8TH INTERNATIONAL

Geological Society of Zimbabwe

THE GREAT DYKE OF ZIMBABWE

1998

PLATINUM SYMPOSIUM

Guidebook for the Pre-Symposium Excursion

23rd to 28th June, 1998

PLATINUM-GENESIS TO BENEFICIATION

PREFACE

Welcome to the Pre-Symposium Excursion to the Great Dyke of Zimbabwe sponsored and organized by the Geological Society of Zimbabwe as part, and on behalf, of the 8th International Platinum Symposium, Rustenburg, South Africa, 28th June to 3rd July, 1998.

The Great Dyke is one of several major mafic layered intrusions world-wide, including the Bushveld Complex, all broadly similar in structure, stratigraphy and petrology, that were emplaced into stable cratonic areas in the late Archaean to early Proterozoic. The geology of the Great Dyke provides important illustrations of many fundamental features of the emplacement and crystallization of mafic layered intrusions. By virtue of its unusual, narrow, elongate structure, it also displays, to better effect than in many other layered intrusions, the variations that can develop across magina chambers in response to a strong lateral heat gradient. The Great Dyke is also host to several world-class mineral deposits including high-grade chromite, platinum-group element (PGE)-rich sulphides, and nickel laterites. The chromite deposits have been mined continuously for 80 years, and, after several false starts since the 1920s, large-scale platinum mining has recently commenced and is expected to expand significantly in the near future... For their part, the nickel laterites still await substantive exploration and evaluation.

This is only the second major international excursion along the Great Dyke in its long history of mining development and geological investigation. The first, also organized by the Geological Society of Zimbabwe, was a 3-day event held in August, 1987, as part of IGCP Project 161's 5th Magmatic Sulphides Field Conference. At that time, no platmam mines were in operation and no underground visits were possible.

The object of the 1998 excursion is to provide delegates with an overview of the geology and mineralization of the Great Dyke with special reference to current platinum resource development. Besides touring areas of the northern part of the Darwendale Subchamber and the central part of the Wedza Subchamber that demonstrate the major layering and transverse variations of the Great Dyke, delegates will also visit Hartley and Mimosa Platinum Mines to view not only underground exposures of the PGE-rich Main Sulphide Zone and its host rocks, but also the different mining techniques employed at the two mines, and, at Hartley Platinum, the metallurgical processing plant. Again at Hartley, delegates will attend presentations on exploration and evaluation of the Mhondoro and Ngezi Platinum Projects.

This guidebook is designed as both a descriptive guide to the excursion programme and a summary of current geological ideas and mineral resource development. A large literature on the Great Dyke has accumulated since the first paper written in 1915, and so included with this guidebook is a comprehensive up-to-date bibliography. Because overseas participants will no doubt be interested in the wider geological, geographical and economic aspects of Zimbabwe, a travel log has been integrated with the excursion guide.

Our industrial sponsors (listed below) are thanked, variously, for their generous financial assistance to the organization of the excursion and the preparation of the guidebook, and for welcoming the excursion to their mining operations. Prospecting Ventures Limited provided the support vehicle. MDP is grateful to all the authors and others who have assisted in one way or another with the production of the guidebook, including Dr H. Gewald and Mr C. Murahwi (Anglo American), Mr D. Butcher (Zimasco) and Mr H. Wilhelmij (Delta Gold) for their contributions to the section on Mineral Resources and Mining Development, and Mrs R. Motsi of Prestige Business Services for word processing.

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Geological Society of Zimbabwe

8th International Platinum Symposium

Pre-Symposium Excursion

to

THE GREAT DYKE OF ZIMBABWE

23rd to 28th June, 1998

led by

A.H. Wilson and M.D. Prendergast

Guidebook

Compiled and edited by M.D. PRENDERGAST

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Cover design shows a photomicrograph of the sulphide-bearing bronzitite below the Main Sulphide Zone, Selukwe Subchamber, Great Dyke. Long dimension is 5 mm

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1.1 THE GREAT DYKE - GEOLOGICAL SUMMARY

A.H. Wilson

Introduction

The Great Dyke (Fig. 1.1.1) is a narrow, linear NNE-trending body of mafic and ultramafic rocks 550 km in length and between 4 km and 11 km wide. Together with a suite of satellite dykes, the Great Dyke was intruded about 2460 Ma (Hamilton, 1977; see Bibliography of the Great Dyke for all references in the text) into a set of parallel fractures cutting the granitoids and greenstone belts of the Archaean Zimbabwe Craton and the granulites of the Archaean Limpopo Province to the south. The northern extremity was deformed by the Pan Adrican orogeny (Zambezi Province) at 500 Ma.

The lower ultramatic rocks of the Great Dyke are very well layered and are overlain in several areas by erosional remnants of the upper gabbroic rocks. The latter mark the centres of up to five discrete subchambers or compartments of the Great Dyke magma chamber system each with an elongate boat-like or doubly-plunging synclinal structure.

The first extensive mapping of the Great Dyke was carried out in the 1950s resulting in the first comprehensive accounts of the entire body (Worst, 1958, 1960). This was followed in the 1960s by detailed studies of the upper chromitite layers and the Main Sulphide Zone (MSZ) in the Darwendale Subchamber (Bichan, 1969, 1970) and in the 1970s and 1980s by major investigations of the mineralogical associations, textures, petrology and structure of the Darwendale Subchamber (Wilson, 1982, 1992). Revived industrial interest in the MSZ led in the 1980s and 1990s to further detailed studies of the MSZ in the Wedza Subchamber (Prendergast, 1988a, 1990, 1991; Prendergast and Keays, 1989). in the Darwendale Subchamber (Wilson and Naldrett, 1989; Naldrett and Wilson, 1989, 1990; Wilson *et al.*, 1989; Wilson and Trederox, 1990), and in the Selukwe Subchamber (Coghill and Wilson, 1993).

Tectonic setting

To explain the co-linear fracture pattern which controlled the emplacement of the Great Dyke and its satellites, a pure shear model with intrusion of magma during a period of crustal extension has been suggested (Wilson, 1987). In this model, the sequence of events relating to the emplacement of the Great Dyke are as follows (Fig.1.1.2).

Stages 1 and 2. A north-northwest-directed maximum compressive stress, caused by overthrusting of the north marginal zone of the Limpopo Province onto the southern part of the Zimbabwe Craton, induced the major Popoteke fracture system, together with the conjugate Mchingwe fault set. Sinistral strike-slip movement occurred along the faults.

Stage 3. Extension occurred along these faults by rotation of the maximum compressive stress (from north-northwest to north-northeast) with subsequent emplacement of Great Dyke magma, periodically and over an extended period, into the dilated fracture system as a series of linked magma chamber compartments. At the same time, quartz gabbros were emplaced as flanking satellite dykes that extend almost the entire length of the Great Dyke (East and Umvineela Dykes).

Stage 4. Subsequent rotation of the maximum compressive stress back to the north-northwest direction caused dextral movement along the Mchingwe fault set together with further dyke emplacement on the north-northwest fracture pattern (Bubi and Crystal Springs Swarms; Robertson and van Breemen, 1970).

Stratigraphic subdivisions and cyclic units

The stratigraphy of the Great Dyke is formally subdivided into a lower Ultramafic Sequence and an upper Mafic Sequence (Wilson, 1982) (Fig.1.1.3). The upper part of the Ultramafic Sequence comprises well-developed cyclic units each made up of a lower dunite or harzburgite layer and an upper pyroxenite layer. Cyclic units in the lower part commence with a thin basal layer of chromitite followed by a thick dunite layer; pyroxenites are absent. On this basis, the Ultramafic Sequence can be further subdivided into an upper Pyroxenite Succession and a lower Dunite Succession (Wilson and Prendergast, 1989), each made up of readily-definable cyclic units.

Although smaller layering units exist in all the major cyclic units, they can be readily defined only in the well-exposed Cyclic Unit 1 at the top of the Ultramatic Sequence. Cyclic Unit 1 has been formally subdivided on the basis of changes in lithology and the presence of several chromitite layers. By local convention, a 'P' notation is used in numbering the pyroxenite layers so that the pyroxenite in Cyclic Unit 1, for example, is the P1 pyroxenite (or P1 layer) (Fig. 1.1.4).



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Fig. 1.1.1 Geological map of the central part of the Zimbabwe Craton showing the Great Dyke, its chambers and subchambers, and its satellites and associated fractures. Circled numbers refer to gravity profiles shown in Figure 1.1.6. Abbreviations: MSC, Musengezi Subchamber; P. Popoteke fault set; GF. Gurungwe Fault: MF, Mchingwe fault set; M, Mutorashanga; H, Hartley Platimum Mine: Mo, Mimosa Platimum Mine. (Inset shows the location of the Great Dyke in relation to the basement and cover rocks in Zimbabwe.)



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Fig. 1.1.2 Schematic representation of events associated with the emplacement of the Great Dyke. (1) Collision of the Zimbabwe and Kaapvaal Cratons and northward overthrusting of the north marginal zone of the Limpopo Province: (2) development of sinistral strike-slip faults of the Popoteke fault set (P in Figure 1.1.1) together with the conjugate Mchingwe fault set (MF in Figure 1.1.1): (3) rotation of maximum compressive stress causing extensional conditions and emplacement of the Great Dyke and its satellites, and (4) post-Greai Dyke re-activation of the Mchingwe fault set resulting in dextral movement.

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At surface, dunite has been totally replaced by serpentinite. Deep drilling in the Mutorashanga area has shown that the degree of serpentinization decreases with depth and unaltered dunites are encountered in unfractured areas at depths of about 300 m.

Chambers and subchambers

A significant feature of the Great Dyke is the longitudinal variation in the stratigraphy of the Ultramafic Sequence and the distribution of remnants of the Mafie Sequence (Fig. 1.1.5). On the basis of these variations, and of the existence of a major break at Lalapanzi (Prendergast, 1987), the Great Dyke is now subdivided into two major chambers and five subchambers with a further possible chamber at the extreme north end (Table 1.1.1; Wilson and Prendergast, 1989).

In the North Chamber, the Ultramafic Sequence is characterized by relatively few, thick cyclic units (100 m thick on average) with well-developed pyroxenite layers. In contrast, the South Chamber has a greater number of thinner cyclic units (10-30 m thick) with olivine pyroxenites predominating over pyroxenites in the upper parts of the units. The Ultramafic Sequence is often well exposed and the layering is well displayed on surface by the different outcrop expressions of the more resistant pyroxenites and olivine pyroxenites and the less resistant serpentinites. In the South Chamber, there is no indication of a lower Dunite Succession on surface although thick intervals of fresh dunite were intersected in a borehole below a depth of 700 m. Unlike the different development of the lower ultramafic units in each of the five subchambers, the stratigraphy of Cyclic Unit 1 and the overlying Mafic Sequence is very similar throughout the length of the Great Dyke.

Structure of the magma chambers

The structure and shape of the Great Dyke and its magma chambers have been determined from gravity investigations (Podmore, 1970; Podmore, 1982; Fig. 1.1.6). Each subchamber is essentially Y- or trumpet-shaped with gently inward-dipping margins steepening at depth. A major deep structure is inferred along almost the entire length of the Great Dyke but is absent where the North and South Chambers abut at Lalapanzi. This deep structure is interpreted as a continuous feeder dyke through which magma was emplaced into the developing magma chambers.

Some gravity profiles indicate local asymmetry and tilting of the structure; this is supported in several areas by the asymmetrical distribution of layering across the Great Dyke. Some models also require the existence of deep-seated magina chambers or deep extensions of the main chambers. The gravity profiles also suggest that the size of the magma chamber varies along the length of the Great Dyke. In particular, the North Chamber is significantly broader and deeper than the South Chamber, and a progressive increase in chamber volume is evident from the Wedza Subchamber northwards.

Transverse structure of the layered sequence

A variably-developed Border Group is present in many places along the margins of the Great Dyke and at several different stratigraphic and structural levels of the Ultramafic Sequence (Wilson, 1982; Wilson and Prendergast, 1989; Fig. 1.1.7). Up to several tens of metres thick, the Border Group varies from a very fine-grained massive zone to a steeply-dipping, complexly-layered package of diverse rock types. Acicular cumulus pyroxenes aligned perpendicular to the wall rocks are common.

The transverse shape of the layered sequence is synclinal, the layers lying flat in the axis, steepening towards the margins and then flattening again in the upper, broader part of the structure (Fig. 1.1.7; Wilson and Prendergast, 1989). The transverse layered geometry is largely primary with minor accentuation due to later downwarping in the axial zone.

In the Ultramatic Sequence, all layers which can be traced from the margin to the axis and those for which deep drilling data are available become progressively thinner, more fine-grained and richer in postcumulus phases towards the margins.

As it approaches the margin, each layer becomes asymptotic to the walls of the magma chamber and gradually merges with the Border Group (Fig. 1.1.7). Thus, the Border Group is essentially a steeply-dipping layered zone, or extreme marginal facies, in which each layer successively dies out against the chamber walls.



Fig. 1.1.3 Subdivision of Great Dyke stratigraphy into the Dunite and Pyroxenite Successions in the Ultramafic Sequence and the Lower, Middle and Upper Successions in the Mafic Sequence. Also shown are the lithological structures of cyclic units in the Dunite and Pyroxenite Successions.

Table 1.1.1. Main subdivisions of the Great Dyke magma chamber system

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Chamber	S	louth	North			Mvuradona
Subchamber	Wedza	Selukwe	Sebakwe	Darwendale	Musengezi	-
Length (km)	80	96	120	210	-	-
Thickness (m)	1900	1900	3350	3350	2450	-

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Fig. 1.1.4 Detailed stratigraphy of the Mafic and Ultramafic Sequences in the Darwendale Subchamber. Also shown are the detailed stratigraphy of Cyclic Unit 1 and the vertical variations in orthopyroxene compositions.



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Fig. 1.1.5 Stratigraphy of the Ultramafic Sequence in all five subchambers of the Great Dyke. The positions and numbers of the main pyroxenite and chromitite layers are shown. Note the minor (unnumbered) chromite concentrations, particularly in the Mutorashanga area.

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Fig. 1.1.6 Bouquer gravity anomaly profiles for six traverses across the Great Dyke. Locations of traverses are shown in Figure 1.1.1. Transverse sectional models consistent with surface geology provide best fits with the gravity data. Sample stations are indicated by dots on the anomaly profile and residuals to the model fit are shown on a scale of -10 to -10 gu. Rock densities are given in kg m³. Each traverse provides important information on the structure of the Great Dyke. (a) Typical section of the South Chamber: (b) Southern extremity of the Sebakwe Subchamber showing a thin layered sequence and the lack of a deep root zone. (c), (d) Deep structures of the North Chamber indicating a feeder dyke. (e) Tilted structure of the layered sequence consistent with field observations. (f) Various fits all showing the presence of deep-seated magma chambers beneath the layered sequence in the northern part of the Darwendale Subchamber.



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Fig. 1.1.7 Transverse section of the layered sequence of the Great Dyke in the Darwendale Subchamber based on borehole intersections, and field and gravity data. Note the small angular decrease and progressive thinning of the layers towards the margin, and the off-lapping relationship of the layers to the wall rocks.

The Ultramafic Sequence

Cyclic units

The stratigraphy of the Ultramatic Sequence in the Darwendale Subchamber is shown in Figure 1.1.4. The ideal cyclic unit encountered in the Ultramatic Sequence of the Great Dyke comprises a thin basal chromitite overlain by a thick durite layer which grades upwards through harzburgite and olivine pyroxenite into a pyroxenite which marks the top of the unit. The ideal cyclic unit is not always complete.

Chromitite

The development of chromitite layers may be related to the size of the subchamber, with the thickest, most economicallyviable and best-known layers occurring in the Darwendale and Sebakwe Subchambers. Eleven main chromitite layers (Figs 1.1.4 & 1.1.5) have been identified in the Ultramatic Sequence of the Darwendale Subchamber (Prendergast, 1987; Prendergast and Wilson, 1989; Wilson, 1982; Wilson and Prendergast, 1989; Worst, 1960, 1964), together with many thin, variably-continuous, minor chromitite layers whose relationship to the main cyclic units is not clear. Although the chromitites were formerly identified from the top down by seam numbers derived from mining practice (e.g. No. 1 seam, No. 2 seam, etc.), each is now numbered geologically from the top down, using a 'C' notation, according to the cyclic unit in which it occurs.

The main chromitite layers are divided, largely on a chemical basis, into two main stratigraphic groups: the low grade upper group chromitites (Clc, Cld, and C2a) of the upper Pyroxenite Succession, and the high grade lower group chromities (C5-C12) of the lower Pyroxenite and Dunite Successions.

Along the axis, chromitites C5 to C12 average 10-15 cm in thickness and are generally massive, comprising a dense linearly-interlocking, monomineralic mosaic of chromite grains averaging 0,5-10 mm. Primary interstitial phases are rare. The lower contacts are generally sharp. An upward decrease of both modal chromite abundance and grain size is observed towards the upper contact which is commonly gradational and often finely layered over several centimetres (or up to 150 cm above chromitite C6). Postcumulus fine-grained nodular textures are rare.

Towards the margins, the chromitites become finer grained and at least one (C7 north of Darwendale) gradually changes from a massive chromitite in the axis to a disseminated olivine chromitite nearer the margin. In strongly-disseminated olivine chromitites, the chromites form clusters of polygonal grains concentrated at olivine triple junctions. Transverse variations in chromite compositions are observed in chromitite C7 near Darwendale. The MgO content and Cr/Fe ratio, respectively, decrease from 14,2% and 3,6:1 near the axis to 12.9% and 3,3:1 near the margin over a distance of 3 km.

Several features of chromitite C5 distinguish it from the other lower group chromitites C6 to C12: (1) a relatively-coarse grain-size, (2) a thick P6 pyroxenite footwall, (3) an olivine \rightarrow orthopyroxene reaction zone in the hanging wall increasing to 100 cm thick near the margins, and (4) a 2-10 cm-thick poikilitic harzburgite layer with fine-grained chromite between the chromitite and the pyroxenite footwall. In one place near the margin, chromitite C6 is broken up into small lenses, locally upright or folded, probably due to gravitational instability in the steep marginal zone.

Unlike the lower group chromitites, the upper group chromitites Clc and Cld can be readily correlated at the same stratigraphic level in all five subchambers. Throughout the Great Dyke, these two chromitites are significantly thicker, more complexly layered and more disseminated than the lower group chromitites of the Darwendale Subchamber. Postcumulus fine-grained nodular textures are common and increase in size and abundance towards the margins. In general, the finest chromite grain size and the largest nodules are commonest in the narrower portions of the Great Dyke and towards the margins of the wider portions. Marginal facies of the chromitites within a few hundred metres of the wall rocks comprise a mass of fine-grained chromite poikilitically enclosed by large orthopyroxene crystals.

Significant longitudinal and transverse variations in internal stratigraphy, olivine/chromite modal ratio, and chromite compositions are a feature of chromitites Clc and Cld. These chromitites vary from a single chromite-rich layer to composite layers of two or more chromite-rich layers separated by harzburgite. Each layer may grade laterally from massive chromitite to strongly-disseminated olivine chromitite, the lower layers and the lower portions of each layer tending to be the most massive. Single layers vary in thickness from 5 cm to 100 cm. In composite zones, the combined thickness of massive and disseminated chromitite layers, together with the intervening harzburgite(s), may reach several metres. Chromitite Cld is the most variable of all the Great Dyke chromitites and unique among the upper group chromitites in several features that

it shares with chromitite C5 of the lower group: a (very thin) pyroxenite footwall, upper and lower zones of olivine \rightarrow orthopyroxene reaction and coarse grain size. These variations are well displayed at Darwendale and Lalapanzi.

All the Great Dyke chromitites have been affected to varying degrees by secondary processes that operated after consolidation (Prendergast and Wilson, 1989). These include slight subsidence along the axis and consequent transverse thrusting along the chromitite planes near the margins, serpentinization, and ground water percolation in hilly terrain leading to precipitation of secondary minerals. These processes in large part account for the strong transverse variations in bulk composition and physical quality (e.g. friability) and in thickness and wall rock conditions observed between the margins, and the axis of the chromitite layers in the Mutorashanga area. In its non-sheared state away from the margins, chromitite C5 is essentially in pristine form with physical properties typical of the massive chromitites enclosed by dunite below the serpentinized zone. Its low friability is probably caused (1) by annealing and intergranular adhesion and (2) by the enclosing footwall pyroxenite and hanging wall olivine—orthopyroxene reaction zone which together protected the chromitite from the effects of serpentinization of the overlying dunite.

Dunite and poikilitic harzburgite

The dunite comprises interlocking olivine grains with typical planar boundaries and triple-point junctions. Fine-grained chromite is an ubiquitous primary mineral (1-4% by volume) and is generally concentrated at olivine grain margins or at triple-point junctions. The olivine grains typically show strain or dislocation twinning related to the triple-point intersections. This may be explained by grain-coarsening or annealing processes. Small-scale layering within cyclic units can often be defined by variations in grain-size and olivine/chromite modal ratio. Towards the margins, there is a reduction in grain-size and an increase in the proportions of interstitial pyroxene and plagioclase. In all subchambers, dunite layers in the axis appear to grade into harzburgite towards the margins.

Poikilitic harzburgite is distinguished in the field by the presence of large (1-5 cm in diameter), optically-continuous orthopyroxene crystals with weathering characteristics different to those of the surrounding olivine grains. Olivine is contained within the orthopyroxene but is highly corroded and irregular in form. That the olivine grains were originally larger and cuhedral is indicated by the mantle of fine-grained chromite outlining the original olivine grains.

The relative abundance of dunite and poikilitic harzburgite in different parts of the Ultramafic Sequence is dependent on stratigraphic position and the size of the magma chamber. The Darwendale Subchamber has extensive dunite in the lower Dunite Succession whereas poikilitic harzburgite is an important component of the Pyroxenite Succession. In the Ultramafic Sequence of the smaller Wedza and Selukwe Subchambers, poikilitic harzburgite is more common than dunite, and the dunites contain more interstitial pyroxene that those in the Darwendale Subchamber.

Granular harzburgite and olivine pyroxenite

Granular harzburgite marks the textural transition from poikilitic harzburgite to olivine orthopyroxenite in which the pyroxene becomes granular and no longer encloses olivine. Olivine occurs as discrete grains. With increasing proportion of orthopyroxene, the rock-type grades into olivine pyroxenite. As the proportion of olivine decreases, its textural form changes from discrete grains to highly-irregular crystals interstitial to and partly enclosing rounded orthopyroxene crystals. This texture contrasts with that of the poikilitic harzburgites where rounded olivine crystals are entirely enclosed by orthopyroxene. In the smaller subchambers, olivine pyroxenite predominates over pyroxenite. Postcumulus plagioclase and interstitial phlogopite become important minor constituents of harzburgite in Cyclic Unit 1 of the Selukwe and Wedza Subchambers and near the margin of the Darwendale Subchamber.

Pyroxenite

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Pyroxenite is the dominant rock-type in the Pyroxenite Succession where it forms the uppermost rock-type of the cyclic units. In the lower cyclic units, it is very coarse-grained with crystals up to 10 mm long and consists almost entirely of orthopyroxene. The pyroxene crystals show well-defined glide twins with planes related to nick points on the crystal margin. Plagioelase and elinopyroxene are minor components and these commonly occur at the well-developed triple-point junctions between the minerals. In general, the average grain-size of the pyroxenes in the lower cyclic units is noticeably dependent on the size of the magma chamber with the largest grain-size in the Darwendale Subchamber and the smallest in the Wedza Subchamber.

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The Mafic Sequence

The Mafic Sequence is best preserved and achieves its maximum thickness in the Darwendale Subchamber, but the general characteristics observed there also apply to the other subchambers. The Mafic Sequence is subdivided into the Lower. Middle and Upper Mafic Successions on the basis of mappable textural characteristics (Fig. 1.1.4: Wilson and Wilson, 1981; Wilson and Prendergast, 1989). Further subdivisions are based on chemical reversals and detailed changes in texture. The rock-types and thicknesses of the subdivisions in the Darwendale Subchamber are summarized as follows.

