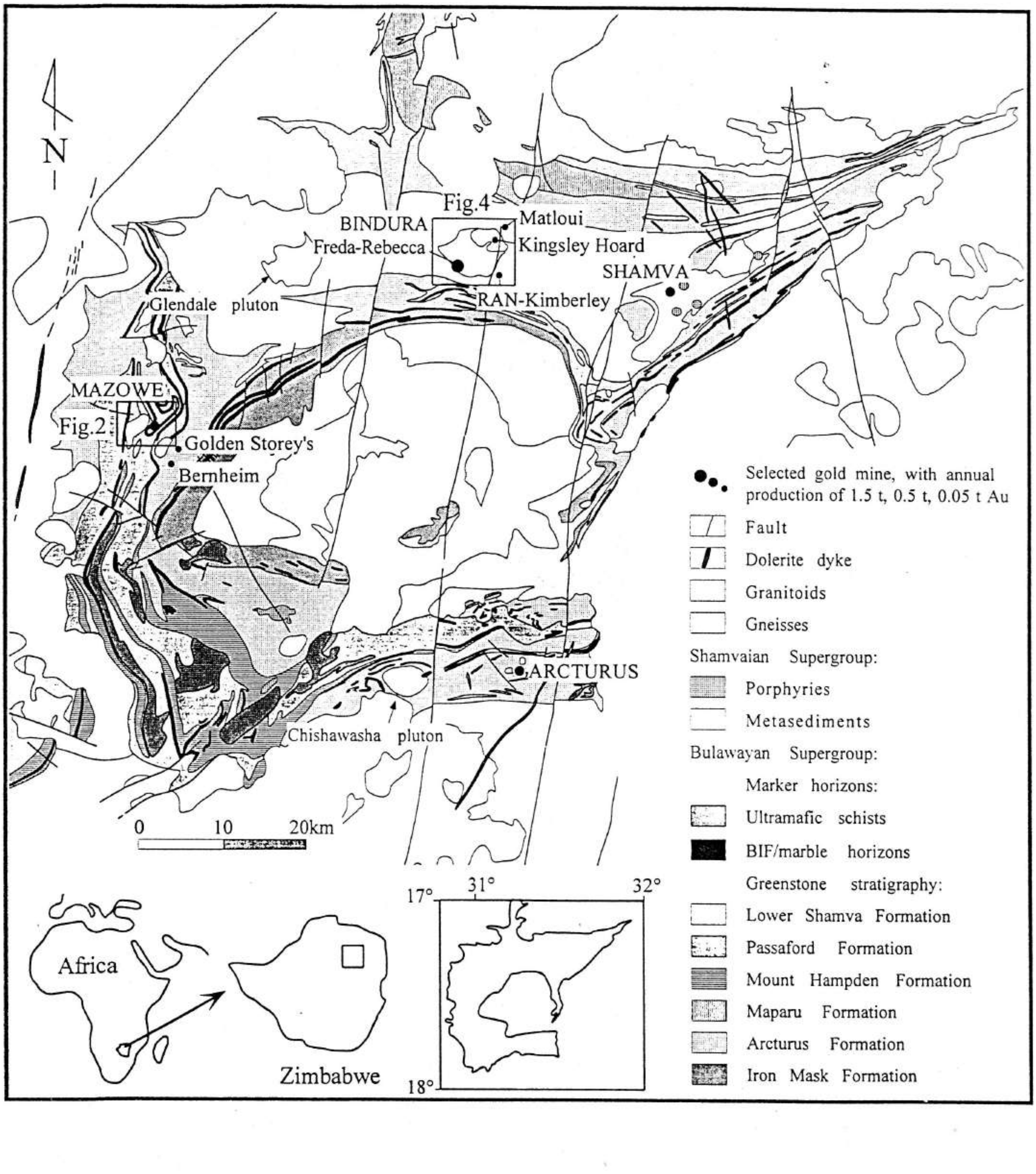
Freda-Rebecca

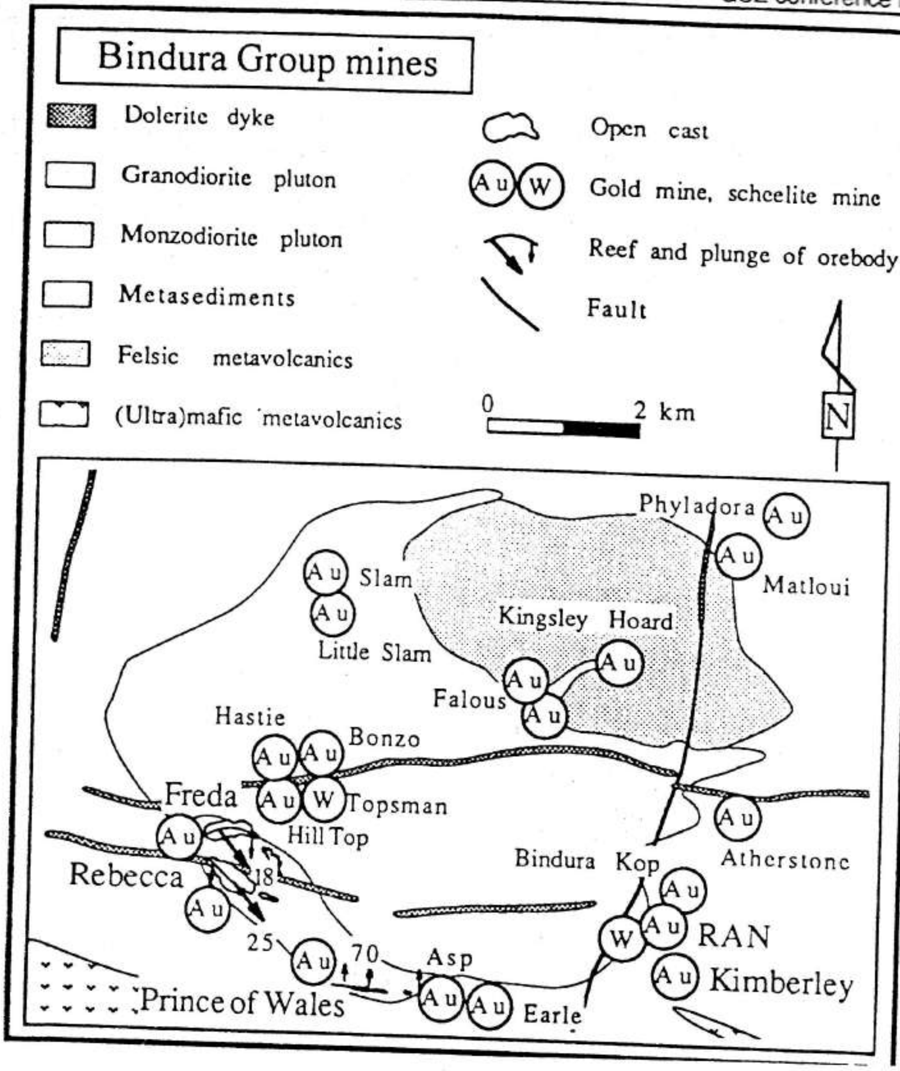
Among the first and second groupings is Freda-Rebecca, currently Zimbabwe's largest producing gold mine, with an annual production since 1988 of 1.5t of gold, at an average recovery grade of 1.5 g/t. The Rebecca orebody, which is up to 10m wide, is hosted by the older monzodiorite phase of the complex, whereas the Freda orebody cuts the contact zone of the monzodiorite and younger granodiorite. Both orebodies are associated with brittle-ductile shear zones which dip at moderate to steep angles to the SSW and SSE. The orebodies plunge at shallow angles to the SE (18-25o). S-C fabrics associated with sulphide and quartz lenses suggest an oblique reverse-dextral sense of movement. Apparent linking structures along strike and depth between the more laterally continuous shear zones at Rebecca are consistent with compressional duplexing in this orientation, in a similar way to the Prince of Wales orebody 1.5 km to the SE (Campbell and Pitfield 1994). As the plunge of the Freda orebody is shallower than that of the structurally overlying Rebecca orebody, the two orebodies converge with depth, intersecting at a depth of ca. 200 m below surface. In addition, the two orebodies also converge along strike to the west. However, although both shear zones continue into the Shamvaian metasediments along strike to the west, and down-dip to the south, no economic mineralization has yet been identified outside the intrusive complex.

