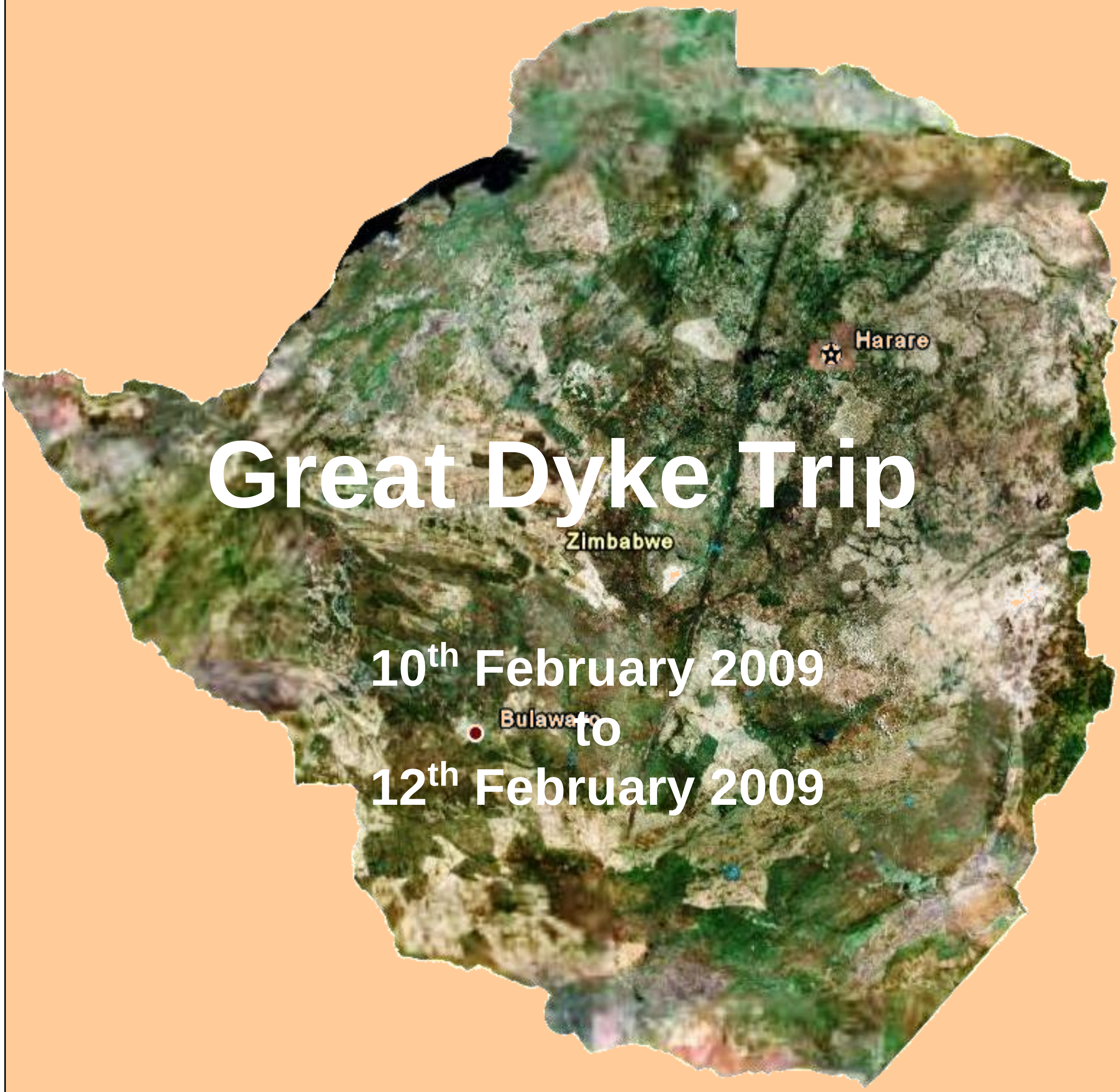
Geological Society of Zimbabwe

Great Dyke Trip



10th February 2009

to

12th February 2009

Filed Trip Schedule

Day	Date	Time	Activity
Tuesday	10/02/2009	6am-8am	Drive to Ngezi
Tuesday	10/02/2009	8am -9am	Induction and Introduction
Tuesday	10/02/2009	9am - 12am	Examine Typical and unusual core
Tuesday	10/02/2009	12-1pm	Lunch
Tuesday	10/02/2009	1pm-3pm	Tour Open pit and selected outcrops.
Tuesday	10/02/2009	3pm-6pm	Drive to Antelope Park to camp the night
Wednesday	11/02/2009	6am-8am	Drive to Unki
Wednesday	11/02/2009	8am -9am	Induction and Introduction
Wednesday	11/02/2009	9am - 12am	Examine Typical and unusual core
Wednesday	11/02/2009	12-1pm	Lunch
Wednesday	11/02/2009	1pm-4pm	Tour selected outcrops.
Wednesday	11/02/2009	3pm-5pm	Drive to Zvishavane - Shabani Club Camping
Thursday	12/02/2009	6am-7am	Drive to Mimosa
Thursday	12/02/2009	7am-8am	Induction and Introduction
Thursday	12/02/2009	8am-10am	Examine Typical and unusual core
Thursday	12/02/2009	10am-12:30pm	Tour selected outcrops.
Thursday	12/02/2009	12:30pm-1:30pm	Lunch
Thursday	12/02/2009	1:30pm-5pm	Drive to Bulawayo (Find own accommodation)
Thursday	12/02/2009	5pm	MacGregor Lecture - School of Mines
Thursday	12/02/2009		Overnight - participants own arrangements
Friday	13/02/2009		Return to Harare