Lower Mafic Succession (approx. 700 m thick). Medium- to coarse-grained gabbro, norite and gabbronorite containing primary orthopyroxene. These rocks are free of olivine except for a narrow olivine gabbro layer at the base.

Middle Mafic Succession (approx. 100 m thick). Fine- to medium-grained gabbro and feldspathic orthopyroxenites some of which contain olivine. Many of these latter rock-types are texturally similar to those of the P1 pyroxenite

Upper Mafic Succession (approx. 300 m thick). Dominantly norites with iron-rich orthopyroxene derived by inversion of pigeonite. Towards the top of the preserved succession, primary magnetite is present.

The base of the Lower Mafie Succession is marked by a thin layer (1-20 m) of olivine gabbro. Preferential weathering of olivine gives rise to a distinctive 'pock-marked' weathered outcrop. This unit is overlain by a thick sequence of monotonous gabbronorites which show an upward-increasing abundance of orthopyroxene and a gradual transition from cumulus orthopyroxene at the base to large optically-continuous postcumulus orthopyroxene at the top. Fine-scale layering is common, and, in the lower part, cross-bedding and erosion structures indicate the operation of magma density currents. Similar features are seen in the lower gabbroic rocks of the Wedza and Selukwe Subchambers. A narrow chromitite layer also occurs in places at the very base of the mafic rocks in these subchambers.

The Middle Mafic Succession is a complexly-layered package of rocks that are more primitive than those of the Lower Mafic Succession. The basal pyroxenite is characterised by extreme elongation of cumulus orthopyroxene. Other rock-types include olivine-bearing gabbro, and feldspathic pyroxenites in which the feldspar forms large interstitial and optically-continuous crystals.

The Upper Mafic Succession is characterized by the presence of cumulus pigeonite (with well-developed elinopyroxene herringbone exsolution) now inverted to large plates of optically-continuous orthopyroxene. Magnetite appears as a cumulus phase, but iron-rich olivine and apatite-rich rocks, characteristic of the upper portions of many large layered intrusions, are absent. Based on mineral composition trends, approximately 150 m have been eroded from the top of the Mafic Sequence. Quartz gabbro occurs in the central downfaulted block of the Wedza Subchamber but the relatively magnesian pyroxenes contained in this rock-type indicate that it formed as a hybrid from extensive roof contamination rather than from extreme fractionation of mafic magma (Wilson and Prendergast, 1989).

Cyclic Unit 1 and the P1 pyroxenite layer

Cyclic Unit 1 and the P1 pyroxenite layer occur at the critical point in the crystallization of the Great Dyke where olivine and orthopyroxene give way to clinopyroxene and plagioclase, and have been investigated in detail because of the economic importance of the chromitite layers and the PGE-rich suiphide mineralization they contain. Cyclic Unit 1 and (particularly) the P1 layer are the most complete and stratigraphically complex of the entire Great Dyke sequence (Fig. 1.1.4). Both display well-developed transverse variations in stratigraphy and petrology and, unlike the lower ultramafic units, both are found with little significant stratigraphic change in all five subchambers (Wilson and Prendergast, 1989).

Poikilitic harzburgite generally comprises the lowest silicate lithology of the lower subunits of Cyclic Unit 1. This rocktype is characterized by large (1-5 cm) orthopyroxene oikocrysts. Upwards within each subunit, there is a progressive change in modal proportions and textures, interstitial phases increasing at the expense of olivine, and orthopyroxene oikocrysts becoming more abundant, but decreasing in size. Plagioclase also begins to form oikocrysts, the adjacent olivine showing cuhedral crystal faces. Poikilitic harzburgite grades upwards into granular harzburgite as the orthopyroxene oikocrysts give way to aggregates of individual orthopyroxene crystals. Initially, the granular harzburgite occurs as discontinuous layers 2-50 cm in length, the granular texture becoming pervasive higher up. Some subunits display the normal upward progression from granular harzburgite to olivine orthopyroxenite; others exhibit a reversal to poikilitic harzburgite. In places, for example near the western margin of the Darwendale Subchamber, plagioclase is an important constituent of the harzburgite. Phlogopite may also be an important minor constituent of the feldspathic harzburgites forming large poikilitie and optically-continuous crystals.

The orthopyroxenite of the P1 layer is the dominant and most complex lithology of Cyclic Unit 1, displaying marked changes in grain-size and texture, modal proportions of cumulus and interstitial constituents, and mineral compositions (Prendergast and Keays, 1989; Wilson, 1992). It is generally much finer grained than pyroxenites lower in the sequence. Oikoerysts of both plagioclase and clinopyroxene become common towards the top of the P1 orthopyroxenite. In places, the plagioclase oikoerysts give rise to a characteristic nodular weathering feature - termed the 'potato reel' - comprising nodules up to 8 em in diameter and resulting from differential weathering of large, spherically-zoned, postcumulus plagioclase crystals. At the very top of the P1 layer is a prominent websterite, also with nodular weathering in places. Interstitial phlogoptic, magnetic, K feldspar, quartz, sphene, amphibole, apatite, zircon and sulphide are ubiquitous minor constituents of the P1 layer as a whole.

Cyclic Unit 1 in the Darwendale Subchamber is divided into six submits. The four lower subunits (1c-1f) are defined by basal chromite concentrations and upper orthopyroxene-bearing rocks. Subunit 1b contains the major P1 orthopyroxenite at the top. The base of subunit 1a is marked by the re-appearance of olivine in an olivine pyroxenite layer, the P1 websterite forming the upper part of the subunit. At least three subunits are distinguished in the P1 layer in the Wedza Subchamber on the basis of pyroxene compositions and mineralogical and textural changes.

Considerable transverse variation occurs in chromitite layers Cle and Cld (see above). Towards the west margin of the Darwendale Subchamber, the harzburgites have a higher proportion of orthopyroxene than in the axis, and plagioclase and elinopyroxene become increasingly important interstitial phases. The olivine pyroxenite at the base of subunit 1a lenses out towards the margin. The P1 layer is 220 m thick in the axis of the Darwendale Subchamber but thins to about 150 m near the west margin. Similarly the websterite is 33 m thick in the axis but only 7 m near the west margin. The same outward thinning is observed in the Wedza and Selukwe Subchambers where average thicknesses are less. Each of the subunits of the P1 layer also displays significant transverse lithological and compositional changes. The size and MgO content of the cumulus pyroxenes decrease, and the sizes and modal proportions of the postcumulus and interstitial phases increase towards the margins. These variations are less marked in the narrow Wedza than in the wide Darwendale Subchambers.

Towards the east margin of the Wedza Subchamber, websterite appears as a major lithology within the orthopyroxenites, and gabbro interdigitates with the websterite at the top of the P1 layer (Prendergast, 1991). This gives rise to important discordant relationships between phase and modal layering with new phases appearing on the liquidus at progressively lower levels towards the east margin. Along parts of the east margin of the Wedza Subchamber, the upper levels of the P1 layer, including the orthopyroxenites immediately below the websterite, were eroded by magma currents, the resulting depressions being subsequently filled by fine-grained mafic rocks (Prendergast, 1991). Similar structures are present at the same level of the Darwendale Subchamber (Wilson, 1992).

PGE mineralization

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In contrast to the very low sulphide content of the pyroxenites of the lower cyclic units, sulphides are an ubiquitous minor component of the P1 layer (Fig. 1.1.8). Their overall distribution is broadly correlated with the proportion of postcumulus phases and they are concentrated in several distinct zones. Two such zones are important: (1) the PGE-rich Main Sulphide Zone (MSZ) situated at, or a few metres below, the base of the websterite, and (2) the Lower Sulphide Zone (LSZ) lying about 30-65 m below the websterite layer. Each zone occurs within a separate subunit. The MSZ is economic (or, in places, potentially economic) and is discussed further below. The LSZ is normally much thicker and lower grade than the MSZ but displays broadly the same vertical metal distributions. Existing knowledge of the LSZ suggests its economic potential is mostly very limited. The MSZ and LSZ are both found in all five subchambers and are essentially continuous and regularly developed throughout the preserved P1 layer.

At the top of the websterite and sometimes encroaching on the overlying mafic rocks is a semi-continuous, irregularlydeveloped zone of sulphide-bearing pegmatoid up to two metres thick. The sulphides are often coarse grained but devoid of significant PGE values.

A major and constant characteristic of the MSZ wherever it occurs is (1) the offset vertical metal distribution profile, and (2) the bimodal distribution of both Pt and Pd (Fig. 1.1.9). Thus the MSZ comprises two main subzones - a lower PGE



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Fig. 1.1.8 Sulphide distributions (based on Ni + Cu assays; solid black) in the P1 pyroxenite layer in four subchambers of the Great Dyke. The orthopyroxenite (open) and websterite (stippled) layers are indicated, as are the Main Sulphide Zone (MSZ) and Lower Sulphide Zone (LSZ). Note the difference in sulphide distribution between the axis and west margin of the Darwendale Subchamber.



Fig. 1.1.9 Generalized vertical distributions of Cu - Ni and Pt + Pd through the Main Sulphide Zone (MSZ) of the Great Dyke. The MSZ is subdivided into a lower PGE subzone rich in Pt and Pd, and an upper BM (base metal) subzone with very low Pt and Pd contents. The PGE subzone can be further subdivided into lower and upper portions on the same basis. This profile is remarkably similar in all subchambers.

subzone rich in Pt, Pd and other precious metals and an upper base metal (BM) subzone with a very low PGE content - and the lower PGE subzone itself consists of two main portions (upper and lower) defined on the basis of both Cu, Ni and Pd, Pt contents. Within the PGE subzone as a whole, and within both the upper and lower portions, bulk base- and precious metals contents increase upwards, whereas Pd/Pt ratios and Pd + Pt contents per unit sulphide (as bulk Cu + Ni content) increase downwards, so the highest metal contents and the lowest Pd/Pt ratios and Pd + Pt contents per unit sulphide occur at the top of the PGE subzone.

The thicknesses of the MSZ and its component subzones vary significantly in different areas. In the Wedza and Selukwe Subchambers and towards the west margin of the Darwendale Subchamber, the MSZ is 2-3 m thick, the PGE subzone being about 1.5 m thick with well-defined upper and lower portions. Elsewhere, especially in and near the axis of the Darwendale and Musengezi Subchambers, the MSZ comprises very low grade mineralization distributed through a much greater thickness (up to 20 m in some cases).

In the narrower, higher grade parts of the MSZ, sulphide mineralization (pyrrhotite, enalcopyrite, pentlandite and minor pyrite) varies from finely-disseminated grains to almost net-textured concentrations. The MSZ is affected by varying degrees of late magmatic-hydromagmatic alteration with primary textures often partially to completely replaced by an intergrown assemblage of sulphide, hydrosilicate(tremolite, tale), magnetite, biotite, chlorite, quartz, carbonate and chromian spinel, together with remnant pyroxene and plagioclase. Alteration is generally correlated with sulphide and trapped liquid abundances and is intense near the margins but insignificant in the axis where cumulus textures are often well preserved.

The PGE mostly occur as discrete phases (Coghill and Wilson, 1993; Evans and Buchanan, 1991; Johan *et al.*, 1989; Prendergast, 1990) the most important platinum-group minerals (PGM) being high temperature species such as braggite ([Pt,Pd]S), cooperite (PtS), laurite (RuS₂) and low temperature species such as moncheite (PtTe₂), merenskyite (PdTe₂), maslovite (PtBiTe), michenerite (PdBiTe), kotulskite (PdTe), polarite (PdBi), sperrylite (PtAs₂) and hollingworthite (RhAsS). The PGM are intimately associated with sulphides at or near their contacts with silicates. A small amount of Pd resides as a solid solution in pentlandite.

From the margins towards the axis, total sulphide contents in the MSZ decrease and there is a strong decrease in Cu/Ni and Pd/Pt ratios and an increase in Pd + Pt contents per unit sulphide. The transverse variations in MSZ metal contents are pronounced in the wide Darwendale Subchamber but relatively slight in the narrow Wedza Subchamber.

Satellite intrusions

Satellite intrusions associated with the Great Dyke are an important part of the magmatic episode (Fig. 1.1.1). Broadly, these are subdivided into two groups called the Southern and Outer Satellite Dykes.

The Southern Satellite Dykes (also called the Main Satellite Dykes) outcrop over a total distance of 80 km immediately south of the Wedza Subchamber. They comprise a series of elongate and aligned mafic bodies between 150-600 m wide. The dominant rock-types of these dykes are norite and gabbronorite together with layers of websterite (some olivine-bearing) and feldspathic harzburgite. In texture and composition many of these rock-types are similar to those occurring in the Border Group of the Great Dyke. Layering, where it occurs, is also subvertical and parallel to the dyke margins. One group of dykes has been dated at 2545±120 Ma (Robertson and van Breemen, 1970) and is therefore strongly indicated to be part of the Great Dyke magmatic event. The largest of these dykes is postulated to be a feeder to, or a root zone of, a higher subchamber of the Great Dyke, now entirely eroded.

The Outer Satellite Dykes, associated with the extensive fracture system lying parallel to the Great Dyke, comprise the extensive Umvimeela Dyke (see Fig. 1.1.1) situated 1-18 km west of the Great Dyke, and the East Dyke, 10-24 km to the east. Space shuttle imagery and aeromagnetic surveys show that the East Dyke is virtually continuous along the entire length of the Great Dyke. Both dykes extend 80 km south of the termination of the Wedza Subchamber and intrude the northern marginal zone of the Limpopo Province. The Umvimeela and East Dykes are similar in bulk composition and mineralogy and are essentially quartz gabbros and gabbronorites with subophitic to intersertal textures. Pyroxene and plagioclase are strongly zoned and generally similar in composition to those of the Border Group of the Great Dyke. There is strong evidence for local wall-rock contamination.

Xenoliths

Inclusions of country rocks are found in many parts of the Great Dyke. Xenoliths of greenstone belt lithologies (diorite,

magnetite gabbro, serpentinite, quartzite and banded iron formation), ranging in size from several metres to many hundreds of metres, are especially common in the upper part of the Mafic Sequence in the Darwendale Subchamber. Extensive recrystallization and partial melting of the mafic xenoliths have resulted in the formation of coarse-grained pegmatitic quartz gabbro. Ultramafic inclusions are essentially unmodified and cross-bedded quartzite and pebble-bearing arkoses have clearly resisted recrystallization. Some banded iron formation shows extensive recrystallization of magnetite to grunerite Small granite xenoliths are also observed in the marginal zones of the Darwendale Subchamber.

In the Selukwe Subchamber, both the Ultramatic and Mafic Sequences contain many hundreds of autoliths from the Border Group as well as xenoliths (including large chromitite bodies) from the adjacent Shurugwi Greenstone Belt.

Mineral compositions

Variations in mineral chemistry reported from many different sections of the Great Dyke (Coghill and Wilson, 1993; Prendergast and Keays, 1989; Prendergast, 1991; Wilson, 1982, 1992; Wilson and Prendergast, 1989) are all consistent with fractionation of a relatively silica-rich tholeitic magma. Mineral composition trends are most comprehensively documented in the Darwendale Subchamber (e.g. Fig. 1.1.4).

In chromites in chromitite layers, MgO and Cr_2O_3 contents and Cr/Fe ratios increase upwards from chromitite C13 to C10 and then decrease upwards from chromitite C9 to C1c. Olivine compositions in the middle portions of the Dunite Succession show normal fractionation trends within individual cyclic units. Major reversals are coincident with, or he immediately above, the basal chromitite layer, and are associated with very magnesian olivines (Fo₃₂). Olivine in Cyclic Unit 1 is more evolved and also shows a regular upward Fe enrichment trend from Fo₃₁ to Fo₈₇. Orthopyroxene compositions display a steady upward Fe-enrichment through the Pyroxenite Succession. The most magnesian pyroxene is En₃₁. Near the top of the orthopyroxenite of the P1 layer, the composition is En₈₅. A very clear feature of the pyroxene chemistry is a progressive reversal to more magnesian compositions towards the tops of the pyroxenite layers. Orthopyroxene compositions in Cyclic Unit 14 near the base of the Ultramafic Sequence are comparable to those in Cyclic Units 2 and 3 at much higher stratigraphic levels and display a reversed fractionation trend. In the websterite unit of the P1 layer, the rate of Fe-enrichment increases sharply and this trend persists into the overlying mafic rocks. Trends of clinopyroxene compositions are similar to those of orthopyroxene where the two pyroxenes co-exist in the websterite and gabbroic rocks. One major reversal in orthopyroxene compositions takes place in the Middle Mafic Succession, but the normal trend is resumed in the Upper Mafic Succession.

The chemistry of fine-grained chromites enclosed by olivine and pyroxene between the main chromitite layers provides strong evidence for varying degrees of down-temperature subsolidus rc-equilibration between the chromites and the silicate minerals, and, in poikilitic harzburgite, reaction between chromites and trapped liquid (Wilson, 1982). The principal process is the diffusion of Fe^{2+} into chromite, thus decreasing the Cr/Fe ratio, and the migration of Mg into olivine.

Initial liquid composition

The early crystallization of high-Mg orthopyroxenes following extensive olivine crystallization indicates that the Great Dyke magma had relatively-high SiO₂ and MgO contents. The compositions of the most magnesian olivine and cumulus orthopyroxene are Fo₉₂₀ and En₉₁₅, respectively. A further indication of the ultramafic nature of the Great Dyke magma is the high Cr_2O_3 contents of orthopyroxene (up to 0,71%).

The initial $S^{3}Sr^{6e}Sr$ ratio of 0,70261 ±4, and the essentially-constant initial Sr values of minerals and whole rocks from many different parts of the Great Dyke (Hamilton, 1977), rule out extensive contamination of the magma by felsic continental crust. The high silica content of the parental magma therefore reflects its source in silica-enriched subcontinental lithospheric mantle.

The composition of a chilled margin of a dyke considered to be an offshoot of the East Dyke (Wilson, 1982) with about 16% MgO and 53% SiO₂ is in good agreement with observed mineral compositions and modelling using this composition is consistent with the observed crystallization sequence (see below). This composition (Table 1.1.2) is therefore regarded as the parental magma composition of the Great Dyke.

	Wilson, 1982	Prendergast and Keays, 1989
SiO ₂ (%)	52,77	52,07
Al_2O_3	11,04	10,69
Fe_2O_3	1,23	•
FeO	8,20	10,77
MnO	0,14	0,17
MgO	15,60	14,61
CaO	7,60	7,25
Na ₂ O	1,77	1,54
K ₂ O	0,69	0,74
TiO ₂	0,55	0,51
P_2O_5	0,11	0,07
Cr_2O_3	0,29	0,34
NiO	0,06	0,06
Pt(ppb)		0,64
Pd		4,20
Au		0,08
Ir		0,22
Os		0,14
Ru		0,92
Cu(ppm)		83
Со		70
S		541

Table 1.1.2. Composition of the East Dyke chill phase

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Petrogenesis

The macrocyclic layering of the Ultramafic Sequence and the consistent compositional reversals at the bases of the cyclic units are readily explained by repeated injections of parental magma into the chamber and by mixing between parental and evolved resident magmas. Mineral compositional trends and the major lithological sequence reflect the gradually-evolving liquid composition throughout the crystallization history (Wilson, 1982). The amount of mixing between parental and resident magmas would have depended on the fluid dynamics of the system and the relative densities and viscosities of the two magmas. The contrast between the sharp reversals in the dunites and the much more gradual reversals in the pyroxenites suggests that mixing dynamics differed in the Dunite and Pyroxenite Successions (Wilson, 1982).

The greater rate of compositional change shown by pyroxenes from the top of the P1 layer upwards indicates a marked decrease in the frequency of magma influx and there is no evidence of any new magma injection in the Lower Mafic Succession (Fig. 1.1.4). A further influx gave rise to the reversal in the Middle Mafic Succession. The first appearance of plagioclase and the formation of the entire Mafic Sequence by injection of more differentiated magma cannot be ruled out (Wilson, 1996). This in itself would not have affected the rate of differentiation within the chamber.

The prominent reversals evident in both rock-types and mineral compositions at the base of the Ultramafic Sequence is a common feature of large layered intrusions ('basal reversal') and probably relates to the mode of initial emplacement of hot primitive magma into the cool juvenile chamber.

The order of crystallization deduced from cumulus assemblages is chromite-olivine-orthopyroxene-elinopyroxeneplagioclase-pigeonite-magnetite, the same as in the microphenocryst and groundmass assemblage of the East Dyke chill phase (see above). The arrival of each new cumulus mineral on the phase boundary is heralded by the prior appearance of the mineral as an abundant postcumulus phase (e.g. orthopyroxene in poikilitic harzburgite beneath orthopyroxenite, clinopyroxene in orthopyroxenite beneath websterite, and plagioclase in the P1 layer beneath gabbro).

The differences in ultramafic stratigraphy between each chamber and subchamber and the striking stratigraphic similarity throughout the Great Dyke from the level of Cyclic Unit 1 upwards suggest that either the barriers separating the compartments were eventually breached as more magma was injected, or the Great Dyke magma chamber system was compartmentalized at lower levels but physically linked at higher levels.

The preserved thickness of the Mafic Sequence is very small compared with that of the Ultramafic Sequence. Modelling of the fractionation trends combined with mass balance considerations indicates that either the magma chamber was effectively an open system during the formation of the Ultramafic Sequence, or there existed a large sill-like lateral extension accommodating the upper Ultramafic Sequence and most of the Mafic Sequence, now entirely eroded away (Podmore and Wilson, 1987).

Origin of the PGE mineralization

The stratigraphic association of the MSZ and LSZ with pyroxenites at the top of the Ultramafic Sequence and the occurrence of the mineralized zones within (and not at the base of) major cyclic units contrast with the association of important PGE-rich sulphide zones in several other layered intrusions with later mafic rocks and with major magma replenishment and mixing events. Sulphur saturation and the precipitation of PGE-rich sulphides within the P1 layer was the result of progressive cooling and fractionation, and of progressive enrichment of the magma in incompatible elements including S. Other important factors included a minor replenishment between the LSZ and the MSZ, periodic overturns of the stratified magma column (giving rise to the modally- and cryptically-layered nature of both mineralized zones), and possibly, in the case of the MSZ, mixing between the resident magma and an evolved magma derived from higher levels of the magma chamber. The order of metal enrichment in the sulphides (Ir-Pd-Pt-Au, Cu, Ni) is attributed to the different apparent partition coefficients of the metals into sulphide and is consistent with fractional segregation of sulphide at the floor of the magma chamber and the extraction of PGE, Au and base metals from the overlying convecting magma in the order of their apparent partition coefficients.

The mineralogy and textures of altered MSZ is a function of the complex, multistage postcumulus development of the mineralized zone involving (1) cooling of silicates and PGE-enriched sulphides, (2) the extreme evolution of the trapped liquid and its subsequent interaction with the sulphides leading to the production of small amounts of a highly-reactive fluid phase, and (3) the release of metals from the sulphide and their incorporation into new phases. (Coghili and Wilson, 1993; Prendergast, 1990).

Thus, the origin of the MSZ and LSZ is readily explained by primary magmatic processes (Naldrett and Wilson, 1990; Prendergast and Keays, 1989; Wilson *et al.*, 1989; Wilson and Tredoux, 1990). There is no evidence for the involvement of large volumes of hydromagmatic fluids which, in any event, could not account for the exceptional regularity of the metal distribution profiles over large areas.

Lateral variations

Significant lateral variations occur across the layered structure. These are considered to be related to the transverse shape and narrow width of the magma chamber, the effect that this had on heat flow and therefore on crystallization processes, and to the replenishment process (Prendergast, 1991; Wilson and Prendergast, 1989). As a result of the upward-flaring structure, the most marked transverse variations occur in Cyclic Unit 1 which lay closest to both the floor and sidewalls and to the roof of the intrusion. Besides major heat loss through the roof, significant heat would also have been lost laterally through the floor/walls. Thus, there was a strong temperature gradient from the hot axial environment underlain by thick hot cumulates and a deep feeder dyke ontward to the cool marginal environment close to the floor and walls. This would have had a profound effect on crystallization processes and magma evolution.