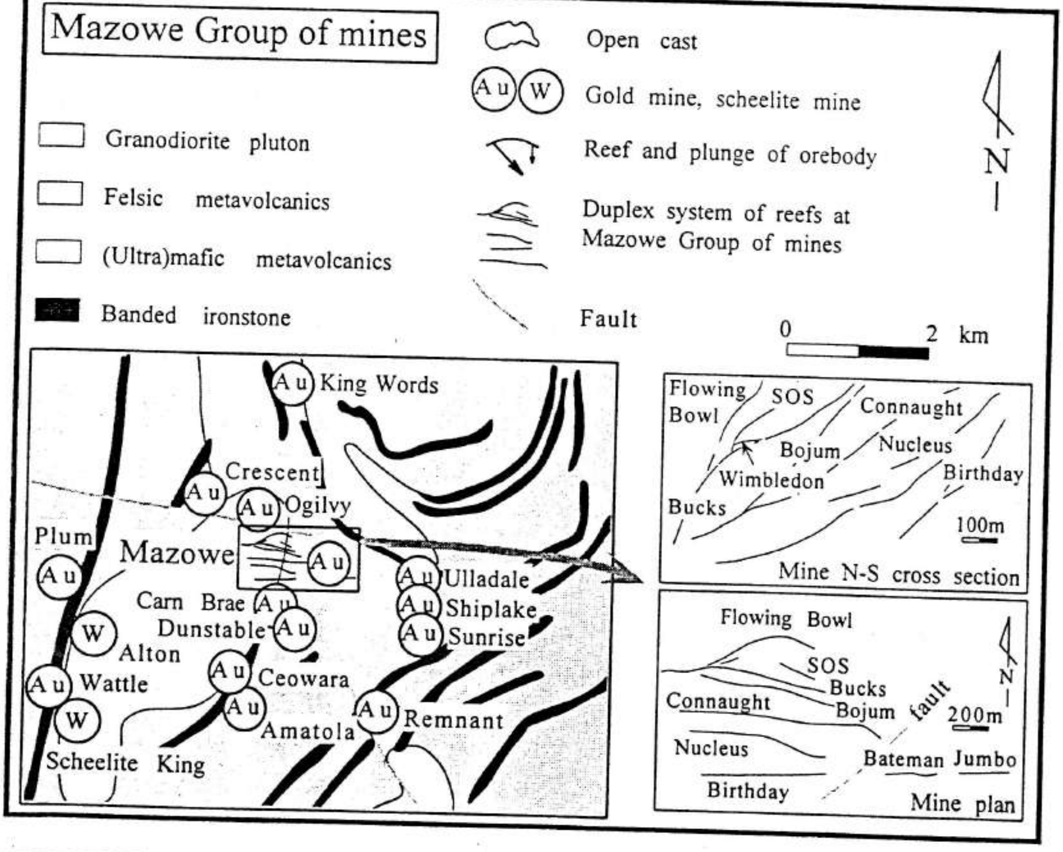
The main gold bearing sulphides at Freda-Rebecca are highly disseminated pyrite, chalcopyrite, and arsenopyrite accompanied by accessory amounts of molybdenite. Alteration associated with mineralization is evident in the monzodiorite with secondary chlorite, actinolite, biotite, microcline, quartz, and carbonate developed along the Freda shear. The Rebecca shear zone within the granodiorite is not associated with any marked alteration, except for the presence of minor quartz lenses and sulphide stringers along the shear fracture.

Kimberley-RAN deposits

Deposits largely hosted by the Shamvaian Supergroup envelope include small scale mines such as Kimberley-RAN, Kingsley Hoard, and Matloui (with a combined total production to date of 9.5t Au). These deposits all occur on the eastern side of the Bindura stock where there is interfingering of granite with the metasediments. The mines work quartz veins and shear zones impregnated with quartz stringers. The reefs strike NW in the north-eastern part (Matloui), E-W in the central part (Kingsley Hoard), and ENE in the south-eastern corner (Kimberley-RAN). The pattern suggests they outline a low strain, pressure shadow regime (Campbell and Pitfield 1994).


N
Fig.4
BINDURA
Freda-Rebecca
Matloui
Kingsley Hoard
SHAMVA
RAN-Kimberley
Glendale pluton
MAZOWE
Fig.2
Golden Storey's
Bernheim
ARCTURUS
Chishawasha pluton
0 10 20km
Africa
Zimbabwe
17° 31° 32°
18°
Selected gold mine, with annual production of 1.5 t, 0.5 t, 0.05 t Au
Fault
Dolerite dyke
Granitoids
Gneisses
Shamvaian Supergroup:
Porphyries
Metasediments
Bulawayan Supergroup:
Marker horizons:
Ultramafic schists
BIF/marble horizons
Greenstone stratigraphy:
Lower Shamva Formation
Passaford Formation
Mount Hampden Formation
Maparu Formation
Arcturus Formation
Iron Mask Formation


Bindura Group mines
Dolerite dyke
Granodiorite pluton
Monzodiorite pluton
Metasediments
Felsic metavolcanics
(Ultra)mafic metavolcanics
Open cast
Gold mine, scheelite mine
Reef and plunge of orebody
Fault
0
2 km
N
Phyladora
Matloui
Slam
Little Slam
Kingsley Hoard
Falous
Hastie
Bonzo
Freda
Topsman
Hill Top
Rebecca
18
25
70
Asp
Bindura Kop
Atherstone
RAN
Kimberley
Prince of Wales
Earle