Zimplats Schedule

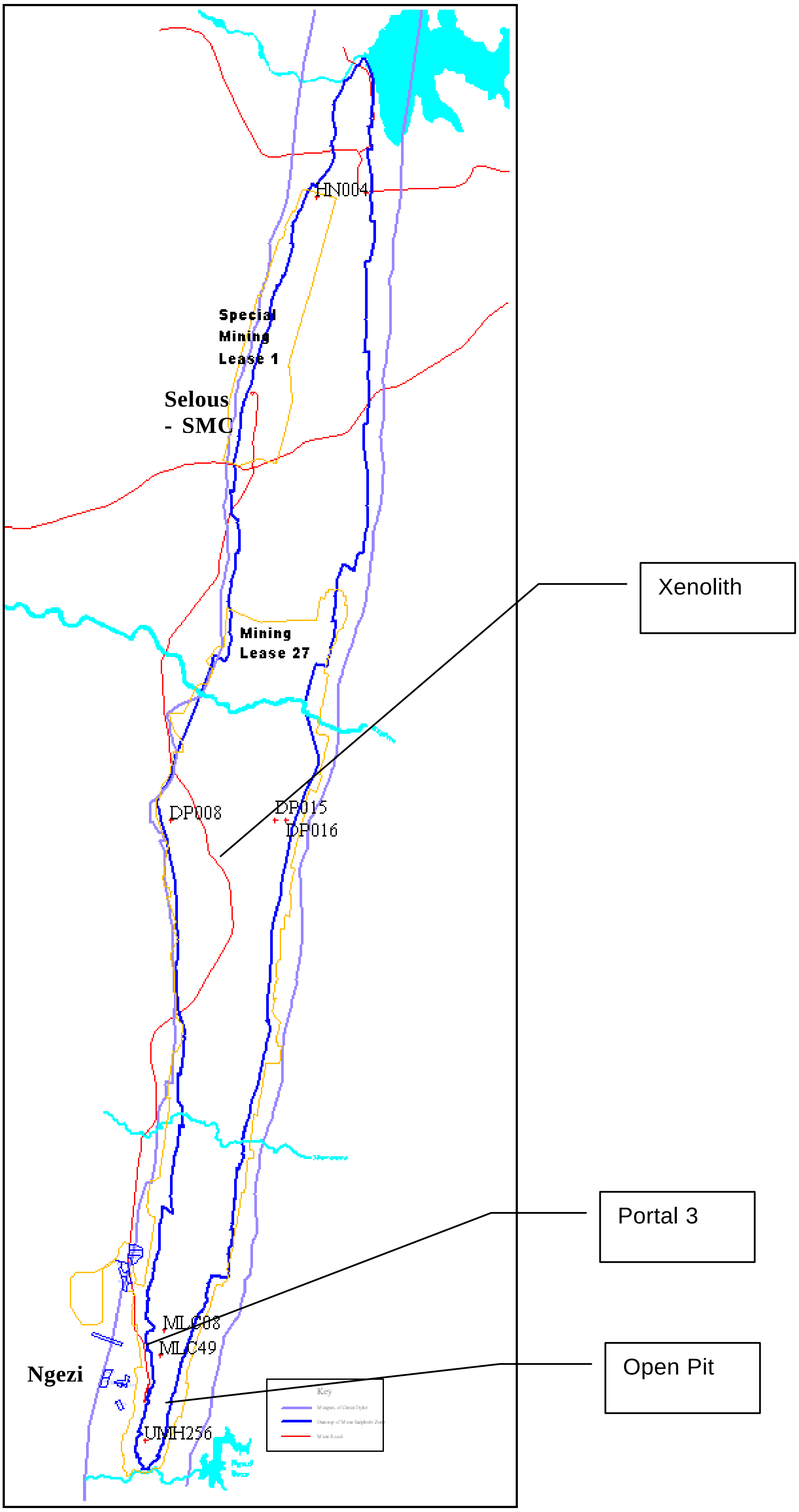
Introduction and Induction at Selous Core Shed.

View following Core

1. DP015 – Deepest hole with magnetite gabbro
2. DP008 – Hybrid lithologies
3. DP016 – variety of the rock types
4. MLC08 – Mulota disrupted profile
5. HN004 - typical Hartlyy hole
6. MLC 49 - typical hole

Outcrop Visits

1. Xenolith near DP010
2. South of East Pit - structures at Base of Gabbronorite
3. Portal 3 – box cut - ‘ potato reef’


HN004
Special
Mining
Lease 1
Selous
- SMC
Mining
Lease 27
DP008
DP015
DP016
MLC08
MLC49
Ngezi
UMH256
Key
Xenolith
Portal 3
Open Pit

Unki Schedule

1 VRS7 Normal MSZ with fwf
2 MR 240 Normal MSZ without fwf
3 VRS8 Abnormal MSZ (replacement pegmatoid)
4 MR 139 Abnormal MSZ (serpentinite xenolith)
5 MR 235 Normal MSZ with xenoliths in the hanging wall