It is likely that compositional and thermal stratification in the magma column was also important in developing the discordant layering relationships observed towards the margins (Prendergast, 1991).

1.2 THE GREAT DYKE - MINERAL RESOURCES AND MINING DEVELOPMENT

M.D. Prendergast

Chromite

The main chromitite layers of the Great Dyke represent a total chromite resource of about ten billion tonnes. About 90% is high-grade chromite in the lower group chromitites. Most lies below present mining depths and far from railheads, but enough chromite is available at or near the established mining centres for many years to come. Chromitites Clc and Cld of the upper group, and chromitites C5, C6, C7, C8 and C10 of the Darwendale Subchamber, and Clc and Cld of the Sebakwe Subchamber, are the best developed and over the years have been the most intensively mined (Prendergast, 1984, 1987; Prendergast and Wilson, 1989). The mining and metallurgical properties of these chromitites are summarized in Table 1.2.1.

The highly-variable mining and metallurgical properties of the Great Dyke chromitites have important consequences for their utilization in the ferrochromium industry. The narrow thicknesses of the chromitites necessitate exceptionally labourintensive mining methods with 55% of operating costs being accounted for by labour. Consequently, variations in thickness have a major impact on labour productivity. Mining costs are also affected by the mechanical strength and hardness of the wall-rock. The serpentinized dunite is soft and disintegrates rapidly when exposed in underground workings, which necessitates costly support but also allows the use of relatively-cheap electric coal drilling. More expensive compressed-air drilling is necessary for harder harzburgite and pyroxenite wall-rocks.

The high Cr_2O_3 content and Cr/Fe ratios of most Great Dyke chromite ores potentially allow the production of high-Crgrades of ferrochrome alloy. Against this advantage are the relatively-high unit mining costs and the high friability of much of the chromitite rendering it unsuitable on its own for high-carbon ferrochrome production by conventional arc smelting.

Chromite was first recorded at Aireys' Pass south of Mutorashanga in 1907, and chromite mining had commenced in several parts of the Great Dyke by 1919. Since then, Zimbabwe's chronium industry has undergone continuous development and transformation in a highly-competitive environment. Up to World War II, mining was confined to surface workings up to 40 km north of the railheads at Darwendale and Lalapanzi. In the late 1940s, deteriorating surface mining conditions forced a shift to underground mining in the Mutorashanga area via inclined shafts and adits. Traditionally regarded as uneconomic, the new underground operations were made profitable by the introduction of electric coal drills and box scrapers, the development of resue mining methods and the extension of the railway and electricity grid northwards. (Resue mining, now standard on Great Dyke underground chromite mines, involves stoping between seam drives on levels spaced at fixed intervals down an inclined pilot shaft, the drilling and blasting of an 80 cm hanging wall cut, the packing of as much waste as possible in the stope behind, and the lifting of the chromite by hand prior to tramming to the shaft).

	Upper group	Lower group
Bulk % Cr ₂ O ₃	36-49	43-54
Bulk refractory ratio*	2,8-3,2	3,9-4,4
Chromite Cr/Fe ratio	2,0-2,7	2,7-3,9
Friability at present mining depths	Ore iumpy to semi-friable	Chromitite $C5 \pm lumpy$ throughout. Chromitites $C6-C12$ highly friable with some lumpy ore
Form/thickness	Composite layers (up to 400 cm +) comprising one or more massive to disseminated layers each 5-100 cm thick	Single massive layers 10-15 cm thick
Wallrocks/mining conditions	Harzburgite wallrocks (except footwall pyroxenite of chromitite Cld). Serpentinized form relatively hard; good ground conditions, but jackhammers required	Dunite wallrock (except for footwall pyroxenite of chromitite C5). Serpentinized form very soft; poor ground conditions, but suitable for electric coal drills. Chromitite C5 requires jackhammers and special extraction techniques

Table 1.2.1 Summary of mining and metallurgical properties of chromitites in the Darwendale and Sebakwe Subchambers

*Bulk refractory ratio: $(Cr_2O_3 + MgO + Al_2O_3)/(total Fe as FeO + SiO_2)$.

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Up to the early 1950s, the country's entire chromite output was exported as unrefined ore. To offset the cost of long sea routes to market, ferrochrome smelters were established in Gweru in 1953 and in Kwekwe in 1961, and a third smelter at Eiffel Flats near Kadoma in 1974; the proportion of chromium exported as refined alloy began to increase steadily through the 1950s-60s. Deep level mining of multiple chromitite layers, principally C7, C8 and C9, via vertical shafts in the axis, was seriously considered at this time. These plans were never put into effect largely because of the high capital expense, although some inclined shaft systems serving two chromitite layers (C7 and C8) were successfully developed at a later stage.

By the late 1960s. Zimbabwe ranked third only to South Africa and the USSR as a producer of metallurgical grade chromite Production levels were determined largely by world economic conditions, and international trade sanctions, imposed on the country from 1966 to 1980, had little effect on the local chromium industry which took full advantage of increasing demand in the 1970s to achieve an all-time record production of 876 000 t of chromite in 1975. This period saw the acme of deep mining at Mutorashanga where large mining sections were developed with long inclined shafts hauling ore from up to 700 m in the axis. Faced with the need to disguise its product, the industry accelerated the trand towards local refining, and by 1979 ferrochrome alloy accounted for 95% of all chromium exported. Eluvial chromite mining (see later section) had begun in the 1950s near Mutorashanga, principally for low-carbon ferrochrome production. As new stainless steel technology reduced the demand for this type of alloy, local smelters switched increasingly to high-carbon ferrochrome production and the mining of eluvial chromite, which, like triable layer chromite, is unsuitable for conventional arc smelting, ceased by 1975.

From a large number of producers up to the 1960s, the Zimbabwe chromium industry has since become concentrated in the hands of only two companies, Zimasco and Zimbabwe Alloys. The former (bought by local investors from Union Carbide Corporation in 1993) is a large, volume producer of high-carbon ferrochrome based in Kwekwe, whereas the latter (owned by Anglo American Corporation), maintains a niche as a smaller producer of specialty low-carbon ferrochrome and ferrochrome silicon alloys. Since the boom years of the 1970s, these two companies have been affected by rapidly-increasing labour and power costs as well as by fluctuating market conditions.

Initially, these factors forced a steady shift in large-scale company production from deep-level mining operations on the high-grade, but thin and friable, lower group chromitites near Mutorashanga to the low-grade, but thicker and less friable, upper group chromitites, which occur at relatively shallow depth in the Lalapanzi and Ngesi areas. This process was accompanied by an increasing trend towards extensive small-scale, low-cost production by co-operatives and tributors from shallow winzes and adits, particularly near Mutorashanga. On the larger mines at Mutorashanga, experiments were conducted in the use of road-headers in development and continuous miners in stoping operations, and stoping applications of diamond wire and chain cutters, pneumatic and electric picks, and hydraulic monitors were also investigated. It is now thought that mechanization employing large underground units is inappropriate to the relatively small-scale chromite mining operations on the Great Dyke, and smaller scale mechanical stoping methods have yet to demonstrate their effectiveness.

Meanwhile, amid the fast-dwindling supply and quality of the country's Archaean podiform ores - especially those at Shurugwi, long the mainstay of the chromium industry producing approximately 50-60% of the ore since 1906 and now not expected to last beyond 2015 - it is now recognized that the industry's future lies in deeper surface and underground mining of the Great Dyke chromitites and that systems must be established to mine these economically. These factors, plus deteriorating market conditions, have recently led to a fundamental change in approach. Most company-mining has now ceased, except at Shurugwi, and both Zimasco and Zimbabwe Alloys now draw almost their entire Great Dyke ore supply from contractor and tributor operations. These range in size and degree of sophistication from traditional 'hole-in-the ground' artisanal workings to well-capitalized operations employing heavy machinery. The companies confine their direct role, where necessary, to management and technical support and to provision of infrastructure. Reliable contractors have been encouraged to develop mechanized surface mining operations produce chromite at a lower cost than underground mining of the same chromitite, and several are now established, or are being planned, in the central and southern parts of the Great Dyke. Resources amenable to mechanized surface mining are limited, and such operations offer only a short- to medium term 'stop-gap' (up to 15 years).

At the same time, new methods designed to reduce underground mining costs in the longer term are being tested in suitable company-supported operations. Critical advances are being made in the limited mechanization of development using trackless mini-loaders and of stoping operations using scrapers. Cost reductions of 25-50% are anticipated together with increases in productivity by up to 60-70% to 8-12 t per man-month, depending on chromitite thickness. The companies' role in providing infrastructure will also enable such operations to mine up to 700 m down dip and thus achieve a mine life of 20-30 years. Such measures, aided by increased co-operation between Zimasco and Zimbabwe Alloys, are expected to

keep Zimbabwe in the low part of the international cost curve. Much of the chromite won by this new approach will be relatively low grade (44% Cr₂O₃ with a Cr/I/e ratio of 2,1-2,2:1). It is considered that the production of 60% Cr alloy from such low-cost ore will be more economic than utilizing high-cost, high-grade ore from the lower group chromitites to produce the more valuable, traditional 65% Cr alloy. Despite adverse conditions, the Zimbabwe chromium industry is confident that it can remain a major player well into the new millenium provided it can successfully manipulate its varied Great Dyke resource base to keep costs down. This confidence is reflected in the recent entry of two small potential producers, one of which plans to refurbish the old Eiffel Flats smelter.

Platinum

Developments to 1987

The likely occurrence of PGE in the Great Dyke was predicted by F.P. Mennell as early as 1908, and the earliest reference to the MSZ was made in 1918 by A.E.F. Zealley who reported the presence of disseminated sulphides on Helvetia Farm near Shurugwi. The discovery of PGE in the Merensky Reef of the Bushveld Complex in South Africa in 1924 led immediately to a platinum-prospecting boom on the Great Dyke. A Mr R. Sacchi is credited with the first discovery of PGE in the MSZ, in the Makwiro area in 1925, and many similar discoveries were soon made elsewhere in the Darwendale. Sebakwe, Selukwe and Wedza Subchambers by local farmers, private entrepreneurs and mining companies. This prospecting activity received considerable official encouragement and the Southern Rhodesia Geological Survey was quick to send its officers to investigate the geology of the MSZ (e.g. Lightfoot).

The Grainger brothers' Wedza Mine, which operated from early 1926 to late 1928, was the most significant of the early attempts at producing platinum from the MSZ. Its eventual failure was directly attributable to low recoveries. Industrial interest in Great Dyke platinum soon waned when it was realized that the fine-grained platinum minerals could not be economically recovered from the oxidized surface ore with existing wet-gravity separation technology.

The next attempt at exploiting the oxidized MSZ was made in 1951-53 by the Great Dyke Wedza Syndicate in the Wedza area under Exclusive Prospecting Order (EPO) 12. Metallurgical testwork showed that the PGE could be economically recovered in terronickel by smelting the ore in an electric furnace, but nothing came of this project.

By the middle 1960s, much of the potential PGE-bearing ground was held under EPOs 127, 128 and 130 by Anglo American Corporation whose initial interest was chromite. Angle American later took out new EPOs (188, 189 and 260) over the same areas to investigate the MSZ. Meanwhile, Union Carbide Corporation acquired through its local subsidiary, Rhodesia Chrome Mines, most of the remaining prospective ground not then held by Anglo American. This covered all the Snakes Head area in the Musengezi Subchamber (EPO 193), most of the Wedza area (EPO 194) and large areas around Selous in the Darwendale Subchamber. Rio Tinto became involved in the early 1970s acquiring small scattered parcels of ground in the Sebakwe and Darwendale Subchamber under EPO 437.

Subsequently, between the late 1960s and early 1980s, all three companies together drilled several hundred boreholes and proved the existence of the MSZ at depth in all four principal remnants of the P1 layer. Union Carbide set up trial mining and metallurgical extraction projects to investigate suitable mining and recovery processes at Wedza (1969-71). Sclous (1971-72) and at Mimosa (close to Wedza, 1974-78). Despite the large potential resources, the Selous project failed, essentially because of rock mechanics problems, difficulties in following the MSZ, and ore dilution. Work at Wedza met with more success and a technically-feasible mining scheme and extraction process was established right through to the sale of refined metal. Anglo American considered that, of all their holdings on the MSZ, the Selukwe Subchamber held the greatest potential. Trial mining was carried out at Unki (9 km ENE of Shurugwi) in the late 1960s and early 1970s but no metallurgical testwork was attempted. Work earried out by Rio Tinto at its Zinca prospect (38 km SSW of Selous) in the Sebakwe Subchamber in 1980-83 met with many of the problems encountered at Selous, although appropriate mining and grade control systems were considered to have been satisfactorily established.

Despite considerable, technically-successful, exploration and evaluation effort between the mid-1960s and early 1980s, and the proving of a huge tonnage of potential ore in a persistent zone up to 1,8 m thick, an economically-viable producing mine was not developed and all the Great Dyke platinum projects were firmly in mothballs by 1984. There were several reasons: (1) the relatively marginal grade which could only be offset by cost-efficient mining and extraction, and by higher metal prices than prevailed at the time, (2) the high capital costs required to develop a mine of the optimum economic size, and (3) the poor market perception of the local investment climate. All these companies maintained their holdings with the exception of Union Carbide which abandoned its Selous prospect by the mid-1980s.

The long history of failed attempts to mine the MSZ was turned around in 1987 when the Australian junior resource company, Delta Gold, acquired the old Selous prospect under EPO 623 and immediately put in train a series of reevaluation studies. This single most significant development in recent years provided the necessary stimulus and catalyst for all subsequent activity on the MSZ, including the Hartley, Mimosa, Unki, Mhondoro, Ngezi, Selous and Snakes Head Platinum Projects.

The MSZ of the Great Dyke has several inherent advantages as an economic source of PGE (Prendergast, 1988b; Prendergast and Wilson, 1989). (1) With uniform grades and thicknesses over wide areas, it is a persistent mineralized zone with no significant magmatic disturbance features such as the potholes which affect parts of the Merensky Reef. (2) The dollar value and revenue distribution is comparable to parts of the Merensky Reef and UG-2 with Au and Ni accounting for significantly greater proportions of revenue. (3) A large proportion is mineable at relatively shallow depth and is also amenable to a high degree of mechanization. (4) Metallurgical recoveries are expected to be marginally higher than on South African platinum mines. In addition, labour costs in Zimbabwe are relatively low, and the MSZ provides an important alternative PGE source to South Africa and Russia.

Possibly the most significant inherent disadvantages of the MSZ as a mineable resource are the problem of grade control in a weakly-mineralized zone with complex metal distributions, gradational boundaries and no visual markers, and the high standard of management required to overcome it.

MSZ resource estimates vary with stope width. Conservative estimates amount to several billion tonnes mostly situated in the Darwendale and Sebakwe Subchambers. [About 9% is near-surface oxidized MSZ. Interest in these cheaply-mined surface resources has centred on extraction processes, including electric smelting (see above) and leach methods.]

Hartley Platinum Mine

In 1990, Delta Gold announced the conclusion of a joint venture agreement with BHP to develop and mine the MSZ at Selous, renamed the Hartley Platinum Project. Following initial confirmatory work by BHP (67%; project operator), including 34009 m of additional drilling, rock mechanics investigations, trial mining and metallurgical testwork, a Mining Agreement - including a special marketing clause - was signed between the Hartley Platinum partners and the Government of Zimbabwe in August, 1994. Mine construction commenced soor, after, and the mine is now in production with the build-up to full planned capacity under way.

The initial resource is 50.9 Mt mineable at 2,6 g/t Pt, 1,8 g/t Pd, 0,2 g/t Rh, 0,5 g/t Au, 0,2% Ni and 0,1% Cu (Chadwick, 1996). Total resources are 160 Mt. At current planned production rates, Hartley Platinum will produce annually 150 000 oz Pt, 110 000 oz Pd, 11 500 oz Rh, 23 000 oz Au, 3 200 t Ni, 2 300 t Cu, 35 t Co and 6 400 t sodium sulphate. Hartley Platinum is expected to be in the lowest quartile of platinum production costs and well able to compete with South African producers (Chadwick, 1996). At a total capital cost of 264 million US dollars, Hartley Platinum is Zimbabwe's most important investment project in many years, and at full production will contribute about 8% of the country's foreign exchange earnings.

Mimosa Platinum Mine

In 1989, eleven years after the closure of the Mimosa trial mine, Union Carbide revived its interest in the Mimosa Platinum Project and commenced a programme of re-evaluation involving dewatering, bulk sampling and metallurgical testwork, mechanized mining trials and limited additional drilling. In 1995, this work culminated in the expansion of the refurbished concentrator from 200 t/d to 700 t/d and Mimosa Platinum Mine - now owned by Zimasco (see above) - has been in production at a rate of approximately 250 000 t/y since then. By contrast with Hartley Platinum Mine, the mining system at Mimosa is designed to take advantage of the relatively flat dips and reduce costs by the use of mechanized trackless mining in 1,5 m-high stopes and by carrying all development on reef. At that stope width the mining probable reserve is 51 Mt containing 2,17 g/t Pt, 1,55 g/t Pd, 0,17 g/t Rh, 0,43 g/t Au, 0.2% Ni and 0.16% Cu. Zimasco has completed feasibility studies for expansions to 750 000 t/y and 3 Mt/y, although no decision on expansion has yet been made.

Unki Platinum Project

Anglo American resumed exploration and evaluation work at Unki in 1989. Besides further drilling, the vertical shaft was rehabilitated and trial mining and bulk sampling for metallurgical testwork were carried out. In February, 1998, after detailed feasibility studies, Anglo American announced plans to proceed at once with the development of a mining operation in partnership with government. The Unki mine plan envisages an annual production rate of 118 000 oz of PGE and Au and 2 500 t of base metals, about half the capacity of Hartley Platinum.

Mhondoro, Ngezi and Selous Platinum Projects

In the late 1980s, interest was also redirected to the substantial prospective ground adjacent to the Hartley Platinum Project (Fig. 1.2.1). Covering the east and west marginal zones from Hartley Platinum in the north to the old Zinca prospect in the south, the Mhondoro Platinum Project was initially owned jointly by Rio Tinto, Angle American and Plateau Mining and Finance of the UK. In a series of deals, Mhondoro was eventually acquired by BHP (61%) and Delta Gold (39%). Exploration in this area, managed by BHP, is presently concentrated on the west margin. Meanwhile, Delta Gold has continued exploration at its 100%-owned Sclous Platinum Project to the east and south of Hartley Platinum in the remaining portion of EPO 623, now converted to claims. In 1995, Delta Gold bought Angle American's claims in the Ngezi area to the south of the Mhondoro Platinum Project.

With 125 diamond drillholes completed and a definitive feasibility study under way, the Ngezi Platinum Project is now the most advanced of the three platinum projects near Hartley Platinum. At Ngezi, the MSZ along the west side is comparable to Hartley in dip (16°) and thickness (1,2 m) (Chadwick, 1996). In the centre and along the east side, the thickness is significantly greater (1,9 m) and the dip much flatter (11°). Although lower in grade, the MSZ in these latter areas contains more recoverable metal and its thickness and dip make it potentially suitable for low cost mechanized mining.

Resource estimates for the Mhondoro, Ngezi and Selous Platinum Projects, supplied by Delta Gold, are given in Table 1.2.2.

Snakes Head Platinum Project

The Snakes Head area is situated in the northernmost Musengezi Subchamber where the MSZ occupies a remote 100 km² tract of rugged ground made up of at least five major fault blocks. The most accessible and least deformed western part has now been partially explored by three different companies (Fig. 1.2.2). The remainder, straddling the Musengezi River to the east, is still largely unknown.

Under EPO 193 (see above) in the late 1960s, Union Carbide drilled four boreholes about 160 m apart down dip. In 1988-90, under EPO 654, Cluff Resources carried out initial mapping to define the major structure and the position of the maficultramatic contact and then drilled four boreholes, one close to Union Carbide's boreholes and three to the north and east. Between 1995 and 1997 further boreholes were drilled in the same area by the Metal Mining Agency of Japan as part of an aid agreement between the Governments of Zimbabwe and Japan. The results were very similar to those of earlier drilling and added little new information.

The combined results of the three drilling campaigns at Snakes Head show the following. (1) Both the MSZ and LSZ are present throughout the area drilled, the MSZ at the base of the websterite and the LSZ lying about 50 m below the MSZ (Fig. 1.2.3). (2) The MSZ and LSZ are very similar in thickness, grade and internal metal distributions (Fig. 1.2.4). (3) The LSZ is exceptionally well developed relative to its development in other parts of the Great Dyke, although metal values are significantly lower than in the MSZ at Hartley and Mimosa Platinum Mines. (4) The thickness, lithologies and textures of the pyroxenite host rocks, as well as the grades and thicknesses of the MSZ and LSZ, make it likely that the preserved P1 layer in the drilled area is part of the axial facies of the primary transverse layered structure. (5) No Hartley-type, narrow, high grade, marginal facies MSZ appears to be present in the drilled area.

According to Cluff Resources' data, the Pt, Pd-enriched lower parts (or PGE subzones) of the MSZ and LSZ are 4.2-5,5 m thick and contain 0,88-1,16 g/t Pt + Pd, and are overlain by a BM subzone 5-7 m thick containing 0,1% Cu + Ni. The total PGE-bearing resources in both the MSZ and LSZ in the western and central parts of the area shown in Figure 1.2.2 amount to about 535 Mt. The eastern part, plus the area straddling the Musengezi River, may contain further large resources, some of which may be in Hartley-type marginal facies MSZ. Apart from significant modifications that are now necessary to earlier mapping (e.g. Worst, 1960), one important implication of recent mapping is that substantial PGE.

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Fig. 1.2.1 Plan showing the area underlain by the Main Sulphide Zone in the Darwendale and Sebakwe Subchambers and the locations of the Hartley Platimum Mine resource and the Mhondoro. Selous and Ngezi Platimum Projects. (Plan supplied — by Delta Gold).

Table 1.2.2.	Resource estimates	for the	Mhondoro,	Ngezi and	Selous	Platinum	Projects
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Project	Mt	g/t Pt	g/t PGE+Au	Moz Pt
Mhondoro	816	2,0	-	54
Ngezi	370*	2,4	4,4	29
Selous	878	2,0	-	57

* Not including 68 Mt in undrilled extreme south.



Fig. 1.2.2 Simplified geological map of the central portion of the Museugezi Subchamber (Snakes Head area): Note the strong faulting of the Great Dyke in this area and the locations of exploration boreholes drilled by Union Carbide and Cluff Resources in the western part. Based on mapping by G. Armitage in 1990 with modifications by M. Banda and M. Prendergast. (Inset shows the distribution of the Majic and Ultramafic Sequences in the greater Snakes Head area. after Worst, 1960).



23

124

Fig. 1.2.3 Simplified drill section through the westernmost portion of the P1 layer in the Snakes Head area. For the locations of the drill holes, see Figure 1.2.2. Note the positions and thicknesses of the MSZ and LSZ and the major stratigraphy intersected by Cluff Resources' deep borehole SH2.



Fig 1.2.4 Vertical distributions of Ni and Pt through the MSZ (left) and LSZ (right) in the axis of the Musengezi Subchamber (Snakes Head area). The profiles are from Union Carbide's shallow boreholes shown in Figure 1.2.3. Assay widths are 15 cm.

resources, perhaps including Hartley-type marginal facies MSZ, may exist in a possible fault block to the north east of the area shown in Figure 1.2.2.

Because of their remoteness and very low grade, and the lack of infrastructure, the MSZ and LSZ in the Snakes Head area are not suitable for development in the foreseeable future. Nevertheless, there would be merit (1) in investigating the application to these resources of low-cost bulk-mining systems, including surface mining, which take advantage of the thickness of the mineralized zones, and (2) in pursuing the search for Hartley-type resources in both the MSZ and LSZ to the east and north east.