Mazowe Group of mines
Granodiorite pluton
Felsic metavolcanics
(Ultra)mafic metavolcanics
Banded ironstone
Open cast
Gold mine, scheelite mine
Reef and plunge of orebody
Duplex system of reefs at Mazowe Group of mines
Fault
0
2 km
N
King Words
Crescent
Ogilvy
Plum
Mazowe
Ulladale
Shiplake
Sunrise
Carn Brae
Dunstable
Alton
Wattle
Ceowara
Amatola
Remnant
Scheelite King
Flowing Bowl
SOS
Connaught
Bojum
Nucleus
Wimbledon
Birthday
Bucks
100m
Mine N-S cross section
Flowing Bowl
SOS
Bucks
Connaught
Bojum
fault
200m
Nucleus
Bateman Jumbo
Birthday
Mine plan

The RAN orebody is a steeply northward dipping shear zone which traverses the Bindura granodiorite contact and changes character from a quartz vein carrying scheelite and molybdenite in granodiorite to a Cu-Au sulphidic impregnation zone in the Shamvaian metagreywackes. The main gold-bearing sulphides are massive to semi-massive chalcopyrite-arsenopyrite-quartz stringers up to 20 cm thick. Clay alteration characterizes the shear zone, whereas a 1-2 m thick, chlorite-biotite halo blankets the shear zone.

The Kimberley orebody is entirely hosted by Shamvaian metasediments. Mineralization is associated with a shear zone and related shear veining. The reef is a laminated (crack-seal), grey to white quartz vein commonly up to 1 m thick, changing along strike into a zone of shearing with minor quartz, but extensive sulphide mineralization. The quartz and sulphide mineralizations are largely mutually exclusive. This relationship appears to be related to strain state, and hence a variation from more ductile (sulphide shear hosted) to less ductile (quartz-crack seal dominated) conditions of deformation. Their reef dips at 50o to the N or NNE, except towards the western end, where dips are highly variable, due to folding. The main ore shoot plunges towards the NE at a shallow angle (23o), parallel to the hinge lines of folds, suggesting a genetic relationship. Lineations seen on C-shear planes and reef contacts plunge to the NNE (25o) and S-C fabrics indicate an oblique reverse-sinistral sense of movement.

There are, as yet, no fluid inclusion, microthermometric and stable isotope data to constrain the temperature of the mineralizing fluids, and the confining pressure at the time of gold deposition.

Timing of mineralization: Constraints from U-Pb zircon, Pb-Pb leach and Sm-Nd scheelite techniques.

There have been several attempts at dating the absolute timing of epigenetic mineral deposits in various greenstone belts within the Zimbabwe craton (Horndorf et al., in prep; Blenkinsop & Frei 1997; Vinyu et al., 1996; Darbyshire et al., 1996; Schmidt-Mumm et al, 1995). Most of the ages determined for these deposits span the 2.65 - 1.9 Ga age range. The Bindura goldfields deposits (Freda-Rebecca and RAN/Kimberly) show a dual distribution of ages which fall in the range 2.65-2.62 Ga and 2.02-1.93 Ga. While the older ages are in agreement with some of the ages on deposits from elsewhere in the craton (cf Darbyshire et al., 1996 and Schmidt-Mumm et al, 1995, the younger ages have been interpreted to represent hydrothermal remobilization of mineralization during events linked to tectono-thermal events in the Triangle Shear Zone (Limpopo Belt) and Magondi belt to the west. There is no evidence of active deformation of the craton during these two contemporaneous orogenies, but it is possible that there was reactivation of movement along existing structures which led to further remobilization and concentration of mineralization. The ages determined on the RAN/Kimberly reefs coincide with some ages determined on mineralization at Renco gold deposits (Blenkinsop & Frei, 1997) which are situated in the high grade Northern Marginal Zone, Limpopo belt, attesting to the possible importance of early Proterozoic mineralization in the Zimbabwe craton.

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Friday 5th September, 1997

THE CHINHOYI - GURUVE GREENSTONE BELT

(Excerpts from Geol Soc. Zimbabwe Bull. 101)

The Chinhoyi - Guruve Greenstone Belt (CGGB) trends mainly SSW-NNE for a maximum distance of 125km, and is up to 30 km wide. The town of Chinhoyi is located near the southern margin of the belt. Its northern end, which is within 12 km of the Zambezi escarpment, is S-shaped in plan view, and its northern contact trends E-W. Compared with other greenstone belts in Zimbabwe, an usually large proportion of the outcrop of the belt comprises Shamvaian sediments. In addition, the western side of the belt is overlain structurally, as well as unconformably, by Proterozoic strata.

Lithostratigraphy

The CGGB is largely in contact around its peripheries with younger rocks (granitoids and sediments). Around the northern margin of the belt, the Escarpment Gneiss Complex, comprising biotite-plagioclase paragneisses, leuco-gneisses, amphibolitic schists and calc-silicate rocks, may have been the original basement of the CGGB. Its age is uncertain, due to later structural overprint, but it is intruded by granitoids of late Archaean age. The Escarpment Gneiss Complex is only seen in contact with the upper part of the greenstone belt succession.