Outcrops

MSZ intersection-road cutting

Xenoliths- serpentintes and pyroxenites-Unki South

Nodular Weathering-Potato Reef- Unki South

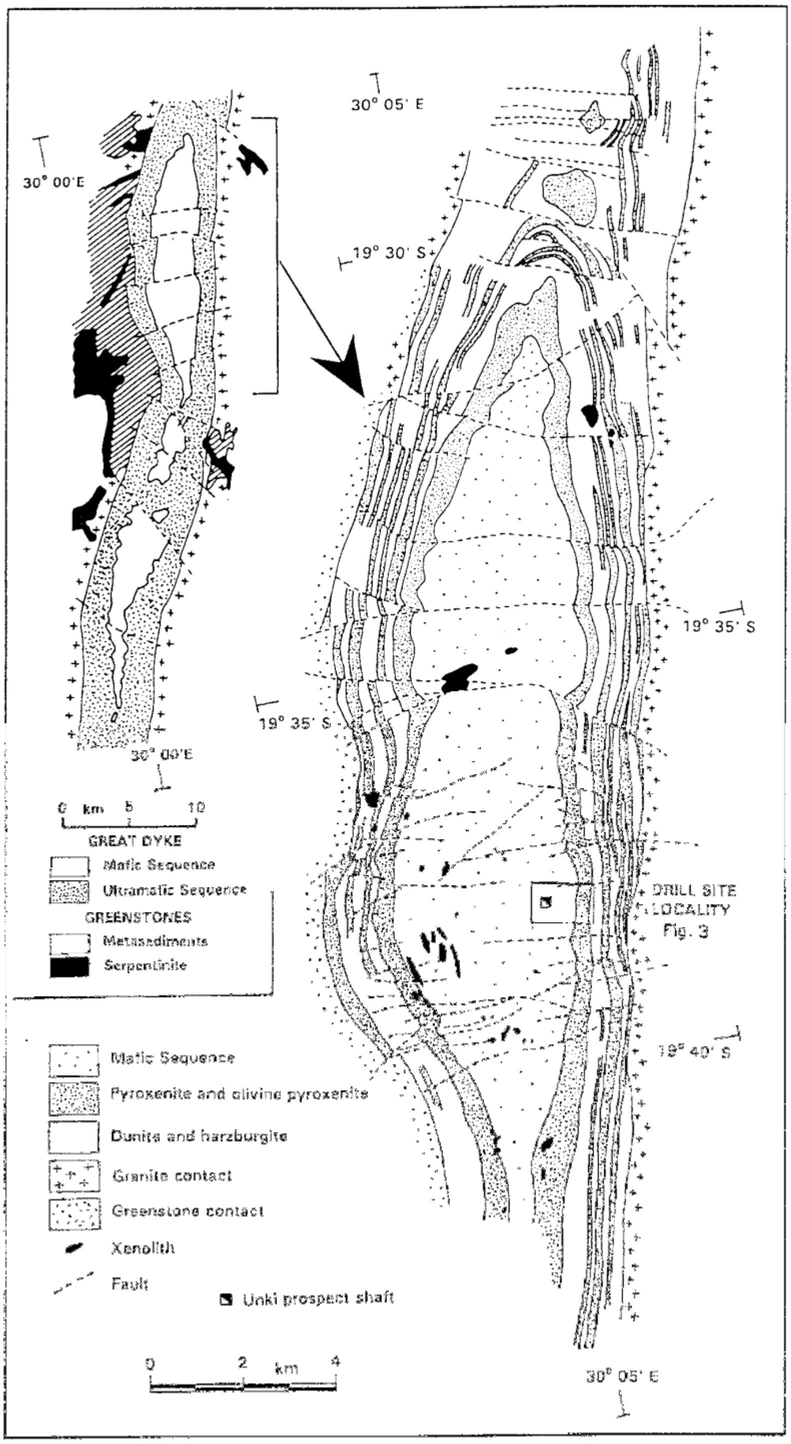


Figure 2 The geology of the north-central zone of the Selukwe Subchamber. The plan shows mapped outcrop, layering features, and localities of mapped xenoliths. The position of the Unki prospect shaft is indicated. (From Wilson *et al*, 2000b)

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 African orogeny (Zambezi Province) at 500 Ma.

The lower ultramafic 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 Tredoux, 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 Umvimeela 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 Ultramafic 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).

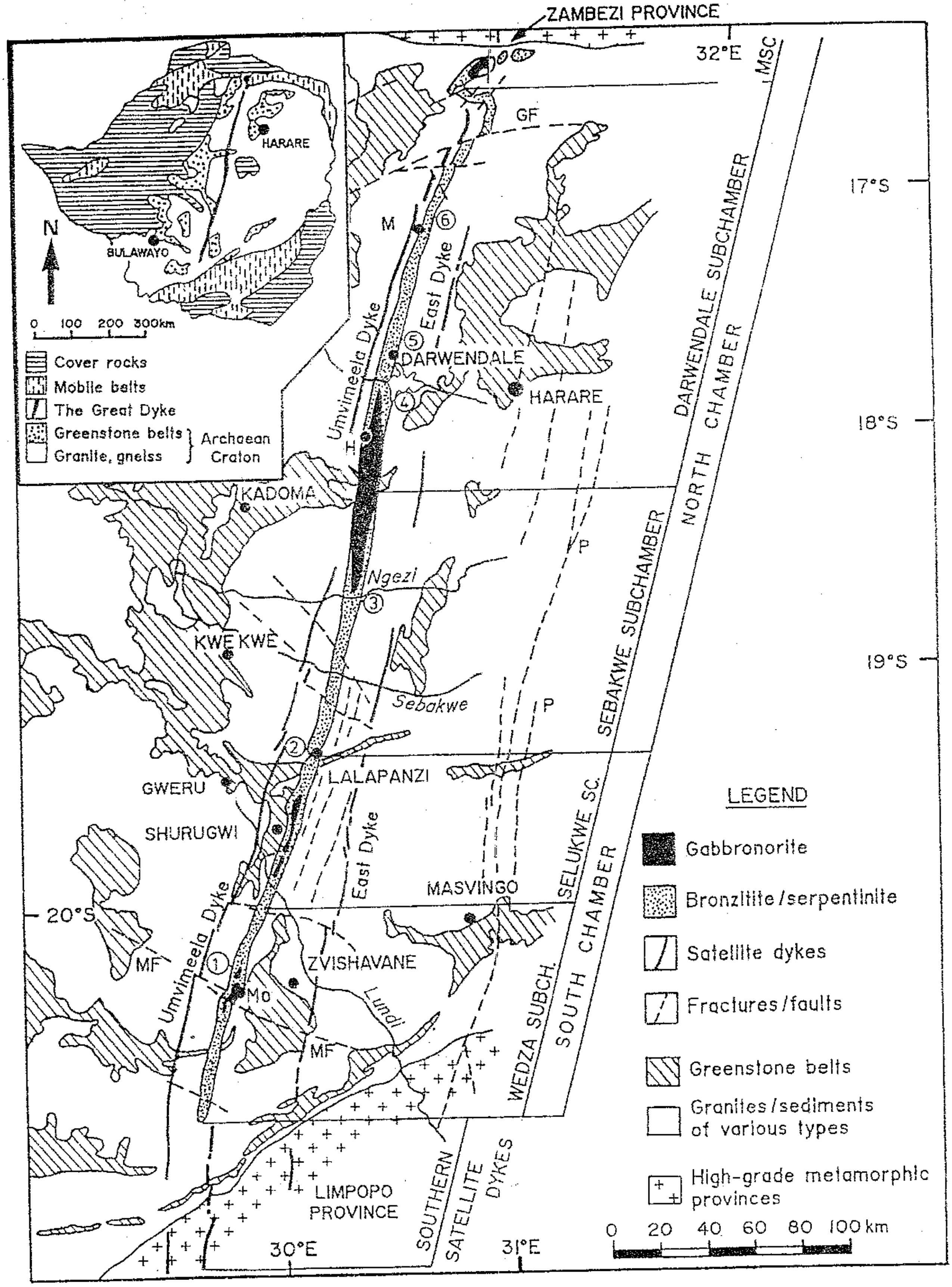


Fig. 1.1.1 Geological map of the central part of the Zimbabwe Craton showing the Great Dyke, its chambers and subchambers, and its satellites and associated fractures. Circled numbers refer to gravity profiles shown in Figure 1.1.6. Abbreviations: MSC, Musengezi Subchamber; P, Popoteke fault set; GF,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