Eluvial chromite and nickel laterites

Chromite-bearing eluvial soils are well developed in the hilly northern part of the Great Dyke north of Mutorashanga where total relief approaches 400 m (Prendergast and Wilson, 1989). The highest concentrations of eluvial chromite occur in the flat valley bottoms, where the soils average 50 cm in thickness and contain 3-40% chromite. The chromite, which is associated with magnetite and nickeliferous hydrated silicates, is very fine-grained (96% -500 microns) and was mostly derived by weathering from the scrpentinite. In the Mutorashanga area, the topographic elevation is 250 m higher on the east than on the west side, where broad valleys dissect the scrpentinite terrain as far as the axis. On the east side, the eluvial chromites are strongly altered to ferrit-chromite and are associated with a high proportion of magnetite; on the west side the chromites are much less altered and magnetite is less abundant. Farther north, the topography is more symmetrical across the Great Dyke; the chromite-bearing soils are similar to those on the west side at Mutorashanga, but more evenly distributed. Between Mutorashanga and Darwendale is a central ridge of pyroxenite layers with few transverse valleys, so eluvial soils are poorly developed.

In the Impinge area, 35 km north of Mutorashanga, the serpentinite bedrock underlying the eluvial chromite-bearing soils is lateritized to depths of up to 2 m, and contains 0,5-2,0% Ni (Prendergast and Wilson, 1989). Nickel laterites are also developed farther north, where grades of 0,8-2,5% have been recorded. Little is known of these deposits, but they appear to conform in general features to the Ni laterites developed over serpentinite terrains elsewhere in the world.

Both the eluvial soils and Ni laterites are associated with the African erosion surface, and probably began to form between the mid-Cretaceous and end-Oligocene. The origin, size and grade of these deposits are attributed to (1) the relatively-high Ni content (0,26-0,43% NiO in olivine) of the primary dunite, and the abundance (1-8 vol%) and relatively high Cr/Fe ratio (generally>2,5:1) of the fine-grained chromites enclosed within the dunites of the lower part of the Ultramafic Sequence, (2) the long weathering time-scale since the mid-Cretaceous and the dominance of mechanical erosion associated with the African cycle, (3) the relatively high local mean rainfall (760 mm), and (4) the development of wide valley bottoms.

The eluvial chromite deposits were mined in the Mutorashanga and Impinge areas between the 1950s and mid-1970s. A chromite concentrate (average, 52-55% Cr₂O₃ and 2% SiO₂ with a Cr/Fe ratio of 2,3-2,5:1) was produced by combined gravity and wet-magnetic methods with 90% recovery. The fine grain-size of these concentrates made them unsuitable for conventional arc smelting to high-carbon ferrochrome for many years; modern technology allows the smelting of greater proportions of fines, and interest in the eluvial chromite resources has recently been revived. The Ni laterites, and the Nibearing waste product from the soil treatment plants (0.6-1,2% Ni), are relatively low-grade by world standards. The laterites are the more refractory silicate (rather than the limonitic) variety and can only be processed economically by electric arc smelting. Testwork has shown that 1% Ni laterites from the Great Dyke can be smelted to 25% Ni in ferronickel (Bartlett, 1972). To be viable, a large resource of at least 2% Ni would be required.

The chromite concentrates, however, can be smelted together with varying proportions of the underlying laterites in an are furnace, in the absence of flux, but with different amounts of reductant, to produce various grades of stainless-steel alloy (Table 1.2.3; Slatter, 1979). Where they exist together, the soils and bedroek could be stripped in sequence at relatively low cost. Although smelting costs would be high, large energy savings may be possible in unit metal terms by smelting the laterites and chromite concentrates together, rather than by conventional refining of Cr and Ni units separately, and this scheme represents a potentially energy-efficient direct route to stainless-steel production. The eluvial chromite resource is relatively limited (~ 2 Mt contained chromite) and could not support more than a modest scale of output, perhaps aimed at a small, specialty alloy, niche market.

A very considerable tonnage of Ni laterite is probably present from Mutorashanga northwards. These areas are relatively remote and future exploitation depends, in large part, on the provision of appropriate infrastructure. The Ni laterites of the Great Dyke are amongst the most significant of Zimbabwe's mineral resources yet to be fully evaluated.

Compositio	Composition of nickel laterite and eluvial chromite concentrate				
	Nickel laterite, %	Chromite concentrate, %			
Ni	-2,02				
Cr ₂ O ₃	-1,5	53,8			
FeO	-7.6	19,8			
SiO	40.3	5.5			
AJ_2O_3	-0,5	13,8			
MgO	29,0	7.0			
CaO	0,8	0,2			
LOI	15,5				

 Table 1.2.3. Production of stainless-steel alloys from Great Dyke nickel laterites and eluvial chromite concentrates by electric arc smelling (after Slatter, 1979)

Charge ratios, alloy compositions and smelt performances in 72-kVA furnace								
Ni laterite/ chromite cone.	Coke	Alloy composition, % Cr Ni C		Si	Average alloy yield, kg/30kg charge*	kWh/t alloy†		
1:1	High	51,0	3,6	7,5	0,05	6,5	3540	
2:1		45,9	5,9	6,8	0,08	5,6	4210	
4:1		38,2	9,0	6,4	1,2	4,5	4810	
6:1		31,3	11,3	5,3	1,2	3,9	5650	
8.1		26,4	11,8	4,9	3,0	3,2	6620	
10:1	Low	23,5	12,3	5,1	2,6	3,0	6660	
HCFeCr		-	-		-	6,2	4000	

iens.

* Experimental tests in 72-kVA furnace. † Estimated equivalent for 18-MVA furnace.

2.1 HARTLEY PLATINUM MINE - GEOLOGY AND GRADE CONTROL

R. T. Brown

Local stratigraphy and structure

In the vicinity of Hartley Platinum Mine, Cyclic Unit 1 is 265 m thick, the P1 pyroxenite 142 m thick, and the websterite layer 9 m thick. The MSZ ore body, lying at or immediately beneath the base of the websterite, dips with minor deviations at a maximum 18° east flattening towards the axis where the succession plunges 4° to the south. The pyroxentes are affected by strike faulting and shearing and by dense jointing resulting in blocky ground. Displacements are normally 1-3 m, and faults and joints commonly display advanced hydration in the form of serpentine tale, amphibele, clay minerais, and more rarely, small occurrences of chrysotile asbestos. Many of the faults are associated with dolerite and aphte dykes, the former generally being thicker and more prominent. Only a few faults lie oblique to strike; these faults have throws of up to 20 m.

Mineralization

The Main Sulphide Zone (MSZ) at Hartley Platinum Mine, is a persistent innecalized zone with no magmatic disturbance. It is hosted by a medium-grained poikilitic feldspathic orthopyroxenite, consisting of ~85% cumulus orthopyroxene of composition En_{stativ} and ~15% postetimulus minerals comprising plagoodase and augite as randomly-distributed ofkoerysts, base metal sulphides and minor phlogopite, quartz, apatite, zircor, rutile and micrographic intergrowths of K feldspar and quartz. The texturally-intercumulus sulphides consist of pyrrhoute, chalcopyrite, penthandite and pyrite in order of decreasing abundance. Pyrite is a minor constituent and largely occurs as a replacement product of chalcopyrite. The sulphides occur as anhedral 0,2-3 mm grains interstitial to the cumulus pyroxenes, and vary from finely-disseminated grains to net-textured concentrations around ofkoerysts. Pyroxene crystals in contact with sulphide grains are commonly altered, with redistribution of sulphides along the pyroxene cleavage planes.

At Hartley Platinum Mine, the MSZ vertical metal distribution profile is very similar to that observed elsewhere comprising a lower PGE subzone relatively rich in PGE and base metals (BM), and an upper BM subzone relatively rich in BM but very low in PGE. As elsewhere, the PGE subzone is further subdivided into an upper portion relatively enriched in both PGE and BM, and a lower portion relatively enriched in PGE but very low in BM. In underground exposures, the visibility of the sulphide concentrations is highly variable. The most readily-visible mineralization is a 10-30 cm-thick zone of relatively densely-concentrated sulphides the base of which normally lies 15 cm below the top of the PGE subzone. For mining purposes, this level is termed the MSZ base. The highest PGE and the second highest BM values occur within the 15 cm interval immediately above the MSZ base. Between 0,7 m and 1.2 m above the MSZ base is another thin sulphide concentration identical in appearance to the MSZ base. This concentration may represent the peak of the BM subzone, although underground sampling to date has not confirmed this.

Typical grade distributions are illustrated in Figures 2.1.1 and 2.1.2. The average Pt/Pd ratio is 1,30, and the average Cu/Ni ratio 0.60. The typical 4-element PGE + Au ratio is Pt 0,497: Pd 0,382; Rh 0,042; Au 0,078.

Grade control

Stope width

The highest-possible combined PGE + BM grades are achieved by mining a 90 cm stope width (SW), at a best cut of MSZ base+30 cm hanging wall (hw) and MSZ base-60 cm footwall (fw). Due to the current tonnage build-up programme, however, the stoping instructions require a 105 cm SW at a cut of MSZ base+30 cm hw and -75 cm fw, with a possibility of further increases to a maximum of 120 cm SW (+30 cm hw and -90 cm fw). Once steady-state production has been reached, the stope widths will be appropriately reduced to maximize grade.

It is immediately evident from the PGE distributions that primary emphasis must be placed on stope hanging wall control. It has been demonstrated that hanging wall overbreak has a far greater negative effect on stope grade than does footwall overbreak over the range of acceptable best cuts. It is for this reason that the blanket hanging wall cut instruction is set at MSZ base+30 cm. In practice, it is still acceptable for this cut to increase to a maximum of +35 cm, provided there is no







Fig. 2.1.1 Hartley Platinum Mine - Average total PGE grade distribution profiles

16a








16b

appreciable grade loss. Localized incidents of high grades extending into the hw have been noted, and are being investigated for possible impact on the hanging wall cut.

Panel and raise/winze MSZ marking

Due to the difficulty in ore body identification, all raise/winze and panel faces are water-jetted clean prior to each drilling and blasting cycle. In the normal procedure, the responsible geological technical assistant and shift supervisor scrutinize the faces and identify the MSZ base together, and if both parties are satisfied that the panel or raise/winze is fully on-reef, collar marking, drilling and blasting may proceed. Although visible along the entire length of a panel, the MSZ base can usually be identified at sufficient points to allow it to be marked by paint line. Yellow paint only is used for this purpose and is only carried by geological staff.

Sampling

Raise and ASG channel sampling Channel sampling is carried out with single-blade hydropower diamond saws. Two slots are cut normal to the layering from MSZ base+60 cm down to MSZ base-120 cm (exposure permitting), followed by thirteen cross-slots to give twelve 15 cm-wide samples (or wafers). The wafers are numbered from the top down as Z13 to Z24. Z16 is always the MSZ base+15 cm wafer, so that the numbering system can be used to identify errors. Each sample is assayed by the mine laboratory for total PGE, Au, Ni, Cu and S, with one composite assay per channel for each individual PGE (Pt, Pd, Rh) and Au, and one for Ni and Cu. Channel samples are taken in every raise and ASG (advance strike gully) at 10 m intervals, and, where required, in any on-reef large end development (LED). Channel sample results are employed primarily to calculate individual mining block planned grades over a range of stope widths and best cuts, planned grades for ASGs, raises/winzes and LED, and actual mined grades for individual panels, ASGs, raises/winzes and LED.

Panel and raise chip sampling. Where the MSZ base is visible, panel and raise chip sampling is carried out by chipping one hand specimen-sized sample off each face before each drill and blast at a position within the MSZ base+15 cm interval. The sample is taken immediately after the yellow MSZ base line has been painted, preferably at a point where the MSZ base is most visible. These samples are treated as routine samples and are assayed for total PGE, Ni and Cu. They serve as both immediate checks and confirmation that the panel or raise is either on- or off-reef, and as permanent records of the on/off-reef history of any panel or raise.

Where the MSZ base is not visible, either along an entire panel, or in the upper or lower portion thereof, one or two positions along the panel are selected and three chip samples taken across the probable zone. They are numbered from the top down and submitted to the laboratory as special priority samples, and assayed for total PGE, Ni and Cu. Results are usually available within 24 hours. From the distribution of the PGE, Ni and Cu values, it is possible to identify very closely where the samples were taken in the sequence, and therefore to be able, if necessary, to issue confident instructions to re-establish on the MSZ. In all cases where the MSZ base cannot be identified, the drilling and blasting cycle is delayed until such time as positive identification has been effected.

Waste dump grab sampling. Waste dump grab sampling has been introduced to monitor reef being trammed to waste. It takes the form of daily grab samples, consisting of a range of gram-sizes, taken from the belt discharge point and assayed for total PGE only. Grab sampling is considered adequate for this application, as the presence of any appreciable values indicates reef trammed to waste.

Stop width control

Routine stope measurements. Stope width control is the most critical element of grade control. Not only the SW itself but also the best cut must both be controlled. Before each blast, geological technical assistants take four sets of measurements throughout the stopes. (1) Total stope width measured at 3-5m back from the panel face at 3 m intervals down the panel, where permanent support is installed, the footwall is clean, and the SW is believed to be stable. (2) MSZ base to hanging wall, measured at one metre back from the panel face where the MSZ base can be accurately estimated, and where the hanging wall profile is not expected to change significantly with the next blast. Measurements are taken similarly at 3 m intervals down the panel. Total stope width measurements are not taken in such cases as the footwall is seldom sufficiently clean. (3) ASG, raise and reraise heights, widths and MSZ base to hanging wall at 4 m intervals. (4) Winch cubby heights, widths and MSZ base to hanging wall. The results of these four sets of measurements are used to calculate actual grades and tonnages, and are presented on their own as average dimensions on both a weekly and monthly basis.

Special panel measurements. Whenever a panel is visited by a geologist or a geotechnician, a series of special measurements is taken on the face at the top, middle and bottom of the panel. (1) Total stope width. (2) MSZ base to hanging wall. (3) MSZ base to top socket, and top socket to bottom socket. (4) MSZ base to top drill collar and top drill collar to bottom drill collar. (5) Top and bottom row drilling angles, either measured on the drill steel in place or inside the completed hole.

Individual results are plotted on a diagrammatic measurement sheet designed to give a quick and detailed picture of the panel face for rapid remedial action. From the measurements given, any other measurement which affects stope width control can be readily derived (for example, the critical measurements between top socket and hanging wall, and bottom socket and footwall). This is useful for determining the effect of the explosive action; if the effect is excessive, remedial action is taken by flattening drilling angles, lowering collar positions, or both.

Waste and reef tramming control

In a further effort to control both the tramming of waste to reef, and reef to waste, the geology department holds sets of numbered steel discs which are regularly planted in the respective source areas underground. Recovery is via the transfer tower belt magnet, which is monitored on both reef and waste tramming.

2.2 HARTLEY PLATINUM MINE - MINING

R.T. Brown

Introduction

Hartley Platinum Mine, a modern and well-equipped trackless mining operation, consists of three decline shaft systems, known as South Decline, Midramp Decline and North Decline. Midramp Decline is also served by the shallow No. 1 vertical shaft sunk for trail mining purposes during the feasibility stage. The declines are collared in the hanging wall and penetrate the gabbronorite and underlying pyroxenite in a westerly direction before accessing the cast-dipping MSZ below the sulphide-oxide interface.

Mine access

Large end development

Each decline system is developed at -11°, and is in two parts, one carrying the conveyor belt and chairlift systems, and the other serving as a material roadway for trackless vehicles. Material decline dimensions are 4,5 m high and 4,5 m wide, and the belt/chairlift declines 2,75 m high and 4,5 m wide. The declines lead to the level stations, the first being O level, approximately 100 m below surface, followed by 1, 2 and 3 levels (Fig. 2.2.1). The vertical inter-level spacing is 50 m which gives a stope back of ~165 m at a dip of 18°; this has recently been increased to 55 m giving a stope back of ~180 m. Levels are accessed by short main crosscuts which break off the declines approximately normal to strike direction. The main crosscuts access the haulages, also 4,5 m by 4,5 m ends, which are driven along strike and positioned at approximately 15 m vertically below the MSZ. From the main crosscut point, the haulages are split into north and south haulages. The haulages, in turn, access the crosscuts to reef, oriented normal to strike. Crosscuts lead to smaller dimension travelling ways to reef which are inclined at +45°. Crosscuts are spaced 108 m apart. Adjacent to each crosscut is a short, slightly-angled, drawpoint crosscut which accesses the vertical boxhole from the stope above (Fig. 2.2.2).

Small end development

From each crosscut and travelling way configuration, the MSZ plane is accessed, and a raise and a winze, both 2,5 m high and 1,5 m wide, are developed up and down on true dip, to hole with the levels above and below, respectively. Advance strike gullies (ASGs) are developed off the raises at 12° updip of strike at an apparent dip of +3,6°, at a centre-to-centre ASG spacing of 30,5 m. The ASGs are developed as 2,2 m-high and 1,5 m-wide access tunnels to the 25 m-long breast panels, which are established to the updip side of the ASGs. Both the large end and small end access development layouts are illustrated in Figure 2.2.2.



Fig. 2.2.1 Hartley Platinum Mine - Generalized section through the inclined shaft system

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Fig. 2.2.2 Hartley Platinum Mine - Three-dimensional breast stope layout showing on-reef and footwall access development

Stoping

Layout

The typical stoping cycle consists of three main parts: (1) cleaning, (2) supporting, and (3) drilling and blasting. Since the cycle is usually considered in that order, the following explanation is ordered similarly, following a brief introduction to the stoping layout.

Currently, Hartley Platinum Mine uses a one-sided scattered breast stoping layout, where ASGs and panels are mined from a raise-winze connection in one direction only, to mine out against a 6 m-wide dip rib giver left against the adjacent raisewinze connection (Fig. 2.2.2). The one-way breast configuration has largely been adopted for rock mechanics reasons, but expanding to a two-way herringbone scattered breast layout is a possibility. The latter is advantageous as it doubles the number of panels per raise connection.

Ledging is carried for 5 m in from the raise centre line, whereby the panel width slot of MSZ base+30cm and MSZ base -75 cm is mined along the length of the raise, and appropriately supported. Footwall is then lifted at 30,5 m intervals from which the ASGs are then established. No downdip sidings are carried with the ASGs. Panels are established on the updip side of the ASGs with the faces orientated normal to the ASG direction. The raise-winze connection becomes known as a centre gully once the stope is established. Unless ASGs are predeveloped, panel faces commonly lag behind the ASG faces by 2-4 m.

Each stope is equipped with one boxhole located at the downdip end of the centre gully. Boxholes are vertically orienteted and open into the drawpoint crosscuts below. They are typically constructed by drilling with a crawler-mounted Atlas Copco® Robbins' BorPak blind raise-boring machine, which produces a smooth, circular, open-ended hole of 1.5 m diameter.

Cleaning

Following the blast, a four-hour re-entry period is mandatory to allow for the noxious gases to be expelled via the ventilation system, after which cleaning commences. The broken rock from the blast is essentially contained at the face with the aid of HDPE blast barricades which are set diagonally within the two rows of hydraulic props placed 2 m and 3 m behind the face respectively. The blast barricades are angled towards the face in the downdip direction. The faces are cleaned with both scrapers and water jets. The scrapers are connected to 55kW electric winches located in cubbies at the centre gully, and scrape the rock into the ASGs. The water-jetting guns are connected to the hydropower manifolds and clean simultaneously with the scrapers, the operator working from within the updip open slots between the blast barricades. The scrapers are then rerigged to scrape rock from the ASGs into the centre gully. There, the centre gully winch, located behind the boxhole at the bottom of the stope, cleans the rock into the boxhole.

Tamrock® EJC load haul dumpers (LHDs), equipped with 3.2 m³-capacity buckets (~5 t broken ore), are used to clean the drawpoint crosscuts and load the rock onto 25 t Bell® B25L 4x4, low profile, articulated dump trucks (ADTs). The trucks transport the ore to the level reef tip, which opens out onto the decline conveyor belt system below.

Support

Natural stope support takes the form of stability pillars left *in situ*, including barrier dip pillars and in-stope grid pillars. Crush pillars are not used at the current shallow mining depths. The configurations take the form of long 6 m-wide barrier dip pillars left on the virgin side of each centre gully, and a pattern of strike grid pillars left immediately downdip of each ASG. The strike grid pillars are 8 m long and 4 m wide with a 2 m-holing between each.

Artificial support falls into the two categories of temporary and permanent support. Temporary support consists of a row of mechanical props at 1 m back from the face and spaced at 2 m intervals on dip, followed by two rows of 20 t hydraulie props at 2 m and 3 m back from the face, respectively, and set at 1,5 m intervals on dip. The permanent in-panel support takes the form of permanently-installed, 15 cm-thick wooden poles which are hammered into place. The strike spacing between sticks is 1 m, and the dip spacing 1,5 m. Every sixth row of pole support is a row of four-stick cluster packs set at the same spacings. Where the panel meets the ASG and centre gully, every second stick support is a six-stick cluster pack, with a single stick between. ASGs and raises/centre gullies are supported with 1,5 m roof bolts.

Drilling and blasting

At the start of the drilling and blasting cycle, the faces are washed clean with water jets in preparation for members of the geology department to mark the MSZ base with a yellow paint line. In accordance with the best cut instructions, two red drill hole collar lines are then painted at the appropriate distances above and below the yellow MSZ line (i.e. one above and one below the MSZ base line for the top and bottom row collar positions, respectively).

Panels are drilled with an \sim 149-hole, 3-row box pattern, with a 0,5 m burden between holes, and the centre row holes staggered between the parallel top and bottom row holes. Drill holes are both angled slightly up and down for the top and bottom row, respectively, and laterally angled at 70° to the face. The 70° angle is measured from the plane of the face from the updip side of the panel, so that the drill steels are pointing 20° towards the downdip side.

Drilling is carried out with hand-held Gullick® hydropower rock drills, using 1.3 m drill steels and 36 mm knock-off button bits. Drill steel effective penetration is ~1,05 m. Each knock-off bit drills about 80 m, whereas the drill steels last for about 100 m. Holes are charged with Explogel® emulsion explosive and detonated using Ezeestepe® shock tube technology.

Stoping is currently carried out on a two-day cycle (i.e. the complete cycle of cleaning, supporting, drilling and blasting is completed every second day). The average advance per blast is 0,9 m, which produces about 81 t of reef per 25 m panel per blast (not including ASG). Efforts are being made to reduce the cycle to one day. Average panel advance is in the order of 8 m per month.

Hydropower drilling was selected in preference to pneumatic drilling essentially because hydropower rock drills consume 30% less power, drill at about twice the rate, are considerably quieter, and do not produce the oily mist caused by pneumatic drilling. The water used to power the drills is pressurised to about 18MPa on surface. Waste water quantities in the stopes present certain challenges, as it is essential to keep ore and water separate as far as possible. Better ways of controlling instope water are being investigated on an ongoing basis.

2.3 HARTLEY PLATINUM MINE - METALLURGICAL PROCESSING

C. M. Rule

Introduction

The metallurgical operations of the Hartley Platinum Mine are housed at one integrated site. They comprise a concentrator, smelter, base metal refinery and the analytical laboratory. The site layout has been designed to allow a future cost-effective expansion to three times the initial project capacity. The plant control will be by a state-of-the-art Scada/P.L.C. control system. This fully-integrated computer system will significantly assist the management of the operation. The metallurgical operation is supported by a centralized engineering department with main workshops adjacent to the plants. The total workforce of the metallurgical department is 330 personnel, the organisational structure being flat with the emphasis placed on multi-tasking.

Concentrator

Planned grades of ore to the mill are 2,64 g/t Pt. 1,79 g/t Pd, 0.47 g/t Au, 0,21 g/t Rh, 0,18% Ni (sulphide) and 0,14% Cu. In the initial phase of operation, the concentrator will treat 180 000 t of run-of-mine ore per month. The design grind is 80% -75 microns. The concentrator flow sheet (Fig. 2.3.1) was developed from a series of pilot plant tests done in both South Africa and North America. The plant is simply described as a SAG-ball mill, bulk sulphide flotation operation.