Lithologies have been assigned in the past, either with confidence (Hahn and Steiner, 1990) or uncertainty (Stagman, 1961), to the Bulawayan (probably Upper Greenstones) and Shamvaian series or groups. There is, however, general agreement that the Archaean sequence comprises a lower volcanic-dominated succession. The lower succession comprises: mainly basaltic pillow lavas; locally schistose phyllites and cherts; and carbonate units. The upper succession comprises variably bedded arkoses, greywackes, grits, conglomerates, siliceous siltstones, micaceous schists, andesites and dacites (including coarse pyroclastics), and carbonate units. The volcanics tend to occur towards the base of the upper succession. BIF is noticeably absent (as is also the case in the Harare Greenstone Belt).

The CGGB is largely surrounded by intrusive granitoids, and these locally penetrate the belt also. Two main grounds of granitoids occur. The so-called 'Older Granitoids' are part of the late Archaean tonlite-trondjhemite-granodiorite suite which is widespread across the Zimbabwe Craton. The 'Younger Granitoids' include dioritic to granitic porphyries.

The CGGB is structurally, and or, unconformably overlain to the WNW by Proterozoic sediments and volcanics. The NNE-trending Great Dyke (early Proterozoic) and its satellite intrusions transect the easternmost arm of the CGGB. Other suites of dykes (mainly dolerite) crosscut the greenstone belt on various trends. (Ref: Geol. Surv. Zimb. Bull. 101)

STOP 1. Ayrshire Mine

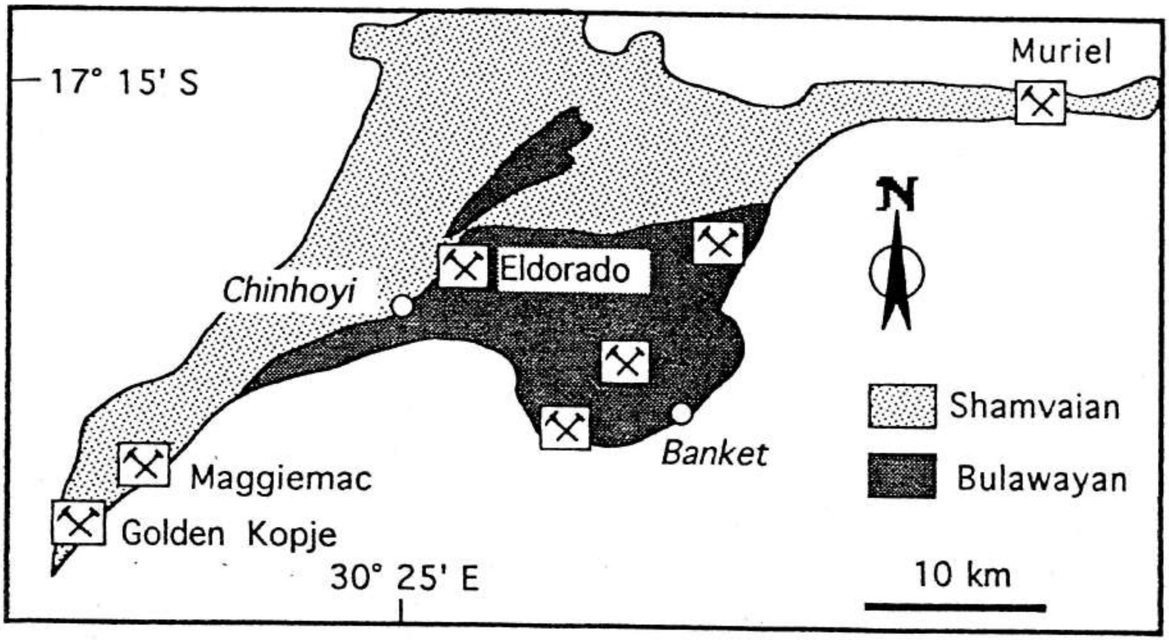
Ayrshire Mine 28 km NE of Chinhoyi, lies just to the south of an ENE-trending structure, along which a substantial quartz dyke has been emplaced, and whose trend is similar to the Eldorado Shear Zone. Also, it is located immediately north of a granitoid of the Chilimanzi Suite. The mine has produced >4.5t of gold (mainly prior to 1917). Recently, very efficient opencasting and heap leaching of the oxide zone (to c.32 g/t) has been undertaken.