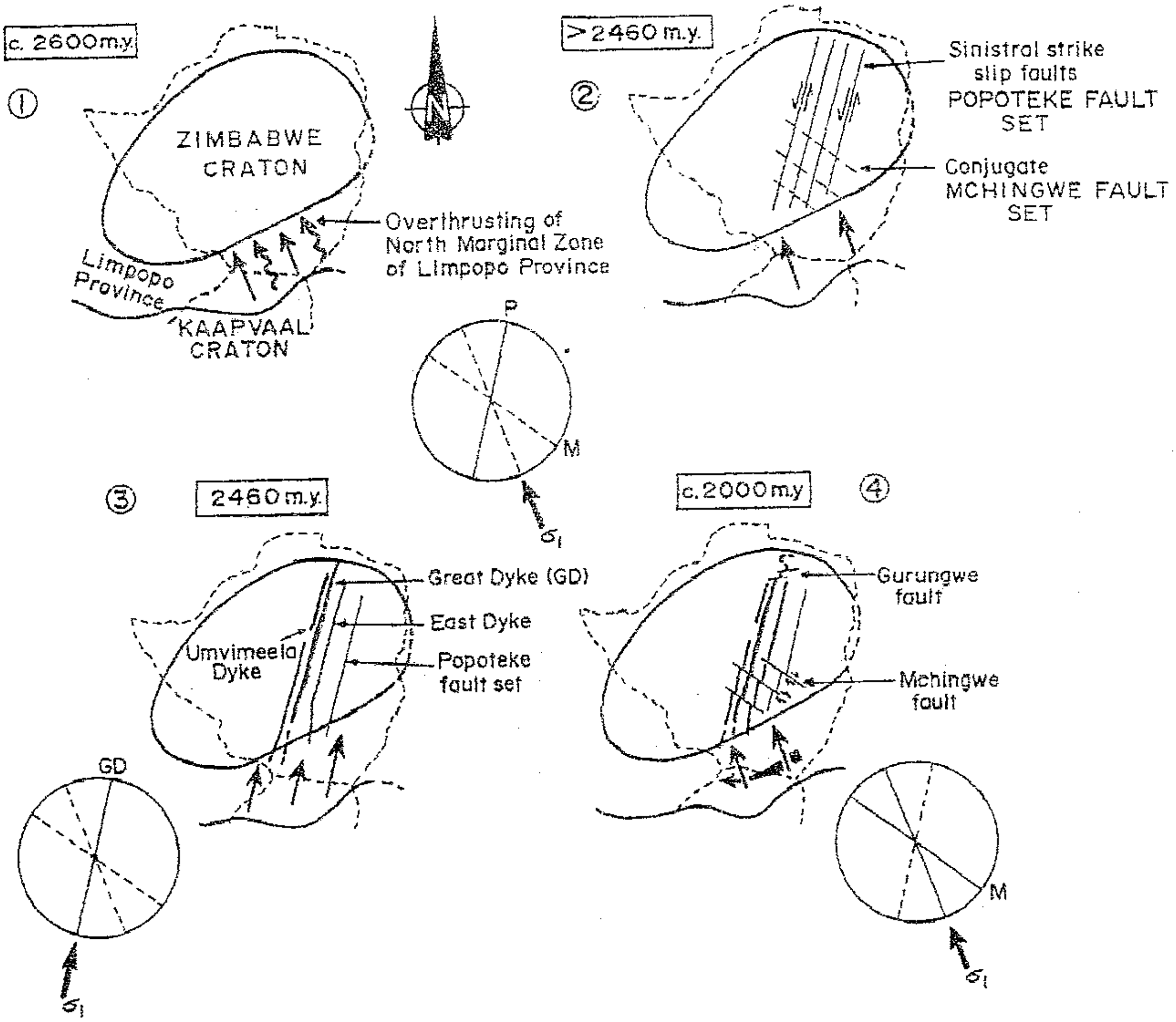


Fig. 1.1.2 *Schematic representation of events associated with the emplacement of the Great Dyke. (1) Collision of the Zimbabwe and Kaapvaal Cratons and northward overthrusting of the north marginal zone of the Limpopo Province: (2) development of sinistral strike-slip faults of the Popoteke fault set (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-Great Dyke re-activation of the Mchingwe fault set resulting in dextral movement.*

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 Mafic 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 magma 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 Ultramafic 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.

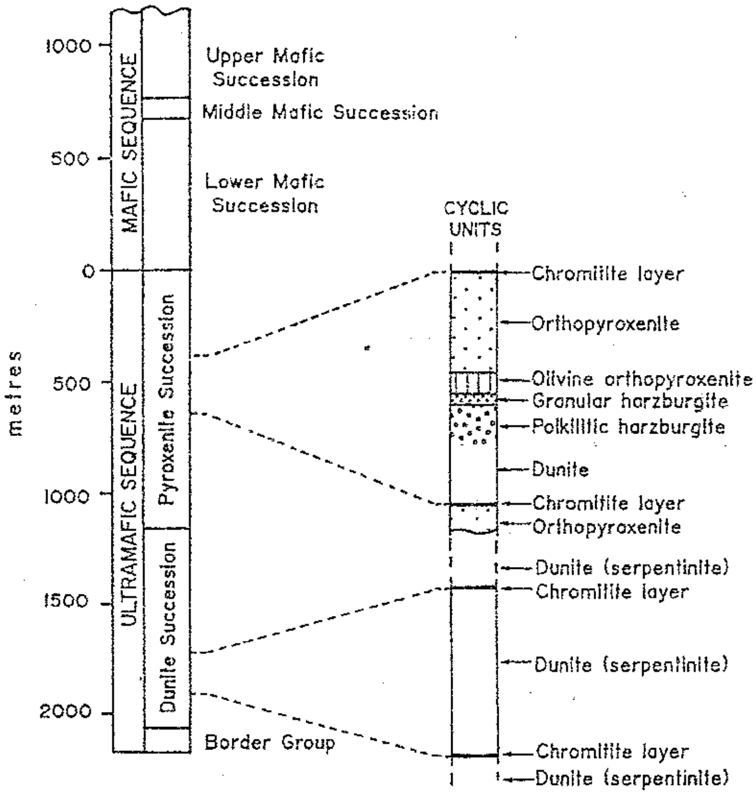


Fig. 1.1.3 Subdivision of Great Dyke stratigraphy into the Dunite and Pyroxenite Successions in the Ultramafic Sequence and the Lower, Middle and Upper Successions in the Mafic Sequence. Also shown are the lithological structures of cyclic units in the Dunite and Pyroxenite Successions.