The ore storage for the weekend mining shortfall is accommodated in a 20 m-diameter concrete silo with a live capacity of 13 500 t. SAG mill feed is by a six-point silo draw-off system using frequency-controlled vibrating feeders. The SAG mill is $8,0 \times 3,2$ m in size. The ball mill is $5,6 \times 8,8$ m. Design tonnage is 290 t per hour. Both mills were manufactured by Fuller-Traylor and are driven using the low-speed, synchronous motor (capacity 4,475 MW), air clutch, single pinion to ring gear system. A flash flotation cell is installed in the milling circuit to recover the metal sulphides as they are liberated in the circuit.



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Milled product is treated in two parallel flotation circuits to produce a low grade bulk sulphide concentrate containing 75 g/t PGM (platinum-group metals) + Au. The circuit was designed to allow circuit and reagent optimization. Due to the relatively-high talcose content, significant depressant is added to the normal industry reagent suite. The concentrate is pumped to the smelter. Tailings are treated in the thickener/clarifier plant to maximize the water recovery. The thickened tailings are pumped to the tailings dam across the road from the plant site.

Smelter

The smelter design (Fig. 2.3.2) embodies the best technologies from the PGM industry. The testwork and comparative analyses of the concentrate feed were used to determine the design criteria.

The concentrate is thickened, and the overflow clarified to minimize metal losses back to the water circuit. The thickened concentrate is filtered in a plate and frame pressure filter. The product, at 15% moisture, is fed to a flash drier. The hot gas is provided by a fluid-bed combuster fuelled by coal. Storage capacity is available between the drier and filter processes. Dry concentrate is pneumatically conveyed to the furnace feed bins. Limestone flux is proportionally added prior to feeding into the six feed pipes in the roof of the 13.5 MVA, three-electrode, circular furnace supplied by Davy (RSA). Capacity of this unit is 10 600 t of concentrate. Slag is tapped from two, water-cooled, copper slag tapholes. The slag is granulated in water, dewatered, and then conveyed back to the ball mill circuit in the concentrator to recover the majority of mechanically-entrained PGM.

The matte is periodically tapped into ladles and transported to the operating unit of two Pierce-Smith converters. In the ensuing process, furnace matte is blown with air at a temperature of 1250° C. The iron is reduced to a value of <1% with its associated sulphur. This oxidation process is finished at a point where the matte contains 44% Ni, 33% Cu, 21% S, 1% Fe, 0,5% Co and 1500 ppm PGM + Au.

The smelter offgas is subject to the regulations promulgated by the regulatory authorities of the World Bank. To meet these standards at all times the design of the converter hooding, offgas system, the hooding of tapping operations and the height of the main stack were all modified. A sophisticated air-quality management system is installed. This includes a real-time environmental model as well as on-site and remote air quality measuring and weather stations.

Base metal refinery

The flow sheet (Fig. 2.3.3) for this circuit was developed on converter matte produced from Hartley concentrate obtained during the pilot plant runs. This testwork was undertaken with the input of Outokumpu's research centre in Finland and the resulting flowsheet patented. Outokumpu was chosen as a technology partner due to its leading position in the base metal industry. The Cu-leaching circuit incorporates the leading edge of technology used in the PGM industry, so that the industry best-operating recoveries are expected from this plant.

The matte fed from the smelter is ground in a ball mill in closed circuit with cyclones to 80% -45 microns before being fed as a thickened slurry to the Ni-leaching circuit. The leach circuit consists of two stages of atmospheric leach and a pressure leaching step. The circuit runs with solid and liquid phases running counter-currently. Essentially, the Ni metal and different sulphides present in the matte are sequentially dissolved as sulphate in an acid medium by the process of oxidation. The result is that the liquid entering the circuit with a 100 g/l Cu tenor leaves the circuit with a 100 g/l Ni tenor. This solution is treated for Co removal by solvent extraction. This step removes other impurities allowing a high-purity Ni (>99,9%) cathode product to be electrowon. Other impurities are removed in a pressure Fe removal step.

The mainly Cu sulphide and PGM residue from the Ni circuit is leached under harsher conditions to allow the removal of the Cu content and the residue from this process is further leached under batch conditions to produce a PGM concentrate of >40%. The Cu stream is treated for the removal of Se and Te by the addition of sulphurous acid. The purified Cu solution is split, a portion returning to the Ni circuit, the rest being electrowon to Cu cathode at better than 99,9% Cu. The sulphur balance is maintained in the circuit by removing it as sodium sulphate in the Ni circuit after the electrowinning step, using sodium carbonate as the reagent. The product is a commercial grade sodium sulphate.

The overall recoveries of the valuable metals are: Pt. 86%; Pd, 90%; Au, 74%; Rh, 83%; Ni (sulphide), 84%; Cu (sulphide), 84%.



Fig. 2.3.2 Hartley Platinum Mine - Smelter flow sheet

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Fig. 2.3.3 Hartley Platinum Mine - Base metal refinery flow sheet

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Analytical laboratory

An ultra-modern analytical facility has been constructed on-site to serve the whole operation. The analytical techniques employed include fire assay, inductively-coupled plasma (ICP), atomic absorption spectrophotometry (AAS), X-ray fluorescence (XRF), spark analysis for trace (SAFT), and numerous wet chemical techniques.

The laboratory will run around the clock to provide monitoring analyses for the metallurgical plants. The laboratory has been designed to minimize the potential for cross-contamination and is also upwind of the metallurgical plants to minimize the effect of wind-borne contamination. The hygiene of the workers has been given top priority in the design of the fire assay and sample preparation sections.

Water recovery and reticulation

The water systems on the plant have been integrated and designed to allow maximum utilization. Water run-off from the tailings dam is collected and pumped back to the plant. Any site run-off from the storm water system is collected locally at the base metal refinery and site-wide at a site collection dam for re-use. Thus, the pollution of local water systems is avoided.

3.1 MIMOSA PLATINUM MINE - GEOLOGY AND GRADE CONTROL

A. Martin

Introduction

The present mining operation at Mimosa commenced in 1994 and is owned by Zimasco under a 5 737 ha Mining Lease. A partly fault-bounded area 5 km long by 3 km wide, known as Wedza South Hill, has been the focus of most of the exploration work but further, mainly oxide resources, exist along the axis to the north and south of the bounding faults (North and Far South Hills).

Mine geology

The MSZ in the Wedza South Hill area, straddling the contact between the overlying websterite and underlying bronzitite, forms an elongate, saucer-shaped basin with inward dips of 10°-15° along the outcrop flattening to zero in the axis, 80% of the mineralized zone dips at less that 6°. The axis of the MSZ basin structure lies 200 m below surface and the mineralization is oxidized up to 300 m down dip from surface, or 30-60 m vertically.

The MSZ shows a distinctive and consistent vertical distribution of metal values (Fig. 3.1.1). High base metal (Ni, Cu and Co) values occupy the upper 45 cm of the MSZ. The precious metals (Pt, Pd, Rh and Au) are confined to the lower part of the MSZ, increasing from less than 1 g/t at the base to a peak of 4-7 g/t some 15 cm below the Ni peak and thereafter dropping off rapidly towards the top of the MSZ.

Irregularity and loss of the ore body is caused by minor faults, aplite dykes, pegmatoids and washout channels. The washout channels both depress and cut through the ore body. The largest encountered in the workings is approximately 25 m wide and has been traced down dip for 120 m. On the basis of drill holes and hanging wall exposure caused by overbreak over a wide area, much larger washout features are inferred to exist in the hanging wall of the MSZ. The pegmatoids have also caused significant loss of ore. These features are thought to be the result of late stage fluids ponding beneath the washout channels and have effectively obliterated the MSZ in places. The largest pegmatoid mass is some 25 m across in the strike direction and at least as much down dip.

In addition to these features, there is a low grade zone about 30 m wide immediately to the south and sub-parallel to the main decline. Within this zone, sulphides are very weakly disseminated and the normal metal peaks are not developed. The full extent of this zone has yet to be exposed. Loss of the ore body due to washout channels and associated pegmatoids is expected to be limited to a relatively small area between the main inclined shaft (Blore Shaft) and Wedza No. 2 Shaft.

The MSZ has a gently-rolling form with amplitudes of a few metres and wave lengths measured in tens of metres. The axes



Fig. 3.1.1 Mimosa Platinum Mine - Distribution of major metals within the MSZ

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Table 3.1.1. In-situ grades and resource tonnes ove	r a range of mining widths, Mimosa Platinum Mine
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Mining width, cm										
	135	150	165	180	195	210	225	240		
	Resource, Mt									
	70	78	86	93	101	109	117	124		
g/t Pt	2,25	2,17	2,00	1,93	1,79	1,73	1,62	1,57		
g/t Pd	1,54	1,55	1,43	1,44	1,33	1,32	1,24	1,23		
g/t Rh	0,18	0,17	0,16	0,16	0,15	0,14	0,13	0,13		
g/t Au	0,46	0,43	0,42	0,39	0,37	0,35	0,34	0,32		
g/t Ag	1,04	0,99	1,01	0,97	0,97	0,93	0,93	0,90		
% Ni	0,22	0,20	0,20	0,19	0,19	0,18	0,18	0,17		
% Cu	0,17	0,16	0,17	0,16	0,16	0,15	0,15	0,14		
% Co	0,005	0,005	0,005	0,004	0,004	0,004	0,004	0,004		

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of the rolls appear to trend down dip. Although the rolls do not pose grade control problems they do constrain the mining methods because the use of scrapers may not be possible along strike and pools of water that collect in troughs impede the use of vehicles.

Joints within the mine area fall into three categories. There are two conjugate sets which trend sub-parallel to the MSZ strike (N-S) and in the down-dip direction (E-W). The N-S joints have moderate dips whereas the E-W joints tend to be more steeply dipping. The third category comprises an anastomosing set lying sub-parallel to the ore body. The more steeply-dipping joints cause overbreak and dilution whereas the flat joints in places provide a good hanging wall parting which assists with grade control. However, the convergence of these joint sets can lead to dangerous conditions and procedures have been adopted to avoid falls of ground.

Resources

A total of 111 core holes drilled at Wedza South Hill were used for evaluation purposes. All core intersections of the MSZ were assayed at 15 cm intervals for Pt, Pd, Ni and Cu. Only the more recently-drilled holes have been assayed for Rh, Ru, Ir, Au, Ag and Co. Evaluating the grade of the MSZ is complicated by the lack of a suitable geological marker horizon, the number of extractable metals and their recoveries and realizable values. The precious and base metal values display a well-defined normal distribution and therefore the arithmetic mean of the drill intersection grades has been taken to represent the overall grade of the deposit. Kriged and least square distance estimates were not significantly different. Because of the distribution of the seven extractable metals, the mining width and position have to be based on the optimum-realizable monetary value. The position and width are relatively insensitive to fluctuations in metal prices. At current metal prices and mining costs, the optimum mining width is a combination of 1,8 m-high development (30%) and 1,5 m-wide stopes (70%). All development, except the inclined shaft, is driven within the ore body. Grade-tonnage relationships at various mining widths are shown in Table 3.1.1.

On this basis, the geological indicated resource at a 1,5 m stope width is 82 Mt. Allowing for unrecoverable resources due to washouts, abnormal reef, faults, dykes, oxidized MSZ and pillars, the mining probable reserve for the Mimosa deposit is 51 Mt.

Grade control

The MSZ is not readily visible to the untrained eye but grade control still depends initially on visual examination and this is supplemented by a self potential (SP) meter and channel assays. The standard procedure for marking off the ore body is to identify by eye the base of the visible sulphides and to confirm this position with the SP meter. Experience has shown that this 'marker' normally coincides with the base of the peak Pt sample. The mining width is then set at 0,5 m above the 'marker' for all mining and 1,3 m below for development and 1,0 m for stoping. The budget mill-feed grade is taken as a weighted average according to the proportions of development and stoping and discounted by 10% to account for overbreak and misidentification of the 'marker'.

Initial problems have largely been the result of overmining due to poor blast-hole drilling control. The necessity for a minecall factor is still under investigation as, theoretically, given the fine-grained, disseminated nature of the mineralization, there should be little or no unexplained loss of metal during mining.

The mined grade is based on channel sampling using a diamond saw with channels cut from floor to roof and sampled at 15 cm intervals. Currently, only Pt, Pd, Ni and Cu are determined in the mine laboratory. The mined grade is estimated by making allowance for unsampled corners in the floor and roof and the overbreak measured 1.5 m back from the face. This agrees fairly well with the average cyclone overflow grade from the mill.

3.2 MIMOSA PLATINUM MINE - MINING AND METALLURGICAL PROCESSING

A. Martin

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Mine design

The grade of the Mimosa ore body is relatively low and the main key to economic success is the ability to mine and process the ore more cheaply than other platinum producers. The regular nature of the deposit, the shallow dips and its large area lend themselves to application of a modular mine design. The areas stoped in the 1970s were examined by geotechnical experts and the recent trial mining assessed. The high compressive strength of the rock-mass and the shallow depth of the operation support the chosen room and pillar mining methods which also allows minimal footwall waste development.

Mine access

The 200 m maximum depth of the ore body and the proposed use of vehicles underground favours access by declines rather than vertical shafts. The inclined Blore Shaft is used for both men and material access and rock removal via conveyors. The Blore Shaft is approximately 15 m in the footwall of the ore body and access to the workings is by ramp crosscuts with vertical rock passes from the ore body to the shaft. Access down dip and on strike is by means of 6 m-wide 'on-ore' declines and access drives equipped with conveyor belts, roadways and services.

Layout

The general mine layout was designed on the basis of experience gained from trial mining and from proven methods used elsewhere. Panel blocks are 154 m on strike, bounded by conveyor belt/access drives every 120 m on dip, and panels are advanced north and south. Each panel has six 1,8 m-high gullies kept approximately 5 m in advance of the stope faces which are mined at a width of 1,5 m. Each working face is 15,5 m in length and bounded by 10 m-long by 3 m-wide pillars. This configuration of advance gullies is used for grade control and also for mapping of joints to avoid any potentially-dangerous falls of ground. Other configurations are being studied, including a 1,7 m panel with no advance gully and a centre gully with 1,2 m-high panels.

Grouted roofbolts. 1,5 m long, are installed on a 1,5 m square grid, particularly where flat joints occur in the roof. Additional bolting is also done on an as-required basis to control other joint sets. Where convergence of joints appears likely as mining advances, leading to a potentially-dangerous situation, pillars are left by reraising from the gully.

Underground services

The Blore Shaft, access declines and conveyor ways are used as the main downcast intake airways and the air is returned through a series of ventilation raises situated near the oxide-sulphide interface. Personnel and materials are transported to and from the workings by diesel-powered multipurpose vehicles.

Concentrator

The plant has been designed on the basis of one crushing and screening stream, two milling and flotation streams, one tailings thickener and one concentrate handling stream. Run-of-mine ore is delivered by the Blore Shaft conveyor to the primary jaw crusher and deposited on a coarse ore stockpile with a 1 500 t live capacity. Ore is then crushed to 80% -9,5 mm in the secondary and tertiary cone crushers, and fed to the primary and secondary ball mills before flotation.

The concentrates are cleaned before thickening and then delivered to a filter press. The filter cake is loaded into 2 t bulk bags, transported 11 km to Bannockburn Siding and then railed to South Africa for toll smelting and refining. The tailings are thickened before pumping to the tailings dam.

A fully-equipped, on-site laboratory with a fire assay section processes all underground and plant process samples.

Smelting and refining

The toll processors smelt the concentrate, refine the white matte and produce saleable base metals. The precious metals are further refined to produce final saleable products.

4. LAYERING, PGE MINERALIZATION AND MARGINAL PHENOMENA, WEDZA SUBCHAMBER

M.D. Prendergast

Geological background

Among the principal interests of the Wedza Subchamber are the development of the MSZ and the pyroxenite host rocks across this relatively narrow part of the Great Dyke magma chamber, and the changes in the petrology and geometry of the layering that are observed towards the magma chamber walls (Prendergast, 1990, 1991; Prendergast and Keays, 1989). The Wedza Subchamber is made up of a lower Ultramafic Sequence of dunites, harzburgites, olivine pyroxenites and pyroxenites, grouped into at least 16 cyclic units cach about 80 m thick, and an overlying Mafic Sequence of gabbros and norites. The layered rocks form a shallow, elongate, boat-like structure 80 km long and up to 6 km wide. Of special interest are the uppermost Cyclic Units 1 and 2 and the lowermost mafic rocks preserved in the central part of the structure. Both cyclic units consists of harzburgite (with chromitite) overlain by pyroxenite. The pyroxenite of Cyclic Unit 1 at the very top of the Ultramafic Sequence forms a prominent layer about 160 m thick. This P1 layer is mostly made up of bronzitites (plus minor transitional bronzitites and websterites) with a persistent 10 m-thick layer of websterite (Main Websterite) at the top. The PGE-rich Main Sulphide Zone (MSZ), constituting the ore body at Mimosa Platinum Minc (Fig. 4.1), straddles the base of the Main Websterite.

The upper half of the P1 layer is subdivided into three subunits on the basis of pyroxene chemistry, cumulus textures, and the presence of cumulus augite and sulphides (Fig. 4.2). The pyroxenites display marked lateral variations in layering and in cumulus mineralogy, mode, textures and fabric. The most striking variations can be seen near the east margin between Mimosa Mine and Wedza No.2 Shaft. This area is characterized by the extreme stratigraphic complexity and locally-erosional nature of the contact between the Main Websterite and the overlying mafic rocks. In many places, the contact zone is marked by a highly-irregular sequence of interdigitating, three-dimensional wedges of websterite and gabbro that dip towards the axis at slightly-steeper angles than the base of the Main Websterite (Fig. 4.3). Also present along the east margin are thin gabbro lenses at the top of websterite modal layers.

The erosional mafic contacts form steep-sided depressions that appear to be channel-like and oriented broadly perpendicular to the east margin, and to lie progressively deeper in the pyroxenites before wedging out rapidly towards the axis (Fig. 4.4). In many instances, the mafic channel fills consist of an upward-coarsening, on-lapping sequence of fine-grained bronzitites, variegated fine-grained norites, medium-grained norites and coarse-grained norites. The channels are interpreted as magmatic erosion, or washout, channels caused by cascades of dense, plagioclase-saturated magma that were initiated higher up the walls of the magma chamber. Erosion was mostly limited to removal of varying thicknesses of the Main Websterite; in one case (Wedza No. 2 Shaft) the whole of the Main Websterite and the uppermost bronzitites plus the MSZ were eroded away. There are indications that the base of the Main Websterite also interdigitates with the upper bronzitites in a manner analogous to that of the gabbros and websterites.

The most consistent lateral variations of the P1 layer are observed in a transverse direction between the margins and the axis (Figs. 4.5 & 4.6). In particular, towards the east margin, there is a systematic decrease in layer thickness, bronzite En content and Cr in augite, and an increase in both cumulus augite/bronzite modal ratio and postcumulus and interstitial phases. Away from the axis, transitional bronzitites and then websterites become increasingly common within the bronzitites; thus, the upper part of Subunit 3 consists of bronzitite in the axis and massive websterite close to the east margin. Also found along the east margin are barren, irregular, locally-discordant, metre-scale lenses of fine-grained bronzite-phyric augitite lying within the Main Websterite (Fig. 4.7). These unusual rocks are considered to have originated as crystal mushes higher up the chamber walls and to have subsequently gravitated to their present position. Pyroxene-plagioclase pegmatoids are a common feature of parts of the P1 layer and lowermost mafic rocks, particularly along the stratigraphically-complex east margin. The most laterally-persistent pegmatoid forms a composite, semi-concordant, 2 m-thick zone immediately beneath the mafic contact. Other pegmatoids are associated with washout channels. The MSZ is generally free of pegmatoids. The stratigraphically-complex layering around Mimosa Mine and Wedza No. 2 Shaft is considered to be a near-marginal facies of the P1 layer and the gabbro-websterite contact zone that extends abnormally far towards the axis at this point and was thus preserved from surface erosion.

In the Mimosa Mine area (Wedza South Hill; Fig. 4.1), the P1 layer forms a slightly-warped, rectangular basin structure 6,5 km long by 4,75 km wide with shallow, marginal inward dips of 15°. Gravity data suggest that the original Wedza magma chamber had a lower trumpet-like and an upper sill-like transverse shape with an axial feeder dyke at depth. The chamber walls are 6 km apart at the approximate level of the P1 layer and slope inwards at angles of about 30° (Fig. 4.6).



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Fig. 4.2 Graphical log of borehole W98. Wedza South Hill. Note the distribution of sulphides and the subdivision into subunits. For location of borehole, see Figure 4.1.



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Fig. 4.3 Perspective diagram showing the interdigitation of websterite and gabbro wedges and its relationship to washout channels. Blore Shaft area, Mimosa Mine. Based on boreholes (numbered) and underground exposures.



Fig. 4.4 Lower part of a washout channel exposed in (old) 2 level drive south and 95 gully raise, Mimosa Mine. The channel is oriented perpendicular to the magma chamber wall (in plan), so A and B are, respectively, transverse and longitudinal sections of the channel. This channel is the same as that shown between boreholes W91A and W92A in Figure 4.3.



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Fig. 4.5 Principal stratigraphic features of the upper part of the P1 layer, and variations between the axis and the east margin, Wedza South Hill. Minor layering units, transitional bronzitite and bronzite-phyric augitite lenses are omitted for clarity. Detailed sections are based loosely on boreholes and surface exposures.



Fig. 4.6 Generalized transverse structure of the Wedza Subchamber and the P1 layer. Note (1) the decreasing thickness of hot insulating cumulates (and therefore increasing downward heat flow) towards the margins, (2) the angular relationship between the horizontal liquid layers and the magma chamber floor, and (3) the marginal factes of Units 1 and 2 exposed along the east margin.

The angular relationship between the P1 layer and the chamber walls implies that the eroded marginal portion lay at progressively-smaller heights above the inward-dipping walls. It is thought that the extreme marginal facies of each cumulate layer merges with a more steeply-dipping Border Group against the walls. Notable features of the extreme marginal facies and Border Group equivalents of Units 1 and 2 in this area are the dominance of bronzite-rich lithologies, the mostly fine-grained orthocumulus textures with interstitial posteumulus augite, and, in the Border Group itself, the total absence of olivine. Because of the apparent structural warping and rotation of the synclinal axis, and the consequent juxtaposition of different structural levels at the same horizontal plane of erosion on either side of the axis, the marginal phenomena of Cyclic Units 1 and 2 observed on the cast margin are no longer preserved on the west margin. Also of special interest in the Wedza Subchamber is the evidence (see above) of discordant relationships between phase and modal layerup such that each new cumulus phase (e.g. bronzite, augite, plagioclase) appears at progressively lower stratigraphic levets towards the margins.

Main Sulphide Zone

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In the Wedza Subchamber, the MSZ is a 2.5 m-thick, modally-layered sulphide pyroxenite with a highly-characteristic and uniformly-developed internal layered structure (Fig. 4.8). In summary, the metal distribution profile comprises two, sharply-defined, main subzones - a lower PGE subzone rich in Pd and Pt and an upper, PGE-poor, BM (base metal) subzone. The PGE subzone consists of two main portions separated by a reversal in metal distribution trends. The upper portion has an essentially-constant thickness of 75 cm. The lower portion is at least 100 cm thick. Within the PGE subzone as a whole, and within each of its component portions, bulk base metal and Pd and Pt contents increase upwards whereas Pd/Pt rados and Pd + Pt contents per unit sulphide (total Cu + Ni) increase downwards, so that the highest metal contents and the lowest Pd/Pt ratios and Pd + Pt contents per unit sulphide occur at the top of the PGE subzone.

In the axis, all sulphide mineralization above the PGE subzone has uniformly very low Pd and Pt contents. Consequently, the axial MSZ assay profile is a split bell-shape with significant Pd and Pt values confined to the lower half. Towards the margin, the BM subzone is more irregular, and PGE-rich sulphide mineralization (associated with transitional bronzitite lenses) has been recorded above the MSZ.