Underground mining concentrated on two orebodies in an arcuate (concave to the north) orezone of c.500 m in strike. The orezones tend to subparallelism with the granitoid-greenstone contact c.25 m into its footwall. The main orebodies, the Western and Eastern sections, plunge steeply (c.80-85°), to the NNE or ENE, and are slightly oblique relative to the respective N and NE dips of the ore zone. They are 3-30 m in width, c.120 m in strike, and were both mined to a depth of c.350 m. They are hosted almost entirely within thin diorite intrusions. The gold is pervasive, but discrete orezones occur. Quartz is virtually absent. Recent opencast mining has concentrated on the low-grade mineralization in thin diorites between the two main oreshoots.

The diorites hosting the gold, are themselves hosted by locally talcose and biotitic, chlorite-, and hornblende-schists, with occasional tuffitic interbeds. The enclosing schists carry little or not gold. Foliation in the schists is intense and dips moderately to steeply to the NNW (52-83°/320-357°). S-C shear relationships are well exposed in the footwall of the current opencast, and indicate normal movement, with or without a dextral component (C-shears dip 66-90°/338-002°, or 63-77°/162-176°). In addition, locally intense kinks (F2), with S-shaped open to tight kinks predominant, plunge mainly to the ENE (e.g. 7-52°/076-083°). Crenulation lineations plunge to the WNW (e.g. 62°/294°). There is little genuine foliation in the deeply weathered diorites at surface. Visible 'fabrics' are highly irregular and appear to be related to weathering. The diorite is cross-cut by pegmatites and leucogranite dykes related to the granitoid to the south. These dip east (e.g. 50°/092-096°), or strike E-W, dipping steeply to both N or S (eg. 86°/357°, 80°162°). The main megacrystic granitoid south of the orezone has a weak to moderate fabric near its margin which is subparallel to S1 in the adjacent chlorite schists.

Normal (extensional) shearing is not commonly associated with gold deposits in Zimbabwe. Furthermore, gold deposits are not often associated spatially (and structurally) with Chilimanzi Suite granitoids. However, there may be a causal relationship between these two features. Hence the gold deposit may have been controlled by dilation, either associated with the emplacement (diapirically?) of the granitoid, or, during its cooling and contraction. The dominant vector of movement in the footwall schists, deduced from the kinematic indicators (normal with a slight dextral component), is colinear with the plunge of the orebodies. The preferred mineralization of the diorite rather than the enclosing schists could be interpreted in terms of a negative fluid pressure gradient from the high strain schists, into the lower strain diorite.

Exposures along the river, 600 m ENE of the mine, include finely laminated sediments and sedimentary breccias dipping very steeply to the east or ESE (80-84°/090-110°), or WNW (e.g 75°/286°) with numerous quartz veins and stringers. S1 foliation is subparallel to bedding, or obliquely anticlockwise with indications of dextral movement subprallel to bedding. Small-scale, late, sinistral shear zones dip to the NW (75-77°/300-324°) and conjugate dextral shears dip to the NE (eg. 63°/042°), indicating a late N-S compression.
(Ref: Geol. Surv. Zimb. Bull. 101)



Stop 2. Structural map of the Chinhoyi Greenstone Belt, showing the position of major gold occurrences relative to the eldorado shear zone and other major lineaments

A low-cost, heap-leach operation at the Ayrshire gold mine, Banket, Zimbabwe

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ABSTRACT: A low-cost heap leach operation at the Ayrshire gold mine, Banket, Zimbabwe, has recently been commissioned by Pan-African Mining (Private) Limited. The realisation of the project has come about after comprehensive geological and metallurgical test-work during the past few years. The mine has quite a colourful history with it once being one of the larger gold mines in the country and now during 1993 it is celebrating its centenary.

The diorite and chlorite schist host rocks to the gold mineralisation occur along the contact between younger granites and a south-west trending sequence of Shamvaian rocks. The gold mineralisation occurs as a low-grade dissemination in diorite which is transected by several chloritic shear zones that dip steeply towards the north. High-grade ore bodies occur in silicified zones within these chlorite shears.

Processing of the ore is two-fold: High-grade ore is initially leached on a cyclic pad where extraction of up to 70% can be achieved after 4 weeks. The tails from the cyclic pad together with low-grade ore are loaded onto a larger permanent pad where leaching can continue over a much longer period of time. Earthmoving is accomplished by mining 4 metre high benches with an excavator and loading a fleet of tractor-trailer-tipper units. A wheel loader assists in the pad preparation and levelling of the ore once on the leach pad. Both the cyclic and permanent pads have been constructed using locally available 250 μm low density polyethylene protected on either side by a 30 – 50 cm layer of slimes. A simple network of drains overlays the top layer of slimes and comprises both loosely fitting clay pipes and waste rocks.