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

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

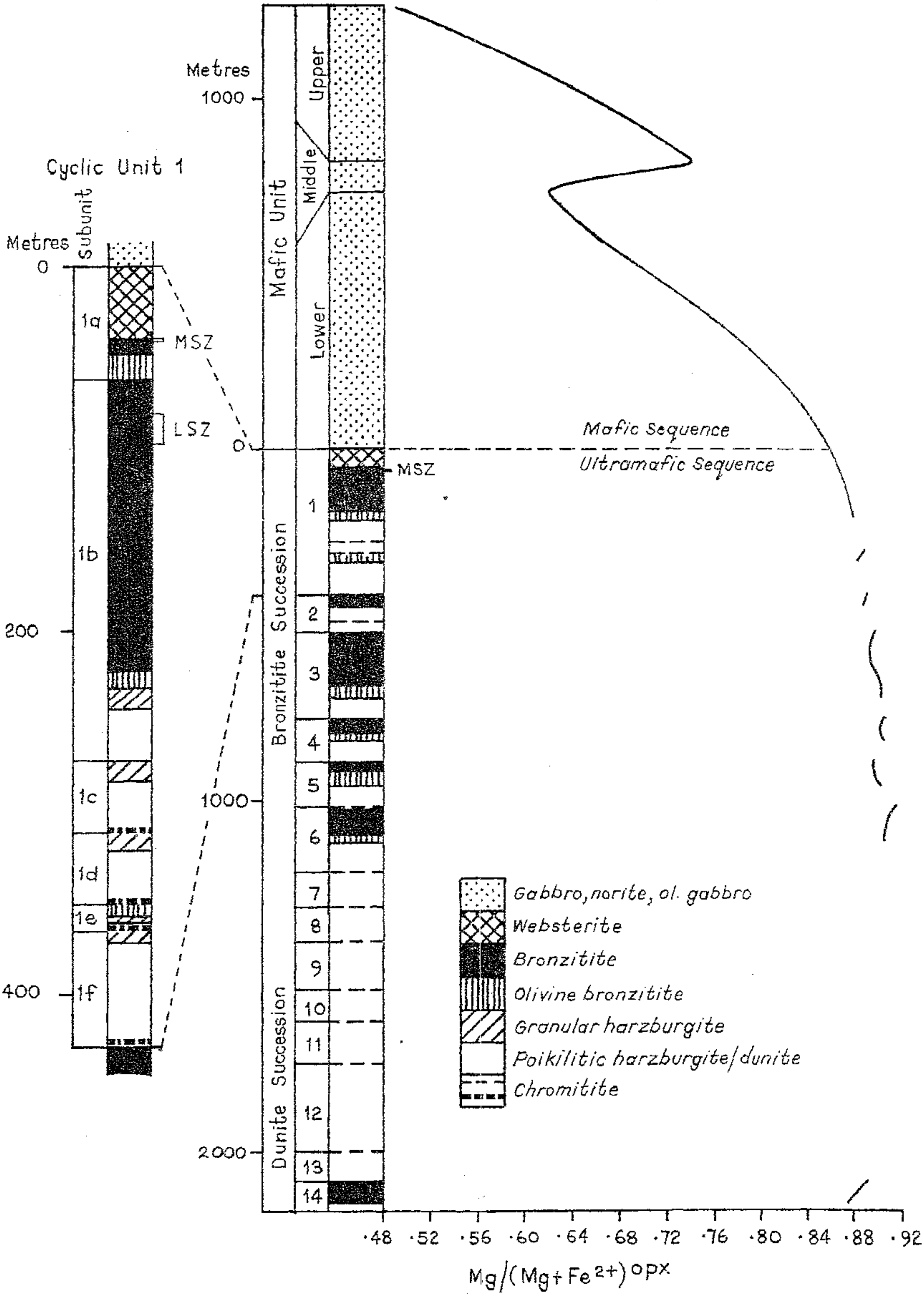


Fig. 1.1.4 Detailed stratigraphy of the Mafic and Ultramafic Sequences in the Darwendale Subchamber. Also shown are the detailed stratigraphy of Cyclic Unit 1 and the vertical variations in orthopyroxene compositions.