Unlike in wider parts of the Great Dyke, the MSZ in the Wedza Subchamber maintains an essentially-uniform thickness between the margin and the axis, and is economic throughout. There is a slight increase in sulphide Cu + Ni contents, Cu/Ni ratios and Pd/Pt ratios and a decrease in PGE contents per unit sulphide towards the margins. The MSZ between Mimosa Mine and Wedza No. 2 Shaft is abnormally thin - the PGE subzone averages about 90 cm - and becomes irregularly developed in the upper levels of the mine. There are significantly-greater variations in metal content along the east margin than along the axis.

Near the margin, the MSZ is usually affected by intense hydrosilicate alteration, but is largely unaltered in the axis. Discordant layering in the pyroxene and plagioclase cumulates is also reflected in the sulphide mineralization, with the top of the PGE subzone (i.e. the middle of the MSZ) lying about 40 cm beneath the Main Websterite in the axis but only 10 cm near the margin.

Interpretation

The development and internal organization of the P1 layer and of the MSZ can be explained in terms of repeated inputs of parental magma, overall cooling of, and progressive enrichment of chalcophile elements (Cu, Ni, PGE, Au, S) in, the resident magma, and the existence of liquid layering phenomena. The minor layering units and sulphide concentrations were produced by cooling, *in situ* crystallization and Rayleigh fractionation of successive basal liquid layers followed by overturn and mixing with the next later up. The MSZ itself was formed from a series of such layers, the PGE being extracted from the rapidly-convecting magma, in the order of their partition coefficients, by sulphide droplets exsolved at the crystal-liquid interface.

The transverse variations within individual layering units, as well as the discordant layering relationships, are attributed to the transverse shape and narrow width of the magma chamber, the consequent effects on the rate and distribution of heat loss, and the replenishment process. The same general interpretation applies to transverse variations within the MSZ.

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Fig. 4.7 Bronzite-phyric augitite lens near the base of the Main Websterite, 154 Raise. (old) 1 level drive north. Mimosa Mine. Note the evidence of slumping, and the bronzitite laminae reminiscent of cross-bedding (inset). The lens exposed in the south wall truncates the MSZ 15 m to the south of this position.



Fig. 4.8 Characteristics of the Main Sulphide Zone (MSZ) and its immediate host rocks in the Mimosa platinum deposit. The basis of the model MSZ assay profile (inset) is similar to that in Figure 1.1.9. The main figure shows the detailed straigraphic location and visual features of the MSZ plus their transverse variations between the axis and the east margin. Y and Z represent, respectively, bronzite-phyric augitite lenses with very low sulphide content and transitional bronzitite lenses with Pd, Pt-rich sulphides.

5. **BIBLIOGRAPHY OF THE GREAT DYKE**

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EXCURSION PROGRAMME

Day O, Monday, 22nd June

Participants assemble at Cresta Lodge, Harare.

Day 1, Tuesday, 23rd June

Dunite and lower Pyroxenite Successions, Darwendale Subchamber.

Stop 1: Underground visit, a chromite mine, Mutoroshanga

Stop 2: Viewpoint above Mutorashanga

- Stop 3: View of cyclic units, Dunite Succession, west side
- Stop 4: Examination of drill core, lower Pyroxenite Succession, Caesar Mine
- Stop 5: Cyclic units, Pyroxenite Succession, east side

Stop 6: Pyroxenite Succession in the axis, Airey's Pass

Stop 7: P3 pyroxenite near the axis, Great Dyke Pass

Overnight Cresta Lodge, Harare

Day 2, Wednesday, 24th June Hartley Platinum Mine

Overnight Cresta Lodge, Harare

Day 3, Thursday, 25th June

Cyclic Unit 1 and Lower Mafic Succession, Darwendale Subchamber

Stop 1: Upper group chromitites, Darwendale area

Stop 2: Axial facies, PI pyroxenite, Manyame Dam wall

Stop 3: Axial facies, Lower Mafic Succession, south of Manyame River

- Stop 4: 'Picrite', Makwiro River, west side
- Stop 5: Marginal facies, Lower Mafic Succession, and 'potato reef,' west side.

Overnight Nilton Hotel, Zvishavane

Days 4 and 5, Friday and Saturday, 26th and 27th June Layering, PGE mineralization and marginal phenomena, Wedza Subchamber

1. Underground visit, Mimosa Platinum Mine

2. Field exposures, Mimosa area

Stop 1: Interlayered gabbros and websterites, near Blore Shaft portal

Stop 2: Marginal facies, chromitite Clc (or Cld?)

- Stop 3: Axial facies, (oxidized) MSZ, Wedza Mine, 1926-28
- Stop 4: Wedza stream section

Stop 5: Wedza No. 2 Shaft, 1969-71

Stop 6: Marginal facies, Unit I harzburgite-chromitite association

Stop 7: Border Group

Stop 8: Marginal facies, Unit 2 harzburgite-pyroxenite association

Stop 9: Mchingwe River section

Friday: overnight Nilton Hotel, Zvishavane Saturday: overnight Fairmile Motel, Gweru

Day 6, Sunday, 28th June

Drive to Harare

Participants depart Harare International Airport for Johannesburg on flight SA039 at 1420 hrs. End of excursion.

EXCURSION GUIDE

Day 1, Tuesday, 23 June

Dunite and lower Pyroxenite Successions, Darwendale Subchamber

Principal guide: A.H. Wilson

Travel log from Harare to Mutorashanga

Mutorashanga is about 80 km north west of Harare and the journey takes about 60 minutes. Beyond the city limits, the rolling, fertile countryside is floored by the arcuate Harare Greenstone Belt. The Mazowe Dam at 30 km is situated close to the contact between the greenstones and the Chinamora granite batholith. The dam wall is built in a constriction in the banded iron formation of the Iron Mask Range. After travelling through the important fruit-growing areas north of Mazowe, the road crosses back onto granite terrain with characteristic large domal outcrops. At approximately 60 km from Harare, the prominent distant range of hills to the left provides the first view of the Great Dyke. The road soon crosses the Great Dyke through the Mutorashanga Pass and enters the village of Mutorashanga on the west side. [For locations of stops on Day 1, see Figures X] and X6.]

Stop 1: Underground visit, a chromite mine, Mutorashanga

This stop examines a chromitite layer of the Dunite Succession. As the underground section to be visited could not be selected in advance, the following notes apply to general features visible in typical underground workings on chromitites C7 and C8 in this area and not to any particular working. This mine is one of the few underground mining sections on the Great Dyke still operated by Zimasco, which now buys in most of its ore requirements. It is being developed for trials of different development and stoping techniques designed to reduce the high production costs of narrow seam mining.

Features that may or may not be observed in this working include (1) the narrow thickness (15 cm max.) and medium to coarse grain-size of the chromitite, (2) the layer-parallel shearing at the base and/or top of the layer (with or without associated slickensides and narrow mylonite zones) which may mask primary sharp footwall and/or normally slightly-gradational hanging wall contacts, (3) the regular dip and thickness of the layer despite the sheared contacts (where present), (4) the friable nature of the chromitite which, on handling, breaks up readily along a fine network of transgranular fractures, and (5) the soft, easily-cut nature of the serpentinite host rock. With respect to mining, note particularly the narrow stope width and the use of electric auger coal drills

Stop 2: Viewpoint above Mutorashanga

This stop provides a spectacular view of the northern section of the Darwendale Subchamber where the lower part of the Ultramatic Sequence is exposed. The location is slightly west of the axis in the Dunite Succession. The view along the axis to the north shows successively lower horizons in the sequence by virtue of the gentle southerly plunge of the layering. Conversely, the view to the south is up-sequence and shows the lower cyclic units of the Pyroxenite Succession.

The outcrop in the area shows scrpentinite weathering in its characteristic form. The elevation of the base of the scrpentinized zone is dependent on local topography and the proximity of faults, and there is a very sharp boundary between fresh dunite and scrpentinite. Fresh dunite is found in drill core 300 m below the valley floor. The original olivine in this part of the succession would have been about Fo_{92} : this represents the most magnesian composition in the Great Dyke. Extensive silicification of the scrpentinite (confined to hill tops) occurs as intersecting veinlets of opaline silica resulting in the observed stockwork structure. Narrow veins of asbestos are also present in dilation fractures. Viewed with the hand lens, the outlines of the original olivine crystals (1-3 mm in diameter) are delineated by grains of interstitial chromite and magnetite excluded during the scrpentinization process. The interstitial chromite is very fine grained (0,015-0,05 mm), particularly when compared with chromite in the chromitite layers where the annealed textures give rise to a very coarse grain size (up to 10 mm in diameter). Although veinlets of magnetite are present, these rocks have characteristically-small amounts of this mineral reflecting the magnesia-rich nature of the parent dunite. Pods and veins of brucite and magnesite are encountered in quarries and in mining operations.

Figures X2a, b & c are detailed maps of this part of the Great Dyke from 7½ km to the north and 15 km to the south of the viewpoint. Simplified longitudinal and transverse sections of the same area, based on surface mapping, accurate



Fig. X1 Simplified geological map of the Darwendale Subchamber in the Mutorashanga area (modified after Worst, 1960). The locations of Stops 2 to 4 on Day 1 are shown. For key, see Figure X6.

underground elevations and several deep boreholes, are shown in Figure X3. The maps and sections demonstrate the following: (1) The laterally-regular vertical interval between adjacent chromitite layers; (2) the transverse synclinal structure of the layering and the mirror-image outerop pattern of the chromitite layers to the east and west of the axis; (3) the 3-8°S pitch of the layering; (4) the curved. \sim 50°S-dipping transverse thrust faults at approximately regular 1½-3 km intervals: (5) the slightly-oblique transverse silicified joints (responsible for the spur and re-entrant topography along the flanks of the Great Dyke in this area); (6) the interaction between the southerly-pitching synclinal structure and the transverse faults (giving rise to a series of repeated synclinal fold closures of the chromitite layers, or 'boat-ends' in local mining terminology), and (7) the horizontal dunite-serpentinite boundary. Below the dunite-serpentinite boundary, the chromitite cannot be efficiently separated from its host rocks and the dunite is too hard for auger drilling. Because of the invard dip and gentle southerly plunge of the chromitite layers, the precise elevation of the boundary will have a major impact on future deep-level mining.

View to the north (Fig. X4)

Deep valleys and high-standing hills characterize the landscape produced by weathering of the serpentinite under subtropical conditions. Much in evidence are the results of extensive chromite mining operations which have taken place almost continuously since the 1940s. The chromitite layers are made conspicuous by trenching along their outcrops and chromitites C7 to C10 may be observed in this way. The inward-dipping attitudes of the layers are obvious but the gentle southerly plunge combined with transverse faults and joints, as well as the steep topography, results in complex outcrop patterns. Most of the mining in this area took place from deep inclined shafts and long adits leaving numerous large waste dumps. Chromitites C7 and C8 are now largely mined out in this area. Today, mining operations in this area are relatively small in scale.

Towards the north west (close to the mining village of Mutorashanga), the granite contact may be observed as a low ridge parallel to the margin of the Great Dyke. Contact metamorphism has resulted in local hardening of the granitic rocks, rendering them slightly more resistant to weathering and erosion.

An important feature of the landscape on either side of the Great Dyke in this area is the difference in general elevation, the west side being some 250 m lower than the east side. The Darwendale Subchamber lies to the west of the central watershed of the Zimbabwe plateau. It appears to have acted as a resistant mass, in places surmounting the Post-African erosion surface, with the west side reflecting a more juvenile erosion surface. Remnants of the mature African erosion surface are observed as high-standing platforms along the axis of the Great Dyke. Subsequent weathering appears to have had a major influence on both the eluvial chromite concentrations and the physical characteristics of the chromitites. A further important weathering effect has been the development of nickeliferous laterites in some areas. In the flat ground on the west side to the north can be seen areas where eluvial chromite-rich soils were stripped several decades ago, as well as a soil-washing plant.

View to the south (Fig. X4)

The view is across the Mutorashanga Pass. General features are similar to those already described. The western contact is again marked by low granite hills. The grassy serpentinite hills are barren of trees but several well-wooded areas may be observed, for example, those associated with dolerite dykes in the middle ground and particularly those marking the pyroxenite layers higher in the sequence. The lowermost P6 pyroxenite is seen to close in the axis and the overlying P5 pyroxenite forms the small central plateau. The precise cause of the vegetation anomalies on this part of the Great Dyke is not clear but it appears that soils with high Ni and low Ca and Al contents and high Mg/Ca ratios, such as those derived from the serpentinites, are toxic to most plant species common on the adjacent granite terrain. The grass cover on the rocky serpentinite slopes is highly specialized, and succulent shrubs such as *Euphorbia monteiri*, together with a few geophytes, are the only other plant species. Of the 20 endemic taxa on the Great Dyke, six are confined to the serpentinites north of Darwendale. The extensive outcrop of the Mafie Sequence in the central part of the Darwendale Subchamber appears to have acted as a barrier to the southerly spread of some of these species.

Approximately 3 km to the west of the Great Dyke and 15 km south west of the viewpoint, a number of isolated rocky hills aligned parallel to the Great Dyke are quartz gabbros of the Umvimeela Dyke.



Fig. X2a Detailed geological map of the Ultramafic Sequence from 1.5 km to 9 km north of the Mutorashanga Pass. Note the traces of the chromitite layers mapped as surface workings. For key, see Figure X2c. Based on mapping by M. Prendergast in 1992.



Fig. X2b Detailed geological map of the Ultramafic Sequence from 1.5 km north to 4 km south of the Mutorashanga Pass. As for Figure X2a.



Fig. X2c Detailed geological map of the Ultramafic Sequence from 4 km to 11,5 km south of the Mutorashanga Pass. As for Figure X2a.



Fig. X3 Longitudinal and transverse sections of the Ultramafic Sequence in the Mutorashanga area. For locations of sections, see Figures X2a, b, c. Note the interaction between the south-plunging synclinal structure, the major south-dipping thrust faults and the location of the dunite-serpentinite interface. Based on surface mapping, underground workings and borchole data.



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Fig. X4 Sketches showing important features of the Ultramafic Sequence observed from the Mutorashanga viewpoint (Day 1, Stop 2). A: view to the south. B: view to the north.

Travel log between Mutorashanga and Stop 7

Stops 2 to 7 are situated at various points along the axis and the east and west margins of the Great Dyke between Mutorashanga and the Great Dyke Pass 45 km to the south. The route follows alternately the east and west margins, crossing the Great Dyke at several points (e.g. Mutorashanga, Caesar, Airey's and Great Dyke Passes). Features to note along the way include (1) the rugged serpentinite terrain in the north, (2) the central wooded pyroxenite ridge further south flanked by serpentinite hills with prominent spur and re-entrant topography, (3) the extensive surface workings along the outcrops of the lower group chromitite layers, and (4) the waste dumps marking the positions of the underground mine workings. The larger workings are now closed and the bulk of current chromite production comes from small companies and from small-scale artisanal miners under contract or tribute to either Zimasco or Zimbabwe Allovs.

Stop 3: View of cyclic units, Dunite Succession, west side.

This road stop provides a spectacular view of Cyclic Units 6, 7, 8, 9, and 10 of the Dunite Succession. The lower contacts of Cyclic Units 7 to 10 are marked by parallel workings along the basal chromitite layers (Fig. X5). Cyclic Unit 6 is defined by the line of workings further up the hill and the P6 pyroxenite on the high ground to the east. The sequence observed is about 500 m thick, and Cyclic Units 8 and 9 are each about 105 m thick. The thickness of each unit is remarkably constant for many kilometres along strike. Small-scale tributor mining of the chromitites continues but the transport of the ore down the steep hill sides is creating a major environmental problem.

The approximate position of the granite contact can be seen ~ 100 m to the west. Note that there are no other pyroxenite layers exposed beneath P6 in this part of the sequence.

Stop 4: Examination of drill core, lower Pyroxenite Succession, Caesar Mine

A selection of drill cores will be viewed at the core yard of Caesar Mine (Zimbabwe Alloys). These boreholes were drilled to intersect chromitite C5 which was mined at Caesar Mine from an inclined shaft. Together, the cores intersect the lower part of the P4 pyroxenite, the serpentinite of Cyclic Unit 4, the underlying Cyclic Unit 5 and the P6 pyroxenite of Cyclic Unit 6. One intersection on view penetrated the entire P6 pyroxenite layer and most of the underlying dunite layer of the same cyclic unit. [Graphical logs will be provided as a hand-out.]

Points to notice in the drill cores are as follows. (1) The dunite of Cyclic Unit 6 of the deep hole has undergone extensive flaky alteration and much of it has completely disintegrated. This is in contrast to the serpentinite in the higher cyclic units (4 and 5) which is very stable. This condition arises from the rapid alteration of partly-serpentinized olivinc once it is exposed to air and moisture. The freshest dunites at the base of this hole contained 85% fresh olivine at the time of drilling. This rapid alteration of the olivine presents problems in carrying out studies of the mineralogy and textures. (2) In Cyclic Unit 6 there is only a very narrow transition zone (harzburgite and olivine pyroxenite) between the dunite (serpentinite) and the upper P6 pyroxenite. This contrasts with the presence of a thick olivine pyroxenite at the base of P5 and P4. (3) The P6 pyroxenite is an almost pure adumulate, with very small amounts of plagioclase at crystal triple junctions, and is the coarsest-grained pyroxenite in the Great Dyke. The composition of the orthopyroxene is Mg# 0.92 with 0.9% Cr₂O₃. The chromium imparts a beautiful green colour to the crystals. (4) Chromitile C5 immediately overlies the P6 pyroxenite. The two layers are usually separated by a narrow harzburgite layer 3-30 cm thick. Very often the lower contact (and sometimes also the upper contact) are strongly sheared because of movement along this plane. This is most likely the result of strainslip due to unloading of the roof rocks. The thickness of the chromitite is remarkably constant at 10 cm. The chromitite is only economically viable because of its lumpy physical quality and its relatively-high Cr₂O₄ content and Cr/Fe ratio. (5) There is no chromitite layer developed at the base of Cyclic Unit 4 (overlying pyroxenite P5) but chromite is often weakly concentrated at this level indicating that magmatic conditions prevailing at the base of Cyclic Unit 4 were broadly similar to those at the bases of most of the other ultramafic units.

Stop 5: Cyclic units, Pyroxenite Succession, east side

At this point on the east side of the Great Dyke, Cyclic Units 3, 4, 5 and 6 can be seen to the north. The resistant pyroxenites and the easily-weathered serpentinite give rise to a spectacular view of the layered structure. Trenching immediately adjacent to the P6 pyroxenite marks the outcrop of chromitite C5. Near the base of Cyclic Unit 4, the serpentinite (after dunite) grades upwards into a granular harzburgite containing narrow and highly-elongate pyroxene crystals up to 5 cm long. The origin of these crystals is not known. This rock-type grades into an olivine pyroxenite and then into the P4 pyroxenite.



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Fig. X5 Geological map of the west flank of the Great Dyke 13,5km south of Mutorashanga (Day 1, Stop 3). The cyclic units in the upper part of the Dunite Succession are well defined by surface workings along the outcrops of chromitites C6-C10. Note the P6 pyroxenite forming the ridge to the east. Based on mapping by M. Prendergast in 1980.

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Fig. X6 Simplified geological map of the Darwendale Subchamber in the Kildonan area (modified after Worst, 1960). This map is contiguous with that to the north in Figure X1. The locations of Stops 5 to 7 on Day 1 are shown.
Stop 6: Pyroxenite Succession in the axis, Airey's Pass

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This stop in the axis of the Great Dyke is on the upper contact of the P3 pyroxenite. Looking northwards, the synclinal structure is clearly seen where the serpentinite layer of Cyclic Unit 2 has weathered down to the P3 pyroxenite. In the distance, the P2 pyroxenite can be seen as a small outlier flanked by the underlying serpentinite layer. Immediately to the south of the stop, the high ground and rocky outcrop is formed by the P3 pyroxenite which has been up-thrown about 40 m to the south by one of the numerous transverse faults in this area.

Stop 7: P3 pyroxenite near the axis, Great Dyke Pass

This pyroxenite is typical of the lower part of the Pyroxenite Succession (Cyclic Units 3, 4, 5 and 6). The rock is very coarse grained with interlocking crystals (up to 1 cm in length) and less than 2% interstitial material (mainly plagioclase with very minor clinopyroxene). This is the classic pyroxene adcumulate of the Great Dyke. The characteristic green colour is the result of the relatively-high Cr_2O_3 content (0,61%) and Mg# (0,895). There is a weak fabric, the long axes of the pyroxenes lying in the plane of the layering but with little evidence of smaller-scale units.

Travel log from Great Dyke Pass to Harare

The return to Harare (60 km to the SE, 40 mins) traverses the same granitic terrain and commercial farm land as the outward journey but by a different route. Seventeen kilometres east of the Great Dyke, a series of low rocky hills may be seen north and south of the road. These are made up of fine- to medium-grained gabbronorite of the satellite East Dyke. Approximately 20 km from Harare, the western margin of the Harare Greenstone Belt is crossed but does not crop out. Several small road-cuttings are through dolerite sheets belonging to the ~2,0 Ga Mashonaland Igneous Event.

Day 2, Wednesday, 24th June

HARTLEY PLATINUM MINE

Principal guides: BHP personnel

Road log from Harare to Hartley Platinum Mine

Hartley Platinum Mine is about 80 km SW of Harare and the journey takes about 60 minutes along the main arterial road to Bulawayo, Zimbabwe's second city. Most of the route crosses relatively-flat commercial farm land underlain by Archaean volcanic and sedimentary rocks of the Harare and Norton Greenstone Belts as well as short expanses of granites. The most prominent geological features are several banded iron formation ridges seen on the way out of Harare and to the left of the road at Norton. At the east margin of the Great Dyke, about 25 km beyond Norton, granitic terrain with low, wooded, rocky outcrops gives way suddenly to a broad linear depression with a gentle grassy serpentinite slope on the far side, soon followed by flat wooded country of the poorly-exposed Mafic Sequence. At Selous, a small farming village in the middle of the Great Dyke, the route turns off the main road to the right and follows a side road for the last few kilometres to Hartley Platinum Mine. The flat topography of this part of the Great Dyke is in marked contrast to the hilly country observed around Mutorashanga on Day 1.

Programme (co-ordinator: R.T. Brown)

07:40	Guests arrive
07:40 - 08:00	Tea/coffee
08:00 - 08:10	Welcoming address by the General Manager, Gordon Taylor.
08:10 - 09:00	Introduction to local and regional geology (<i>Allan Wilson</i>), and geology and mining at Hartley Platinum Mine (Chief Geologist, <i>Ray Brown</i> , and Manager Production, <i>Johan Botha</i>). Short

presentation on Ngezi Platinum Project (Consulting Geologist, Delta Gold, Harry Wilhelmij), time permitting. 09:00 - 09:30 Travel to decline shafts and change in preparation for underground visit. Short safety induction at decline. 09:30 - 11:45 Underground visit, escorted by members of mining and geology departments. 11:45 - 12:15 Change and travel to open cast operation 12:15 - 13:00 Open cast visit, Dave Bowen, Open Cast Geologist, N. Sekar and D Chigonda. 13:00 - 13:50 Lunch at main office. 14:00 - 15:30 Metallurgical plant visit (co-ordinated by Manager Metallurgical and Surface Operations, Chris Rule). 15:30 - 16:30 Demonstration of Mhondoro surface drill core (D. Chigonda and N. Sekar, former and present Managers Mhondoro Platinum Project), and poster and core display by Delta Gold (Harre Wilhelmii). 16:30 Guests depart

Day 3, Thursday, 25 June

Cyclic Unit 1 and Lower Mafic Succession, Darwendale Subchamber

Principle guide: A.H. Wilson

Travel log from Harare to Darwendale

Darwendale is about 50 km west of Harare (about 60 mins by road). Initially, the route takes the same road as the return journey on Day 1 before turning off to the south west about 20 km from Darwendale. Darwendale village is on the east margin of the Great Dyke and chromite workings, dumps and the railway siding may be observed. The village is built on the thick pyroxenite of Cyclic Unit 3. The road turns south and crosses the railway line near the axis of the Great Dyke and proceeds along the harzburgites of Cyclic Unit 1. Wooded outcrops of the P1 layer in the axis may be seen to the right. [For locations of stops on Day 3, see Figure X7.]