Treatment is accomplished using 0.25 g/l cyanide solution at pH > 10.5, the latter being achieved by adding slaked lime to both the ore and barren cyanide solution. Application is through wobbler sprays at a fixed rate of 12 litres per square metre per hour. Pregnant solution is pumped from the pregnant pond through a carousel of 5 carbon columns. Counter-current movement is achieved by changing inter-column pipes, thus negating the need to physically move carbon.

After a three year period of evaluation and numerous feasibility studies the heap leach project was brought on-line in 6 months at a capital cost of Z$800,000. The mine which was evaluated, designed and constructed by a team of three geologists, currently produces gold at a cash cost of US$120 per ounce.

1 INTRODUCTION

The Ayrshire gold mine is located in the Banket area within the Harare Mining District,

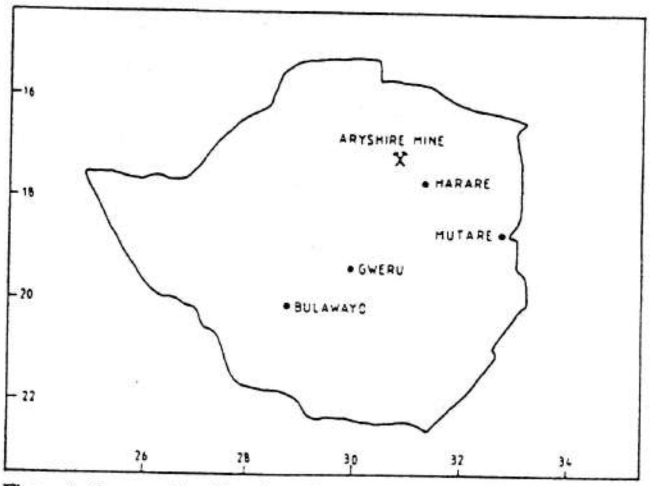

Figure 1. Geographical location of the Ayrshire Mine, Banket, Zimbabwe.

approximately 120 km north west of Harare, Zimbabwe (Fig. 1). Since 1991, Pan-African Mining (Pvt) Limited has developed the mine as an open-cast, heap-leach operation and is currently investigating the potential of the sulphides at depth through a core drilling programme.

2 HISTORY

The earliest records of the mine date back to 1893 when a pioneer and prospector named J. Cochran was shown two large overgrown ancient workings by a local of the area. It is estimated that some 70,000 tonnes of oxidised ore were removed by the ancients. Apparently the absence of a quartz reef caused him to sell his claims for a blanket to J. Carruthers whilst on his way to Harare (Salisbury) to register the claims. Mr. Carruthers, after inspecting the claims, sold them for a length of cloth to replace his worn out trousers to three prospectors who registered blocks 176 and 177 in May 1893 and block 191 in August of the same year (Stagman 1961).

In 1894 the Lomagunda Development Company Limited was formed which carried out shallow mining operations that yielded high values but the Mashona rebellion in 1896 caused the mine to close (Bowen 1978).

Subsequently, in 1900 the Ayrshire gold mine and Lomagunda Railway Company was formed and raised some £550,000 to start up the mine. The optimism of the company directors was such that a narrow gauge railway was constructed, at a cost of £150,500, from Harare to the mine to overcome the transport difficulties experienced previously. Construction started early in 1901 and reached the mine in October 1902 and it was in fact the first narrow gauge line to be built in Zimbabwe. By this time the main shaft (Edwards Shaft) had been sunk to 200 ft. It was located centrally between the two ancient workings in barren ore, and by 1903 the headgear and machinery had been brought in using the railway line. In 1904 a 30 stamp mill started crushing while construction of a second set of 30 stamps started.

Unfortunately, problems started early and included on-site mis-management, very little exploration, dilution of the ore, unstable ground around the Edwards Shaft and labour shortages and by January 1909 the mill and mine closed down (Bowen 1978). After re-evaluating the old reports Phaup (1939) concluded that 'the history of the mine is a tale of optimism and great hopes built on false promises followed by a most depressing tale of errors, accidents and failures which brought work to an untimely and disastrous end.' By the time the mine closed down 480,000 tonnes of ore were milled producing 4.42 tonnes of gold.

Production started again during 1932 to 1944 by a small worker (Macaulay) during which time some 86,500 tonnes of ore @ 5.43 g/tonne was mined from the upper levels of the mine and milled recovering an additional 470 kg of gold.

Between 1944 and 1987 several other companies investigated the mine both on the surface and underground but no production was recorded. From 1987 to 1989 Cluff Resources Zimbabwe Limited completed a sizeable percussion drilling programme which identified 5 possible ore bodies but they considered the project too menial to develop a mine.