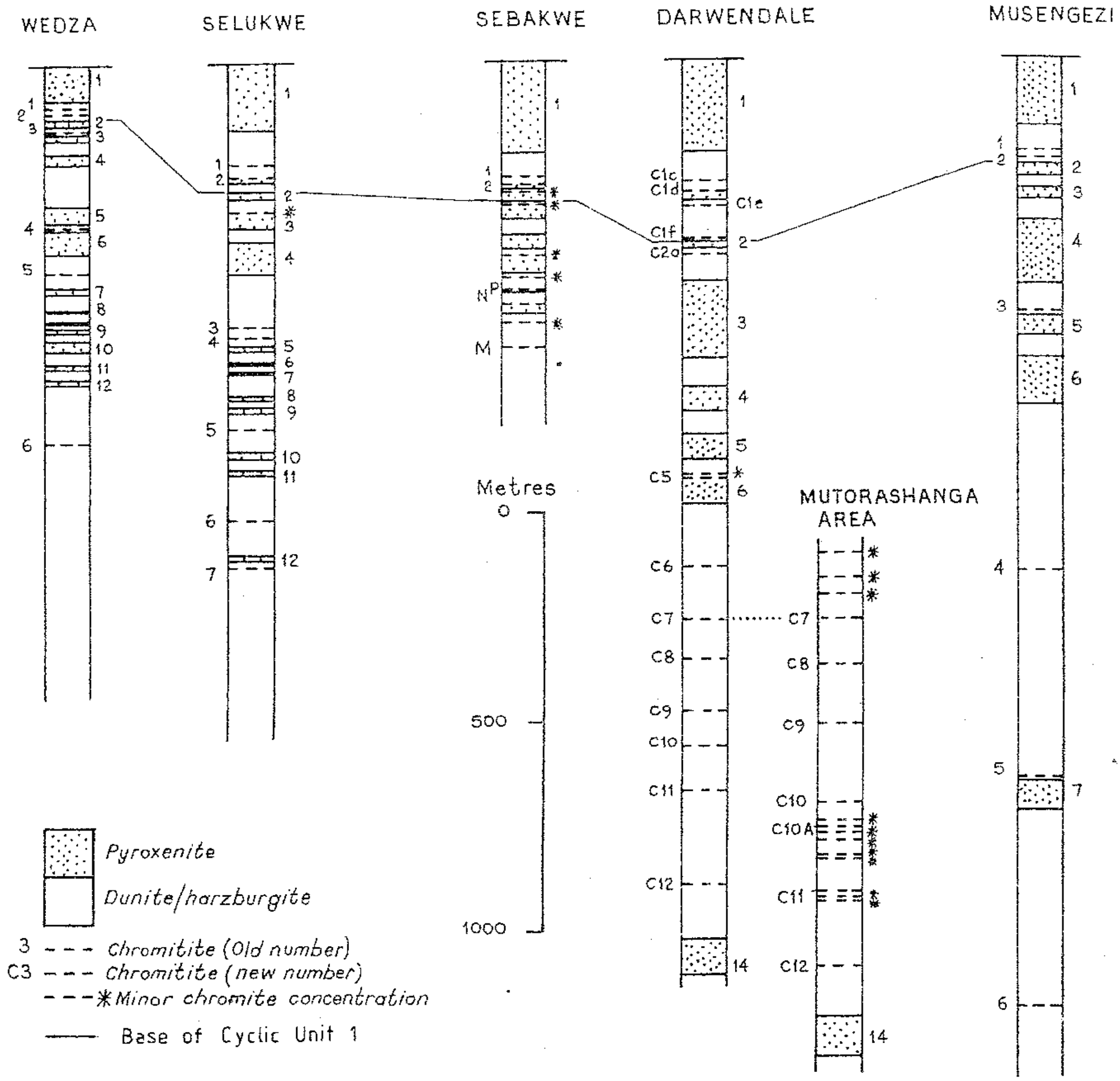


Fig. 1.1.5 Stratigraphy of the Ultramafic Sequence in all five subchambers of the Great Dyke. The positions and numbers of the main pyroxenite and chromitite layers are shown. Note the minor (unnumbered) chromite concentrations, particularly in the Mutorashanga area.

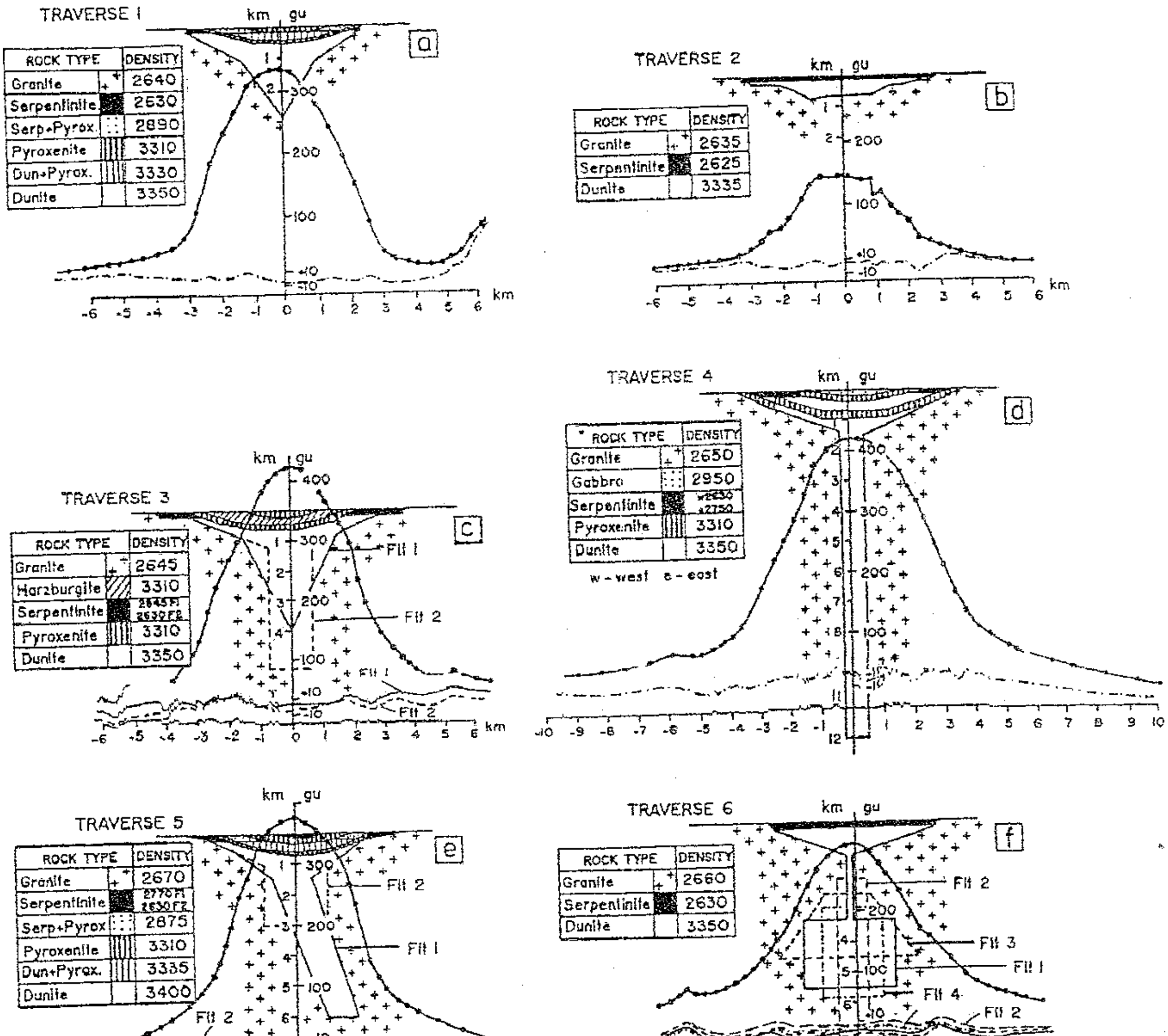


Fig. 1.1.6 Bouguer gravity anomaly profiles for six traverses across the Great Dyke. Locations of traverses are shown in Figure 1.1.1. Transverse sectional models consistent with surface geology provide best fits with the gravity data. Sample stations are indicated by dots on the anomaly profile and 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.