Stop 1: Upper group chromitites, Darwendale area

At Darwendale, the topography of the Great Dyke changes from rugged and hilly in the north to flat or subdued in the south. This area also marks the northern extremity of Cyclic Unit 1 in the Darwendale Subchamber. The purpose of this composite stop is to examine, depending on the current availability of suitable exposures, several aspects of the upper group chromitite layers and their host rocks.

Chromitites Clc and Cld of Cyclic Unit 1 have been extensively mined in this area and Darwendale was formerly an important chromite mining centre. Recent mining operations, largely by contractors and tributors, have been relativelysmall scale. The locality is cut by the major NW-trending Darwendale fault zone, and by several smaller transverse faults, resulting in warping of the major structure, rotation of the layering and the formation of repeated 'boat ends' (Fig. X8). The chromitite layers are hosted by serpentinized dunite and harzburgite, and chromitite C1d overlies a 9 m-thick olivine pyroxenite layer. Large plates of polikilitic orthopyroxene are visible in the harzburgite and in oxidized and highly-weathered dunite the original olivine crystals are clearly outlined by concentrations of interstitial fine-grained chromite. The olivine pyroxenite has a characteristic red-spotted appearance because of the preferential weathering of olivine. Within the fault zones, serpentinization increases in intensity and veinlets of asbestos and of magnetite - often a fibrous variety after

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Fig. X7 Simplified geological map of the Darwendale Subchamber in the area south of Darwendale (modified after Worst, 1960). The locations of Stops 1 to 5 on Day 3 are shown. Hartley Platinum Mine is located on the west margin a few kilometres south of Makwiro.



Fig. X8 Detailed geological map of the axial portion of the Pyroxenite Succession south of Darwendale (Day 3, Stop 1). For location, see Figure X7. Note the asymmetric outcrop pattern of chromitites Clc and Cld and the P2 and P3 pyroxenites suggesting warping of the layered structure possibly by the oblique Darwendale fault zone. Stop 1 on Day 3 encompasses several localities on this map. Based on mapping by M. Prendergast in 1979.



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Fig. X9 Chromitite Cld in the Darwendale mining area. These sections show the variations in lithologies and thicknesses of this composite chromitite between the axis and the near east margin. Bulk and recalculated gangue-free compositions are given for the upper and lower layers.

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asbestos - are well developed. The abundance of magnetite in this area (relative to the magnetite-poor serpentinites at Mutoroshanga) is due to the relatively iron-rich compositions of olivine (Fo_{gd}) in Cyclic Unit 1. A series of low wooded hills near the main road are formed by outliers of the basal part of the P1 layer separated by faults and preserved along the synclinal axis. The chromitite layers crop out east and west of the P1 outliers and in the 'boat-ends' in between, and dip towards the axis at small angles.

Chromitite Clc at Darwendale is a massive medium-grained layer about 15-30 cm thick. Fine-grained nodular textures are seen in many exposures. The grade varies from 45% to 51% Cr₂O₃ and the Cr/Fe ratio from 2.2 to 2,4:1. The average grade and Cr/Fe ratio are significantly higher than in chromitite Cld (see below). This upward reversal between the two chromitites is widespread in many parts of the Darwendale Subchamber and suggests that the influx of new magma at the level of chomitite Clc was much larger than that at Cld. Both the upper and lower contacts of chromitite Cle are usually sheared and often marked by chromite mylonite, slickensides and/or siliceous veining and gouge. (This contrasts with the generally undeformed primary contacts of chromitite Cld).

Transverse variations in chromitite Cld in the central third of the synclinal structure have been carefully documented in the Darwendale mining area (Fig. X9). Here the chromitite comprises two chromite-rich layers separated by harzburgite, the lower layer either directly overlying the footwall olivine pyroxenite or separated from it by a thin layer of durate or harzburgite with extensive olivine-orthopyroxene reaction. This stratigraphic grouping displays systematic transverse variations between two lithological facies. In the axial facies, the chromitite is separated from the footwall pyroxenite by a dunite or harzburgite up to 20 cm thick and is represented by two relatively-thick chromite-rich layers, each comprising disseminated, often finely-layered, medium-grained olivine chromitite, separated by a relatively-thick harzburgite, with a total thickness of up to 225 cm. Outwards from the axis, there is a systematic increase in chromite grain-size and a decrease in olivine/chromite ratios and individual layer thicknesses. In consequence, the chromitite of the 'marginal' facies (1.5 km to the east and west of the axis) usually directly overlies the footwall pyroxenite. The two chromite-rich layers dominantly comprise massive, coarse-grained, slightly-nodular chromitite and are thin and close together, with a combined thickness. including intervening harzburgite, of not more than 50 cm. The cumulative modal content of chromite in the chromite-rich layers is approximately constant in both axial and 'marginal' facies, and the increase in layer thicknesses towards the axis is entirely due to an increase in the modal content of olivine relative to chromite. In exposures to the south east (1,7 km from the axis), chromitite Cld is massive and highly nodular, and most likely represents an even more 'marginal' facies. In some parts of the axial zone, the upper layer is highly complex, consisting of three or more bifurcating (and sometimes lenticular) units of disseminated and finely-layered olivine chromitite separated, along sharp planar contacts, by concordant lenses of dunite.

A sub-economic, 5-10 cm-thick chromitite layer (Cle) occurs stratigraphically 10-15 m beneath chromitite Cld. Its footwall is granular harzburgite. The hanging wall is poikilitic harzburgite merging up with the olivine pyroxenite beneath chromitite Cld.

Travel log from Stop 1 to Stop 2

From Stop 1 the road continues south along the base of the P1 layer which may be seen on the left. After a sharp turn to the east the road crosses the pyroxenite and reaches Stop 2 after 2 km.

Stop 2: Axial facies, P1 pyroxenite, Manyame Dam wall

This stop is at the Manyame Dam wall in the axis of the Darwendale Subchamber. Lake Manyame was completed in 1977 as an additional water supply to the City of Harare. The earth-wall dam with clay core is approximately 1 km long and sited in the narrowest part of the gorge where the Manyame River cuts through the P1 layer. The northern end of the dam wall is close to the contact between the orthopyroxenite and the websterite of the P1 layer. Very fresh exposures of these rock-types are seen as *in situ* poulders, rubbly outcrop and material used in the wall itself. Both rock-types are medium-grained, orthopyroxene is cumulus and plagioclase is interstitial. In the orthopyroxenite, clinopyroxene occurs as a bright green interstitial phase (with Cr_2O_3 as high as 0,9%) and as large echedral oikocrysts. In the websterite, both pyroxenes are cumulus. Clinopyroxene in the websterite is dark green in colour and the orthopyroxene is brown.

Although not exposed at this locality, the Main Sulphide Zone (MSZ) is situated close to the dam wall. The MSZ here is about 2,5 m thick, significantly thicker but lower grade than at Hartley Platinum Mine near the west margin further south. Weathered sulphide can be seen in some outcrops. Also apparent is the nodular texture of the 'potato reef' caused by the development of large oikocrysts of plagioclase up to 10 cm in diameter. The oikocrysts were formed early in the

crystallization sequence and the precipitated sulphide liquid became concentrated around their margins. This distribution is clear in some outcrops near the dam wall.

Travel log from Stop 2 to Stop 3

Returning to the main road the route crosses the Manyame River and reaches Stop 3 several hundred metres further south.

Stop 3: Axial facies, Lower Mafic Succession, south of Manyame River

At this road stop are seen rocks which lie stratigraphically about 10 m above the base of the Mafie Sequence and close to the axis of the Darwendale Subchamber. Exposure is characterized by boulders and poor outerop. The rock-type varies widely from anorthositic gabbronorite to anorthositic gabbro due to changes in the relative amounts of ortho- and clinopyroxene. The different varieties form discontinuous layers ranging in thickness from a few millimetres to 10 cm. The most striking characteristic of these rocks is the 'pock marked' appearance on weathered surfaces. The deep circular cavities are caused by weathering of olivine eikocrysts. Each eikocryst is a single crystallographically-continuous crystal enclosing small plagioclase laths. The oikocrysts vary in size from 3 mm to 30 mm and are commonly arranged in layers The olivine composition is Fo₈₈ and the enclosed plagioclase laths are reverse-zoned from An_{81} at the centres to An_{81} at the margins. The remainder of the rock comprises stubby subhedral crystals of dominantly-cumulus clinopyroxene with lesser amounts of irregularly-shaped orthopyroxene and plagioclase (An_{81}).

This important rock-unit marks the momentary re-appearance of olivine in the Mafic Sequence after its disappearance in the olivine pyroxenite at the base of the P1 layer. The development of this rock-type is strongly facies-dependent as it dies out towards the margins (see Day 3, Stop 5). The axial facies is considerably more anorthositic than the marginal facies. The re-appearance of olivine at the same stratigraphic level as the first occurrence of cumulus plagioclase in the Great Dyke requires comment. Although the magma had become saturated with plagioclase at this level, detailed studies have shown that the coincident arrival of plagioclase and olivine cannot be explained by simple fractionation, and modelling requires injection of approximately 10% of relatively Mg-rich but Cr-poor magma.

Travel log from Stop 3 to Stops 4 and 5

Stop 4 is 24 km from Stop 3. The road follows the eastern mafic-ultramafic contact for approximately 8 km before crossing the railway line and turning west. The vlei (wetland) and low region to the east is floored by the Ultramafic Sequence. Exposure of the gabbroic rocks is also very poor in this area. The black soils of the Great Dyke give way to sandy granitic soils where the road passes over the western contact and swings south past the railway siding at Makwiro. Stop 5 is about 1 km beyond Stop 4.

Stop 4: 'Picrite', Makwiro River, west side

This stop is located on the marginal facies of the harzburgite of Cyclic Unit 1 approximately 250 m below the base of the Mafic Sequence. Despite the black serpentinized appearance of the outcrop, this rock is remarkably fresh with less than 30% of the olivine altered to serpentine. The outcrop is characterized by large spheroidally-weathered boulders in a highly-decomposed matrix, the weathering being controlled by the local fracture pattern. This rock-type, once referred to as a picrite, is a phlogopite-bearing plagioclase harzburgite. It comprises zones of medium- to coarse-grained olivine crystals together with large oikocrysts of crystallographically-continuous orthopyroxene enclosing fine-grained and highly-rounded olivine. The orthopyroxene, together with the rounded olivine, can be easily seen by rotating a freshly-broken sample to reflect sunlight. Coarse-grained phlogopite is interstitial to the clusters of olivine and located between (but never within) the orthopyroxene oikocrysts. The phlogopites, together with very small amounts of primary K feldspar, both formed by crystallization of late stage liquid, give rise to the relatively-high K_2O content of this rock-type (0,28%). Plagioclase (always partly altered) appears milky white and is also interstitial to the mafic phases. Small amounts of very fine-grained chromite are present throughout the rock and are mainly located at the boundaries of the olivine crystals and within the orthopyroxene oikocrysts. Chromite released by weathering can be seen concentrated in the river sand.

The general dip of the layering in this area is 24° to the east and olivine-rich layers can be observed due to their preferential weathering. Approximately 100 m downstream towards the west is an outcrop of highly-weathered olivine pyroxenite to pyroxenite underlain by phlogopite-bearing plagioclase harzburgite. This is one of the thin pyroxenite layers which appear in the marginal facies of Cyclic Unit 1. With a few notable exceptions, these narrow pyroxenite layers are not observed in

the axial facies of this unit.

Approximately 20 m downstream from the bridge is a narrow granite dyke intruding the harzburgite. It dips steeply to the east and trends approximately north-south parallel to strike. The dyke is one of several in this area which were derived by partial melting of the granitic wall rocks and then intruded back into the layered sequence. This may be the result of high heat flow and the proximity of the granite floor rocks. This granite dyke contains variable amounts of chromium, up to several hundred ppm.

Stop 5: Marginal facies, Lower Mafic Succession, and 'Potato reef', west side

This outcrop provides comparison with Day 3, Stop 3 where the axial facies of the same rock-unit was examined. Here, the rock is relatively homogeneous but shows signs of thin wispy layering. Two pyroxenes are present but olivine is absent. Feldspar is cloudy due to minor alteration. (Even in drill core it is difficult to find completely-unaltered examples of this rock-type). Stratigraphically, this outcrop hes approximately 20 m above the base of the Mafie Sequence. The fracture pattern and mature weathering in this area give rise to the bouldery outcrop characteristic of the Mafie Sequence. Low ground to the west is underlain by deeply-weathered ultramafic rocks. In the distance can be seen hills formed by the granitic wall rocks. As at Mutorashanga, melting and recrystallization has rendered the granitic walls slightly resistant.

Trenching of the MSZ nearby has revealed the well-developed nodular pyroxenite (potato reef) associated with the MSZ. Large plagioclase oikocrysts are observed together with smaller Cr-rich augite oikocrysts. Phlogopite occurs at the zoned margins of the feldspar oikocrysts. Sulphide mineralization may also be seen together with Cu-staining caused by oxidation of the sulphides

Travel log from Stop 5 to Zvishavane

After Stop 5, the excursion proceeds direct to Zvishavane without further scheduled stops. Zvishavane is a small town, 300 km to the south and the journey takes about 4 hours. The Makwiro road continues south along the Mafic Sequence parallel and close to the mafic-ultramafic contact. The exceptionally-poor exposure of the gabbroic rocks should be noted. Hartley Platinum Mine is soon passed on the right, and shortly afterwards the route joins the main Harare-Bulawayo road near the small village of Selous.

From Selous, the route to Zvishavane passes through the midlands of Zimbabwe which contains some of the country's principal greenstone belts as well as much of its industrial infrastructure.

The following are some points of interest to note on the way.

- 1. About 4 km from Selous, the road leaves the Great Dyke and crosses flat granite terrain to the west. Twenty-five kilometres farther on, the road enters the main Midlands Greenstone Belt which it follows, apart from brief excursions onto the adjacent granites, for the next 190 km. The geomorphology of the midlands is dominated by the rolling, relatively-flat, Post-African (Miocene) land surface. Note the flat-topped ridges of Archaean metasediments which belong to the oldest preserved Pre-Karoo (late Palaeozoic) land surface and, near Gweru, the highly-mature African (mid-Cretaceous to end of Oligocene) land surface.
- 2. The towns of Chegutu, Kadoma and Kwekwe were all originally gold-mining centres. Although gold mining in the surrounding greenstones continues to be important, the country around Chegutu and Kadoma is now a major maize- and cotton-growing area.
- 3. About 15 km beyond Kadoma, a road branches west to the old Empress Mine. This was an important nickel producer until closure in 1983, and was the first major discovery of nickel sulphide ore in Zimbabwe. The mine worked disseminated ore in a differentiated mafic sill within the calc-alkaline suite of the 2,7 Ga Upper Greenstones.
- 4. Fifteen kilometres north of Kwekwe is Sable Chemical Industries, the country's main producer of nitrogenous fertilizers. Closer to town, Zimasco's ferroalloy smelter, one of the world's largest producers of high-carbon ferrochrome, is visible a few kilometres to the left of the road. Kwekwe is now a major industrial centre,

although the head gears and slimes dumps of the old Globe and Phoenix Mine and the old Gaika Mine (in the deformed Que Que Ultramafic Complex) are reminders of the town's gold-mining past.

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- A few kilometres south of Kwekwe, a branch road to the right leads to the small steel-producing town of Redcliff. Originally located on rich haematite and limestone deposits at Redcliff, the Zimbahwe Iron and Steel Corporation (ZISCO), the only fully-integrated steelworks in Africa north of the Limpopo, drew much of its iron ore from Buhwa in the south of the country in the 1970s and 1980s. It is now dependent on the Ripple Creek deposit 17 km south of Redcliff. Several manufacturers of steel products are located in nearby Kwekwe
- From the railway fly-over 25 km south of Kwekwe can be seen a prominent fault gap in a major iron formation ridge to the right of the road. This is the site of the Hunters Road nickel deposit (Anglo American Corporation), a major resource of low grade disseminated sulphide mineralization hosted within a very thick komatiite flow near the base of the 2,7 Ga Upper Greenstones. Although thoroughly explored and evaluated since its discovery in the early 1970s, this resource has not been developed because of present market conditions. Just beyond, to the left of the road, are the slimes dumps of the old Connemara Mine, a Au-bearing pyritic replacement deposit in banded iron-formation. Surface oxidized ore is now being exploited in a small open pit/heap leach operation.
- 7. Gweru is Zimbabwe's fourth largest city. An important administrative and communications centre, it is also the site of Zimbabwe Alloys, the country's second largest ferroalloy smeller.
- 8. Between Gweru and Shurugwi, the narrow Ghoko Greenstone Belt can be seen far to the right of the road. Shurugwi, set in fine scenic country, is another former gold-mining town. Well before reaching the town, the long ridge visible far to the left of the road is the major Wanderer iron formation hosting the Wanderer and Camperdown Mines, which have produced more than 40 t of gold between them. Today, Shurugwi is dependent on chromite mining. The Shurugwi Greenstone Belt contains some of the oldest rocks in Zimbabwe (3,5 Ga plus) and has been complexly deformed, principally by thrust and fold tectonics. The chromite ores occur in a series of pod-like bodies within highly-sheared and -metasomatized ultramafic rocks. Despite their present form, the chromitites and their enclosing rocks are thought to be the remains of an intrusive komatilitic sill emplaced within the greenstone sequence. The ore bodies are worked from two main underground mines, both owned by Zimasco, and the entire output is railed to the Kwekwe smelter. Chromite has been mined at Shurugwi continuously since 1906, and, with their high-quality ores and relatively-cheap mining, these deposits have long been the mainstay of Zimbabwe's chromium industry. Ore quality has declined in recent years, and the remaining resource is limited. On the other side of Shurugwi town, the road follows the steep Wolfshall Pass, dropping 180 m in 3 km. From the top of the pass, the following stratigraphic sequence can be observed in the road-cutting: chromitite-bearing ultramafic rocks, 2,7 Ga Wanderer clastic sedimentary rocks and iron formations, and overlying Tibilikwe basalts which terminate the preserved greenstone succession at Shurugwi.
- 9. From the foot of the Wolfshall Pass, the road follows the west margin of the Great Dyke (Selukwe Subchamber). Farther on, the road runs along the base of the P1 layer which, together with its capping of mafic rocks, forms a prominent ridge along the axis of the Great Dyke. Layering can be seen in the deeply-weathered pyroxenites in several road-cuttings. Just north of the Runde River, the road crosses the axis to follow the east side of the pyroxenite ridge, represented in this area by a series of outliers. Old chromite workings on the upper group chromitities are located adjacent to the road near the Runde bridge.
- 10. Further on, the road runs through communal farm land close to the east margin of the Great Dyke, here marked by a prominent range of hills formed by contact metamorphism of the granite wall-rocks. To the right of the road is seen flat country of the Ultramafic Sequence near the point where the Selukwe Subchamber merges with the Wedza Subchamber to the south. Eventually the road leaves the Great Dyke through a gap in the granite ridge. Between the Great Dyke and Zvishavane, the road passes over granite and the northern extension of the Belingwe Greenstone Belt. The low wooded greenstone hills contrast with the more open, cultivated, granite terrain.
- 11. Zvishavane is another typical mining town, in this case based on world-class asbestos deposits at Shabanie Mine (Africa Resources Limited). Chrysotile asbestos has been mined here since 1916 from a series of discrete ore bodies within a large komatiitic sill (Shabani Ultramafic Complex). The scale of the workings, now mostly

underground, is shown by the huge waste dumps which dwarf the neighbouring hills.

Days 4 and 5, Friday and Saturday, 26th and 27th June

Layering, PGE mineralization and marginal phenomena, Wedza Subchamber

Travel log from Zvishavane to Mimosa Mine

Mimosa Mine is about 30 km west of Zvishavane and the travelling time about 45 minutes, mostly on a bad road. The main road is followed out of Zvishavane to the west. The adjacent hills are serpentinites and periodotites of the Shabani Ultramafic Complex. A narrow strip of granite is crossed and the road then passes over the eastern margin of the Belingwe Greenstone Belt, which is then traversed almost without break as far as Mimosa Mine. About 10 km from Zvishavane, the route turns right off the main road onto a poorly-maintained strip road - one of the few still in use - which it follows to the Mimosa Mine turn-off. The Belingwe Greenstone Belt has become a classic of mid to late Archaean geology with spectacular exposures of a basal unconformity, komatiite flows and stromatolites.

With the exception of Stop 3, Days 4 and 5 are spent entirely along the east margin of the Great Dyke up to 4 km and 5 km north and south of Mimosa Mine, respectively. The topography of the Great Dyke in this part of the Wedza Subchamber is dominated by the low central ridge (Wedza North, South and Far South Hills) formed by the Mafic Sequence and the underlying P1 layer and flanked by low-lying ground of the upper ultramafic units. The contact metamorphosed granite wall-rocks are topographically subdued to the east of Mimosa Mine, but the large hill 9 km to the north marks the southern end of the marginal granite range observed near the end of Day 3. [For locations of Mimosa Mine and stops on Days 4 and 5, see Figures X10 and X12.]

1. Underground visit, Mimosa Platinum Mine

On arrival at Mimosa Mine there will be a welcoming address by the Mine Manager, Peter Breese, and a short introduction to the geology and mining operation (geological consultant to Zimasco, Tony Martin).

Principal guide: A. Martin

[The underground tour is designed to show participants six principal features of the mine geology (footwall bronzitite, hanging wall websterite, MSZ, washout channel, pegmatoid and hanging wall bronzite-phyric augitite) as well as aspects of the mining operation. The following are brief descriptions of the geology to be seen at each stop. Since the stops may vary according to available exposure, it may not be possible to make every stop or to see every detail described here. [A plan of the underground workings will be provided as a hand-out.]

Stop A. Footwall bronzitite

The aim of this stop is to examine the mineralogy and textures of the bronzitite which forms the footwall lithology of the MSZ. The principal mineral phase is cumulus bronzite with subordinate amounts of postcumulus plagioclase and augite. The bronzite forms brown stubby crystals about 2 mm long. Augite occurs as conspicuous green oikocrysts up to 20 mm in long dimension. The augite oikocrysts decrease in size and increase in abundance up towards the MSZ which is situated several metres above this position. The plagioclase forms very large oikocrysts but their boundaries are less easy to observe in fresh rock.

Stop B. Hanging wall websterite and MSZ

This exposure shows the MSZ and the hanging wall websterite. The websterite consists of cumulus bronzite and augite in approximate cotectic proportions, plus postcumulus plagioclase oikocrysts. The websterite is readily distinguishable from the footwall bronzitite by its green colour and by the prismatic habit and layered fabric of the bronzite crystals. The MSZ straddles the contact between the bronzitite and the websterite. Near the cast margin, this contact is gradational over about 50 cm and difficult to define. Essentially, the gradational contact zone marks the transition in the textural status of augite

from small postcumulus oikocrysts in the footwall, through abundant interstitial crystals, to full cumulus status at the base of the websterite. The term 'transitional bronzitite' is applied to that portion of the contact zone containing abundant interstitial augite. Near the east margin, the gradational contact zone is often obscured by hydrosilicate alteration.

The MSZ is visible as a zone of weakly-disseminated sulphides with the highest concentration occurring near the base of the websterite. The top of the Pt-bearing zone (PGE subzone) is situated at broadly the same level but cannot be identified by eye. Its approximate position can be demarcated by reference to several visual features: (1) The bronzitite-websterite contact, (2) the distribution of sulphides, (3) the distribution of hydrosilicate alteration, and (4) the presence of late magmatic lenses (mainly quartz, K feldspar).

Stop C. Washout channel

This exposure shows a lens of fine-grained norite and minor anorthosite within the hanging wall websterite. The norite displays irregular segregations of cumulus plagioclase and bronzite. The contact with the websterite is unconformable and locally interdigitating. The lens is part of a large flat-lying mass of mainly norite overlying and locally cross-cutting the base of the websterite over an elongate area 125 m by 50 m and oriented perpendicular to the east margin. In places, up to 1.5 m of the uppermost bronzitite and transitional bronzitite, plus the MSZ, are absent. The orientation and contact relations strongly suggest the removal of the websterite and upper bronzitite crystal mush by density currents of plagioclase-rich magma. Such washout channels are a feature of this part of the mine and several other examples have been mapped, or are inferred, nearby. In places, a layer of fine-grained bronzitite is present at the base of the washouts. Pegmatoids are frequently developed, particularly at their bases.