It was at this stage that Pan-African Mining (Pvt) Ltd was offered the property and using the extensive data generated by Cluff's drilling, instituted a trenching programme to confirm Cluff's interpretations and to provide sufficient sample material for column leach testwork. These tests were conducted between 1989 and 1990 and established that the gold could be extracted from run-of-mine ore through heap leaching. The go-ahead for developing the property was delayed until late 1991 when the Board of Directors made the decision to start work on the property. This work started in September and mining itself began in March of 1992.

3 GEOLOGY

The mine occurs in the southern parts of the Chinhoyi-Guruve greenstone belt within metasediments of Shamvaian or Archaean age (Stagman 1961). This greenstone belt is disposed in the form of a 'Y' and starts approximately 15 km south-west of the city of Chinhoyi. It is at Chinhoyi where it splits into two arms, one arm extending north-east to the town of Gururve and the other eastward to the town of Banket. The metasediments are bounded in the south by a syn-tectonic porphyritic granite (Fig. 2) and associated pegmatitic and aplitic veins which transect the lithologies.

The metasediments within the mine area and surrounds consist mainly of feldspathic amphibolite and diorite, the former occurring as a chlorite schist in the open pit. Typically the diorite contains the gold mineralisation although it is not uncommon to find gold in the chlorite schist adjacent to the diorite. Fey (1980) describes thin sections of diorite containing stumpy laths of thermally clouded and patchily altered andesine (0.3-0.5 mm) set in a matrix of blue-green actinolite. Sphene derived from ilmenite and epidote are also present.

In the oxidised environment the gold is dispersed within a wide (20-30 m) envelope whereas in the sulphide regime the gold is confined to an ore zone typically less than 15 m wide. Pyrite is the most dominant sulphide occurring as either fine-grained (< 1 mm) disseminations in the diorite or medium- to coarse-grained (1-4 mm) grains in later cross-cutting veinlets and fractures. Fine-grained disseminated pyrrhotite is also present but in minor amounts. Study of core samples suggests that the sulphides are typically associated with the mafic phases of the diorite, commonly occurring along grain boundaries.

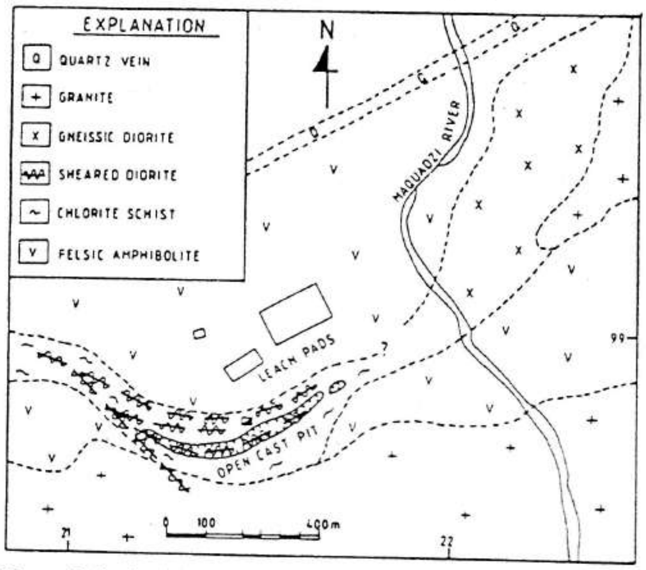

Figure 2. Geological map of the area around the Ayrshire mine.

The structural development of the mine is still being assessed but currently the model for the gold mineralisation involves a major shear zone which runs along the contact between the footwall granite and the metasediments. Secondary shears splay off the major shear at various intervals and it is along these shears that the gold mineralisation is found (Fig. 2).

4 FEASIBILITY

The results from the trenching, Cluff's sizeable percussion drilling and the limited core drilling programme by Pan-African confirmed the presence of five separate ore bodies which are covered by 23 claims. These ore bodies are the Ayrshire Main, North-West Pit, North West Extension, Chambadzi East and Chambadzi West, which by calculation gave an ore reserve of some 260,000 tonnes at 1.2 g/tonne.

Numerous metallurgical tests were carried out on bulk samples collected from both the surface and depth, to determine the leaching characteristics of the ore. Although in some instances recoveries of between 90 and 100% were achieved, a recovery of 70% was deemed more realistic.

5 ESTABLISHMENT

With the decision to go ahead with the project, applications were made through the Zimbabwe Chamber of Mines for foreign currency to import the equipment needed. It was at this time that the Mineral Marketing Corporation of Zimbabwe (MMCZ) had a foreign currency facility of some $75 million for use in the mining industry and it was from this that the currency was allocated to purchase the equipment. An excavator, wheel loader, 4 wheel drive tractors and wobbler sprays were ordered through the local agents.

Ground preparation started in earnest during October 1991 with work concentrating on