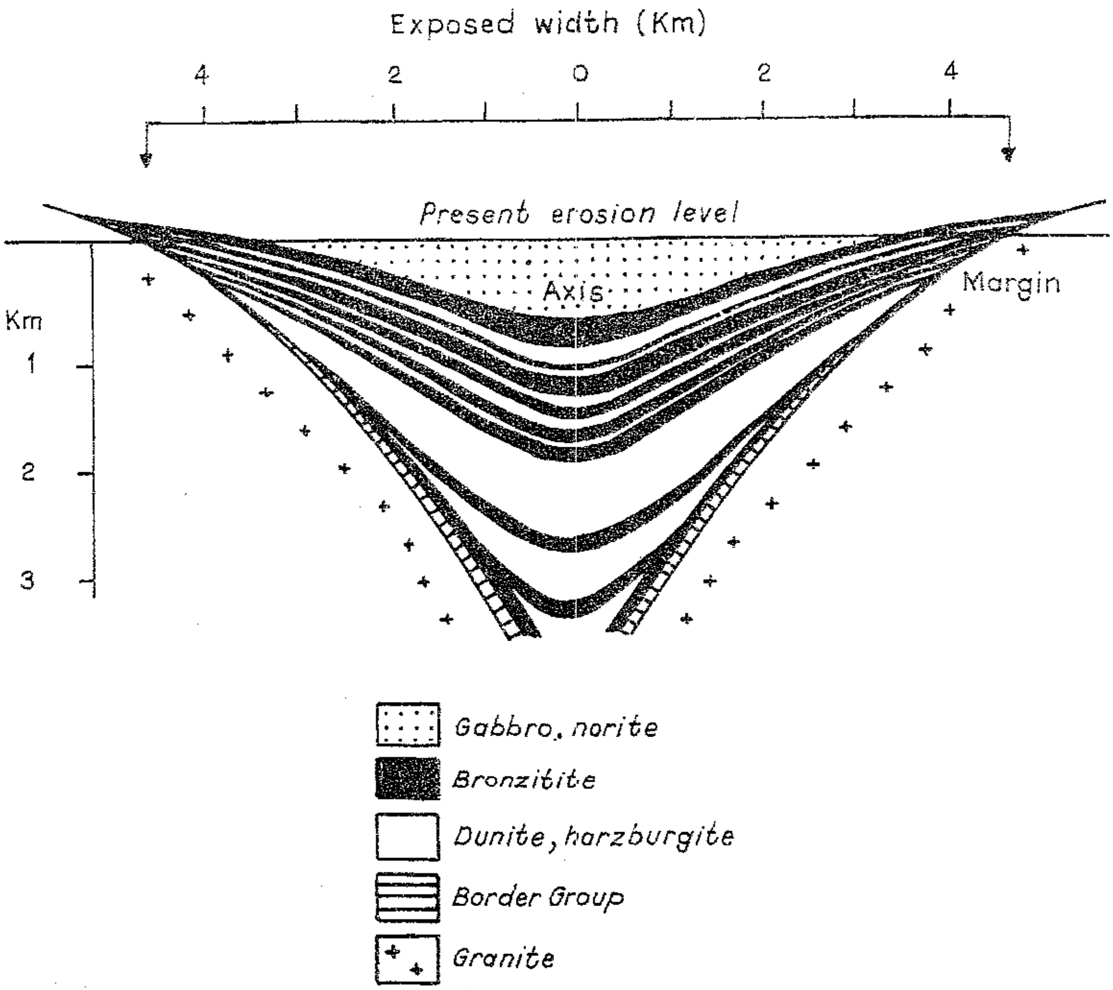


Fig. 1.1.7 Transverse section of the layered sequence of the Great Dyke in the Darwendale Subchamber based on borehole intersections, and field and gravity data. Note the small angular decrease and progressive thinning of the layers towards the margin, and the off-lapping relationship of the layers to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

The Ultramafic Sequence

Cyclic units

The stratigraphy of the Ultramafic Sequence in the Darwendale Subchamber is shown in Figure 1.1.4. The ideal cyclic unit encountered in the Ultramafic Sequence of the Great Dyke comprises a thin basal chromitite overlain by a thick dunite 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 economically-viable 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 Ultramafic 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 chromitites (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 → 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 → 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 euhedral 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

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. Plagioclase and clinopyroxene 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.

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 Mafic 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 clinopyroxene 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 sulphide 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 rock-type 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 euhedral 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 poikilitic 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. Oikocrysts of both plagioclase and clinopyroxene become common towards the top of the P1 orthopyroxenite. In places, the plagioclase oikocrysts give rise to a characteristic nodular weathering feature - termed the 'potato reef' - comprising nodules up to 8 cm 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 phlogopite, magnetite, 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 subunits. 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 C1c and C1d (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 clinopyroxene 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

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, irregularly-developed 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