Stop D. Pegmatoid

In the hanging wall at this stop is a development of pegmatoid marked by coarse crystals of clinopyroxene, quartz and feldspar. The pegmatoid has been traced at the same stratigraphic level down dip and appears to be flat-lying and oriented perpendicular to the east margin. It is inferred to underlie a washout channel hidden in the hanging wall. At this stop, the pegmatoid extends down into the Pt-bearing zone of the MSZ where it is associated with significant lowering of Pt values. Sulphide blobs up to 20 mm in diameter are present. These have very low Pt contents, but may be nickeliferous.

Stop E. Bronzite-phyric augitite

This unusual rock, normally found only in the Main Websterite near the east margin, comprises a mass of fine-grained augite crystals together with isolated stubby prisms of bronzite up to 10 mm long and partially enclosing augite crystals at their margins. Almost completely barren, the augitite lenses display sharp contacts and, in some exposures, evidence of slumping and cross-bedding. In some instances, the lenses truncate the top of the MSZ. The origin of this rock-type is uncertain but appears to be a near-marginal phenomenon.

2. Field exposures, Mimosa area

Principal guide: M. D. Prendergast

[Note that the following programme may be modified according to the time available and the water level in the Mchingwe River]

Stop 1: Interlayered gabbros and websterites, near Blore Shaft portal

This exposure (Fig. X11) illustrates, on a relatively-small scale, the interdigitating gabbro-websterite contact common in places near the east margin. Also observed are narrow gabbro lenses and small pegmatoids (or late magmatic lenses) at the tops of some websterite modal layers. Note too the sharp and locally-uneven contacts and the textural variation within the websterite. The MSZ and the base of the Main Websterite lie a few metres below this outcrop but are not exposed.

Stop 2: Marginal facies, chromitite Clc (or Cld?).

Exposed in this small working is a 50 cm-thick massive chromitite layer dipping gently towards the west. It is made up of fine-grained chromite crystals enclosed by large plates of postcumulus orthopyroxene formed by reaction of olivine and trapped liquid. Very minor postcumulus clinopyroxene and plagioclase may also be present. This chromitite layer, either



Fig. X10 Simplified geological map of the central portion of the Wedza Subchamber (modified after Worst, 1960). The locations of Stops 1, 2, 3 and 9 on Days 4 and 5 are shown.



Fig. X11 Drawing of outcrop near Blore Shaft, Mimosa Mine (Days 4 and 5, Stop 1). Note the interlayering of websterite and gabbro. 42a

Clc or Cld, is typical of the fine-grained marginal facies of the upper group chromitites, and is most probably continuous with the more extreme marginal facies chromitite exposed at Days 4 and 5, Stop 6.

Stop 3: Axial facies, (oxidized) MSZ, Wedza Mine, 1926-1928

This pioneering operation was set up by the Grainger brothers to exploit the surface oxidized portion of the MSZ soon after its discovery here in the mid-1920s. The ore was mined from long strike trenches by undercutting methods, the local topography and flat northerly dip allowing a relatively low waste to ore ratio. Average head grade was claimed to be 4,3g/t Pt, with very little Pd. (This indicates the relatively-high mobility of Pd in the weathering environment; in sulphide ore, the average Pd/Pt ratio is 1:1,3). After crushing and grinding, the sands and slimes were passed over a series of riffled cement floors, or strakes, about one metre wide and up to 50 m long, constructed down the gentle hill slope. Despite much experimentation, recovery was rarely better than 50% as the main Pt-bearing mineral, now known to be spertylite (PtAs₂) with a mean grain diameter of 10 microns, was too fine for efficient gravity concentration, and the mine closed in 1928

Notwithstanding this early failure, the oxidized portion of the MSZ represents a considerable resource of potentiallyrecoverable platinum. Although a Pt concentrate is difficult to make from such ore by flotation, metallurgical test work has shown that the Pt can be efficiently recovered by direct smelting in an electric arc furnace followed by normal treatment of the ferronickel product. Pad leaching may be another possible process route.

The old Wedza slimes dumps are to the south of the road with the remains of the old mill plant immediately to the north, and the opencast workings (now heavily overgrown) just beyond. Remnants of the riffled cement strakes may still be seen as well as a shallow inclined shaft in one of the old surface workings. The oxidized MSZ may be recognised at the entrance to the shaft with the approximate position of the base of the Main Websterite shown by paint line. Assay profiles of the face from the hanging wall down to the lower part of the PGE subzone are given in Table X1. Of interest in this axial exposure of the MSZ is (1) the relatively sharp base of the Main Websterite, (2) the large vertical gap between this contact and the top of the PGE subzone, and (3) the limited amount of hydrosilicate alteration. These features contrast with those of the MSZ near the east margin.

The first boreholes to test the MSZ below the oxidized surface zone were drilled in 1966 higher up the slope above the old Wedza Mine. To the south, the wooded slopes of Wedza South Hill mark the northern limit of the Mimosa platinum deposit. The low-lying ground in between is made up of harzburgites of Cyclic Unit 1.

Stop 4: Wedza stream section

Stop 4 consists of a traverse through the upper 60 m of the P1 layer where it is well exposed in a dry stream cutting (Figs. X13a, b), and the stratigraphic setting of the MSZ may be examined. These exposures are mostly highly weathered, thus revealing many layering features that are not readily observed in either borehole core or underground exposures. The stream section is broadly similar to that intersected in borehole W98 drilled about 1,5 km to the NNW, and illustrates the principal features of the stratigraphy and the distribution of sulphides in this borehole. The layers dip approximately 15-20° to the west and the stream bed is oriented roughly perpendicular to the strike of the lower layers, but cuts obliquely across the uppermost layers.

Subunit 3

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The outcrop between the road and the stream section shows websterite near the top of Subunit 3 (Lower Websterite). Bronzitites of the lower half of Subunit 3 are exposed at the start of the traverse. Note the Fe-staining and the nodular structures similar to, but not as well developed as, the 'potato reef' in the Darwendale Subchamber. A few metres upsection (contact masked) is the base of the Subunit 3 websterite. This is the stratigraphic equivalent of the zone of interlayered bronzitites, transitional bronzitites and websterites in W98. Farther towards the axis, Subunit 3 usually consists entirely of bronzitite. The upper portion of this subunit exhibits a marked facies variation with increasing amounts of transitional bronzitite and then websterite, towards the margin.

In the Subunit 3 websterite, note the following: (1) Small, more-regular nodular weathering and the larger scale 'spheroidal' weathering and Fe-staining; (2) minor bronzitite lenses, which, towards the top of the websterite (at ~ 65 m) are associated with regular rhythmic layering on a scale of about 20 cm; (3) thin irregular pegmatitic stringers containing quartz, K feldspar, apatite, plagioclase and coarse clinopyroxene; (4) a sharp fine/coarse grain-size contact at the top of the websterite (at ~ 78 m), and (5) massive bronzitite at the top of Subunit 3 with lenses of strong Fe-staining.

	% Ni	%Cu	g/t Pd	g/t Pt
Тор	0,062	0,067	0,02	0,08
	0,059	0,064	0,03	0,02
	0,064	0,076	0,02	0,08
	0,068	0,082	0,03	0,12
	0,071	0,092	0,03	0,09
	0,067	0,067	0,04	0,15
	0,184	0,095	0,04	0,10
	0,182	0,129	0,05	0,19
	0,268	0,176	0,06	0,17
	0,218	0,161	0,10	0,24
	0,157	0,135	0,27	1,25
	0,239	0,209	0,53	3,73
	0,071	0,079	0,86	3,07
	0,064	0,076	0,86	2,28
	0,071	0,080	0,81	1,96
Bottom	0,077	0,077	0,78	1,89

Table X1. Assay profile, oxidized MSZ, Wedza Mine, 1926-28

(1) All sample widths 15 cm
(2) Upper dashed line, approx. base of Main Websterite
(3) Middle dashed line, approx. top of MSZ.
(4) Lower dashed line, approx. top of PGE subzone



Fig. X12 Geological map of the east marginal portion of Wedza South Hill. The locations of Stops 4 to 8 on Days 4 and 5 are shown.



Fig. X13a Wedza stream section, south portion (Days 4 and 5, Stop 4). Distances are indicated on the ground in paint. Layering units correspond to those shown in Figure 4.2. 43b

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Subunit 2

The top of Subunit 3 is provisionally placed within the upper bronzitite at the point where sulphide mineralization decreases sharply. Above this, the bronzites in a narrow zone at the base of Subunit 2 contain chromite nuclei. Broadly, this point coincides with a break in pyroxene and whole-rock chemistry, and, towards the margin, with the level at which cumulus augite crystallization ceases. Most of Subunit 2 comprises massive bronzities with very minor sulphide mineralization. Note the narrow Fe-stained websterite layer near the base (at ~95 m) and the steady decrease in the size of augite oikocrysts towards the top.

Subunit 1

The top of Subunit 2 is marked, in the axis, mostly by a grain-size contact and, near the margin, by a narrow intermittent layer of websterite or extreme transitional bronzitite. Subunit 1 is further subdivided into two sublayers. Sublayer 1b at the base comprises a narrow layer of bronzitite and transitional bronzitite and contains the PGE subzone of the MSZ. Sublayer 1a is made up largely of the thick Main Websterite and may also include lenses of other rock-types (e.g. gabbro and bronzite-phyric augitites in W98). Unlike the websterites lower in the sequence, the Main Websterite is rhythmically layered on a scale of 15-40 cm, and the bronzites tend to be strongly prismatic in habit. Near the margin, the silicates in the MSZ invariably are intensely altered to a hydrosilicate assemblage. This alteration overlaps the base of sublayer 1b and affects the bronzities, but not the extreme transitional bronzities or websterite. Another conspicuous feature of Subunit 1 is the presence of numerous, small, zoned, late magmatic bodies. They are ovoid to linear in form, usually concordant and related to the layering, and comprise quartz. K feldspar, carbonate and minor plagioclase and clinopyroxene. Usually a coarse, sulphide-rich, but PGE-poor, pegmatoid occurs at the top of the Main Websterite immediately below the mafic contact.

Features to observe are as follows:(1) The alteration zone commencing below the top of Subunit 2 and extending up into the MSZ; (2) the absence from, or non-exposure in, this section of the narrow websterite, or extreme transitional bronzitite layer, which normally marks the top of Subunit 2 near the margin, (the latter, in the traverse log, being extrapolated from its approximate relative level in nearby borcholes); (3) the MSZ, which, in this section, is relatively thin and recognized as a gossanous zone dipping west parallel to the east stream bank, and its relatively-sharp base exposed in the stream bar (at 207 m); (4) the base of the Main Websterite, essentially coterminous with the top of the MSZ in this area, and following the stream bed for the first 70 m; (5) the Main Websterite with its prismatic bronzites, small, even nodular weathering and conspicuous rhythmic layering principally defined in this exposure by alternating pale nodular and non-nodular Fe-stained zones); (6) the absence, or poor development, of the mafic contact pegmatoid in this section, and (7) the massive norites at the base of the mafic succession.

The gossans in this area were extensively trenched in the 1920-30s. Average grades are reported as 3,8-5,3 g/t Pt + Pd over widths of 1-1,25 m along a total combined strike of almost 4 km.

Stop 5: Wedza No. 2 Shaft, 1969-71

Fresh rock specimens may be collected from the old waste dump at this stop. Most of the principal rock-types associated with the MSZ are represented, including the ore itself. Note that not all the sulphide-bearing rock is PGE-rich. Some is well mineralized but PGE-poor websterite from the base of sublayer 1a. The best visual guides to ore here are the presence of sulphide mineralization, plus stubby (as opposed to prismatic) bronzites, usually intense hydrosilicate alteration, and, possibly, very small augite oikocrysts.

The Wedza No. 2 Shaft was the first attempt at mining and processing the MSZ below the weathered surface zone anywhere in the Great Dyke. Ore was mined from two experimental stopes at a vertical depth of 107 m. Flotation and smelting were carried out on site, the principal metals being extracted from the resulting converter matte elsewhere. This prospect established the technical feasibility of mining the MSZ and the recovery of the precious metals.

Also at this stop can be seen blocks of mined rock with a very narrow, fine-grained chromitite layer. This is the uppermost chromite concentration known in the Great Dyke and came from the base of a norite-filled washout channel cutting bronzitites beneath the MSZ at the north end of these workings.

Stop 6: Marginal facies, Unit 1 harburgite-chromitite association

The rocks in this and nearby stream exposures (Fig. X14) comprise olivine-bronzitites and bronzitites, together with several thin chromitic harzburgite layers. The stream is almost parallel to strike and the rock sequence dips 26° west. The main chromitic harzburgite is a layered, bifurcating zone of chromite-rich feldspathic harzburgite. In places, the zone is 50 cm thick, comprising at least three chromite-rich layers separated by feldspathic, pegmatitic layers. Near the north end, the zone is represented by a single layer up to 20 cm thick, locally with small-scale undulations. Each chromite-rich layer has a sharp top and base, and a zone of disseminated chromite-rich layers formed as feldspathic, clinopyroxene-bearing olivine-chromite cumulates. The olivine has largely reacted to orthopyroxene, forming small nodules of fine-grained chromite surrounded by patches of slightly-coarser chromite. At the south end of the exposure, a 20 cm-thick olivine—orthopyroxene reaction zone occurs immediately below the main chromitic harzburgite.

The footwall rocks beneath the main chromitic harzburgite consist of two distinct facies of feldspathic bronzitite. At the north end of the exposure, the rock is a medium-grained olivine-bearing bronzitite and contains several, sometimes bifurcating, chromitic harzburgite layers 1-5 cm thick. The olivine content progressively decreases southwards, and in the southern half of the exposure, the footwall rock is an olivine-free, medium-grained, crudely-layered bronzitite with no chromitic harzburgite layers.

Above the main chromitic harzburgite is a layer of relatively fine-grained feldspathic bronzitite with small augite oikocrysts. In places, the bronzite is prismatic to acicular in habit and both the bronzite crystals and the augite oikocrysts may show a lineation fabric perpendicular to the margin of the Great Dyke. Elsewhere, especially near the south end, the bronzitite is slightly coarser grained with a higher proportion of plagioclase and no pyroxene fabric, and is associated with irregular to ovoid pegmatitic zones up to 2,5 m long. Near the top of the hanging wall bronzitite is a rare chromitite lens 3 cm thick and 20 cm long. The hanging wall bronzitite is overlain along a sharp contact by an olivine bronzitite.

Both the hanging- and footwall bronzitites are associated with Fe- and Cu-stained gossans. The hanging wall gossans are up to 4 m thick and more continuous than the footwall gossans which are lenticular in form and restricted to the olivinebearing facies of the footwall bronzitites. The strongest gossans contain significant Pd and Pt with a mean Pd/Pt ratio of 1:0,48 (Table X2). (In view of the high mobility of Pd in the weathering environment indicated at Days 4 and 5, Stop 3, these sulphides evidently had a much higher Pd/Pt ratio than the MSZ higher in the sequence; see also Days 4 and 5, Stop 9). Parts of the exposed sequence are intruded by narrow irregular pegmatitic dykes containing quartz, K feldspar, apatite, plagioclase and coarse clinopyroxene crystals.

The main chromitic harzburgite is again exposed in the stream bed 100 m to the south. Here, it consists of a single layer with a relatively low chromite content and appears to lens out further to the south. The hanging wall rock is a gossan-free olivine bronzitite (containing at least one minor chromitic harzburgite layer) which grades into bronzitite as the olivine content decreases upwards. Below the main chromitic harzburgite, the footwall rock is a relatively fine-grained feldspathic bronzitite with no chromite, olivine or gossans. The bronzitite extends eastwards to within 90 m of the granite contact, the bronzite becoming progressively more prismatic and oriented perpendicular to the margin.

Significant features of these exposures are the rapid facies variations along strike and the occurrence of abundant cumulus orthopyroxene in association with chromite-rich cumulates. It is considered that these rocks represent a marginal facies of the harzburgite-chromitite association of Unit 1 which can be traced to the north progressively farther in from the margin (e.g. Days 4 and 5, Stop 2). If this correlation is correct, these exposures illustrate several aspects of the possible behaviour of some of the Great Dyke layers as they approach the margins. First, the cumulus grain-size becomes progressively finer towards the margin. Second, near the margins, the harzburgite layers of Unit 1 appear to grade sequentially into, initially, olivine bronzitite, then bronzitite. Effectively, the structural level at which bronzite appears on the liquidus is progressively lowered towards the margins.

Stop 7: Border Group

An outcrop of fine-grained bronzite crescumulate (or 'perpendicular pyroxene rock') lies within 5-10 m of the granite contact (note the sandy soil nearby), and forms part of the Border Group of the Great Dyke. Traces of layering on a scale of 10-20 cm are visible dipping 30-40° west. Prominent features are the highly-acicular bronzites (up to 10 mm long), and their marked lineation fabric. Generally, the lineation lies sub-parallel to the plane of the layering and perpendicular to the margin. In places, the lineation is sinuous and locally may become completely disoriented. The variation in fabric may be



Fig. X14 Detailed geological plan of a stream exposure of the marginal facies of the Unit 1 harzburgite-chromitite association (Days 4 and 5, Stop 6). Symbols K1 to K5 and K13 and K14 refer to samples of gossanous bronzitite; for Pt, Pd, Ni and Cu assays, see Table X2.

Table X2. Assays of grab samples of gossans, marginal facies of the Unit 1 harzburgite-chromitite association

	%Ni	%Cu	g/t Pd	g/t Pt	
K1	0,021	0,017	0,08	0,09	
K2	0,056	0,046	0,32	0,25	
K3	0,039	0,076	0,38	0,21	
K4	0,051	0,080	0,47	0,32	
K5	0,045	0,101	0,91	0,23	
K13	0,040	0,270	0,83	0,02	
K14	0,030	0,050	0,61	0,02	

For sample positions, see Figure X14

confined to specific layers. Augite is a relatively minor interstitial postcumulus phase and does not form oikocrysts. Similarly, postcumulus plagioclase occurs as rather small poikilitic crystals and is, in places, almost interstitial. Quartz, K feldspar, pargasitic hornblende, phlogopite, apatite and sphene are also present in significant proportions.

Stop 8: Marginal facies, Unit 2 harzburgite-pyroxenite association

This bronzitite exposure lies approximately 125 m in from the granite contact. In contrast to the Border Group bronzitite, in this rock the fine-grained bronzite crystals form small stubby prisms with poorly-defined fabric and postcumulus augite occurs as both small slightly-aligned oikocrysts and as interstitial grains. This rock is identical to, and probably a continuation of, the lowest footwall bronzitite exposed in the stream bed south of Days 4 and 5, Stop 6. Structurally, these rocks are equivalent to the P2 pyroxenite layer. It seems possible that, close to the Border Group, the pyroxenite-harzburgite association of Unit 2 grades into a fine-grained pyroxenite which is vertically continuous with the overlying pyroxenite at the base of Unit 1.

Stop 9: Mchingwe River section

The road bridge crosses the Mchingwe River near the eastern margin of the quartz gabbro in the central part of the Wedza Subchamber. This section has been down-faulted by several hundred metres with a horizontal displacement of nearly 4 km. The confinement of the quartz gabbro to this down-faulted block is particularly striking. The lack of quartz gabbro in the Mafic Sequence elsewhere in the Wedza Subchamber, and in all other subchambers, may indicate that the block-faulting was initiated soon after the emplacement of the magma with continued movement through to the postmagmatic stage. Significant interaction of the magma and wall/roof-rocks is postulated for this section.

The quartz gabbro is exposed for several hundred metres to the east of the Mchingwe River bridge and is underlain by the pyroxenites of Unit 1 of the Ultramafic Sequence. Several hundred metres beyond the mafic-ultramafic contact, rocks of the Border Group and their contact with granite wall-rocks have been recorded at low water level and will be examined, river conditions permitting.

Quartz gabbro and mafic-ultramafic contact (Fig. X15A)

The rocks in the Mchingwe River are coarse-grained quartz gabbros. Orthopyroxene is either absent or occurs as a minor constituent. The augite is characteristically mantled and partly replaced by pale green amphibole and tremolite. The plagioclase is irregular in form, strongly zoned and commonly altered and saussuritized. Elongate crystals of augite are strongly deformed and fractured in some rocks, but this deformation does not continue into the surrounding plagioclase crystals or the matrix. The matrix comprises optically-continuous quartz partly enclosing the cumulus minerals, with minor phlogopite, sulphide and magnetite. The pyroxenes are relatively magnesian.

In the vicinity of the contact with the pyroxenite, a complex association of gabbroic rocks is well exposed on a river pavement. The irregular nature of the contact with the underlying websterite is demonstrated in the outerop. Effectively, several layers of differing mafic rocks are exposed which range from fine-grained metagabrro to coarse gabbroic pegmatoids. Heterogeneity within the various rock-types is also apparent. The coarser-grained varieties show large individual crystals of quartz commonly in reaction relationship with the matrix. Some of these grains may be xenocrysts from the granitic wall/roof-rocks. The significance of the quartz gabbros is that these rocks crystallized in close proximity to the granitic roof-rocks and essentially represent the results of downward crystallization from a hybrid magma rather than extreme fractionation of a mafic magma (Fig. X15C).

The underlying websterite crops out on the pavement as irregularly-shaped inliers in the quartz gabbro but also occurs as narrow (generally less than one metre wide) linear bodies. The websterite comprises cuhedral to subhedral crystals of cumulus augite and bronzite set in a matrix of large poikilitic plagioclase crystals and quartz. The quartz commonly occurs as a granophyric intergrowth with K feldspar giving rise to the high $K_2O(>0,50\%)$ content of these rocks. Minor phases in the matrix consist of amphibole (commonly replacing the augute), phlogopite, magnetite and sulphide.

An exposure on the pavement to the south of the permanent pools shows a layer of websterite sandwiched between layers of fine-grained gabbroic rocks. A pegmatoidal zone occurs on the upper contact of the websterite layer.

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Fig. X15 Detailed geological maps of portions of the Mchingwe River, east part of the Mchingwe fault block (Days 4 and 5, Stop 9). A: The contact zone between the websterite and the quartz gabbros. B: The marginal Border Group and the granitic wall rock contact. C: Hypothetical transverse section of the east part of the Mchingwe fault block.

Border Group (Fig. X15B)

Approximately 400 m down stream from the mafic-ultramafic contact is a sequence of rocks representing the Border Group. This sequence is classified broadly into two parts: (1) A hybrid zone 5-10 m in width consisting of feldspathic pyroxenite and norite/gabbronorite closest to the granite contact, and (2) an inner zone of bronzitites characterized by elongate pyroxenes aligned perpendicular to the wall. In the norite closest to the granitic wall, the orthopyroxene and plagioclase laths are strongly zoned and are contained in a matrix of quartz (commonly as granophyric intergrowths with K feldspar), primary amphibole, phlogopite, sulphide and magnetite.

Farther in from the granite contact, but still within the hybrid zone, clinopyroxene becomes more abundant, orthopyroxene is less strongly zoned and the rock-type becomes coarser grained. The mesostasis is also modally less abundant. Coarse sulphide segregations are found towards the inner part of this zone.

The inner part of the Border Group is characterized by highly-elongate (5-15 mm) orthopyroxene crystals aligned perpendicular to the wall rocks. The rock-type is essentially a feldspathic bronzitite and may be described as a bronzite crescumulate. The zone between the crescumulate and the hybrid rock-types comprises a bronzitite with stubby and interlocking orthopyroxene crystals tending towards an adcumulate. Pyrrhotite and chalcopyrite are abundant in the latter rock-type but these rocks do not carry significant PGE mineralization (0,09%Ni, 0,16%Cu, 0,31g/t Pd, 0,20 g/t Pt and 0,09 g/t Au).