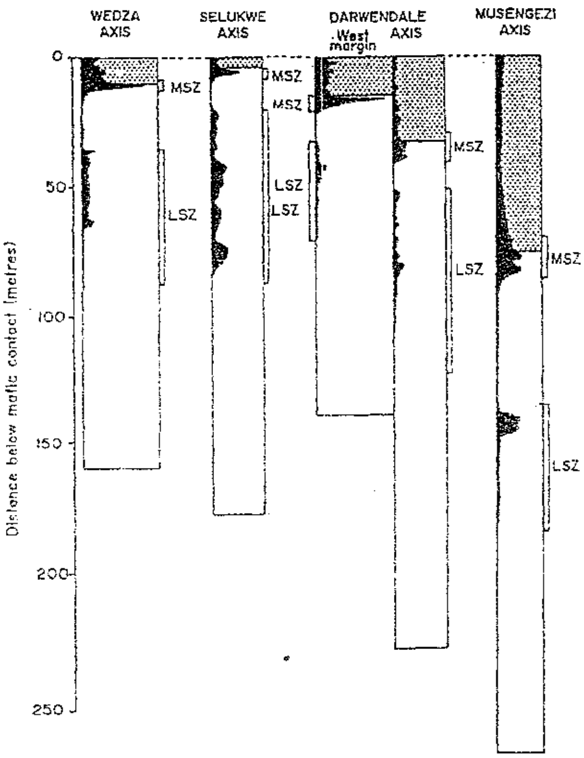


Fig. 1.1.8 Sulphide distributions (based on Ni + Cu assays; solid black) in the P1 pyroxenite layer in four subchambers of the Great Dyke. The orthopyroxenite (open) and websterite (stippled) layers are indicated, as are the Main Sulphide Zone (MSZ) and Lower Sulphide Zone (LSZ). Note the difference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

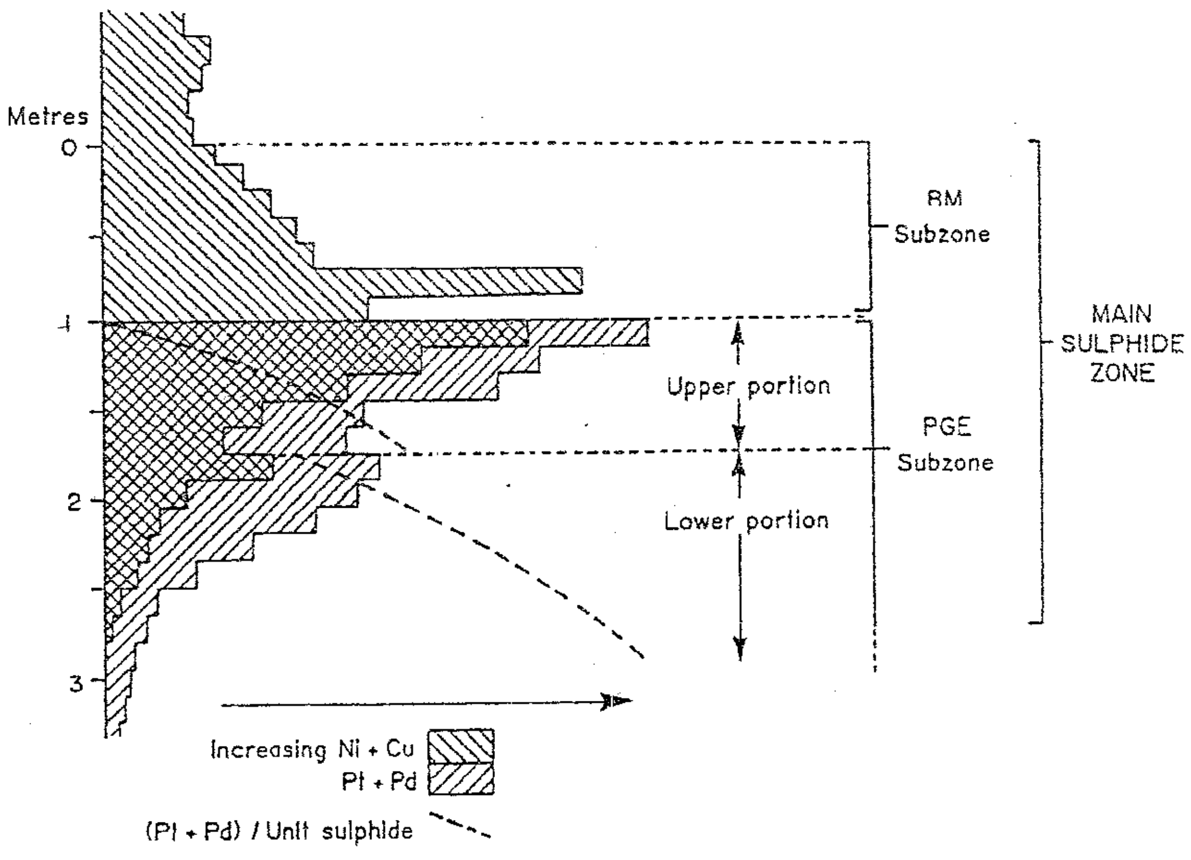


Fig. 1.1.9 Generalized vertical distributions of Cu – Ni and Pt + Pd through the Main Sulphide Zone (MSZ) of the Great Dyke. The MSZ is subdivided into a lower PGE subzone rich in Pt and Pd, and an upper BM (base metal) subzone with very low Pt and Pd contents. The PGE subzone can be further subdivided 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, chalcopyrite, 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, talc), 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 (RuS_2) and low temperature species such as moncheite ($PtTe_2$), merenskyite ($PdTe_2$), maslovite (PtBiTe), michenerite (PdBiTe), kotulskite (PdTe), polarite (PdBi), sperrylite ($PtAs_2$) 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 Ultramafic 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 lie immediately above, the basal chromitite layer, and are associated with very magnesian olivines (Fo_{92}). Olivine in Cyclic Unit 1 is more evolved and also shows a regular upward Fe enrichment trend from Fo_{91} to Fo_{87}. Orthopyroxene compositions display a steady upward Fe-enrichment through the Pyroxenite Succession. The most magnesian pyroxene is En_{91}. Near the top of the orthopyroxenite of the P1 layer, the composition is En_{85}. 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 re-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 SiO_2 and MgO contents. The compositions of the most magnesian olivine and cumulus orthopyroxene are $Fo_{92.0}$ and $En_{91.5}$, 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 $^{87}Sr/^{86}Sr$ 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% SiO_2 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.

Table 1.1.2. Composition of the East Dyke chill phase

	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_2O	1,77	1,54
K_2O	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
Co		70
S		541

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-clinopyroxene-plagioclase-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. (Coghill 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 outward 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).