CHROMITE GEOLOGY OF ZIMBABWE AND RELATED MINING CHALLENGES

PRESENTATION

GREAT DYKE : MUTORASHANGA

AUGUST 2017

WORLD CHROME RESOURCE

Estimate World Chromite Resource : +-12 Billion Tonnes

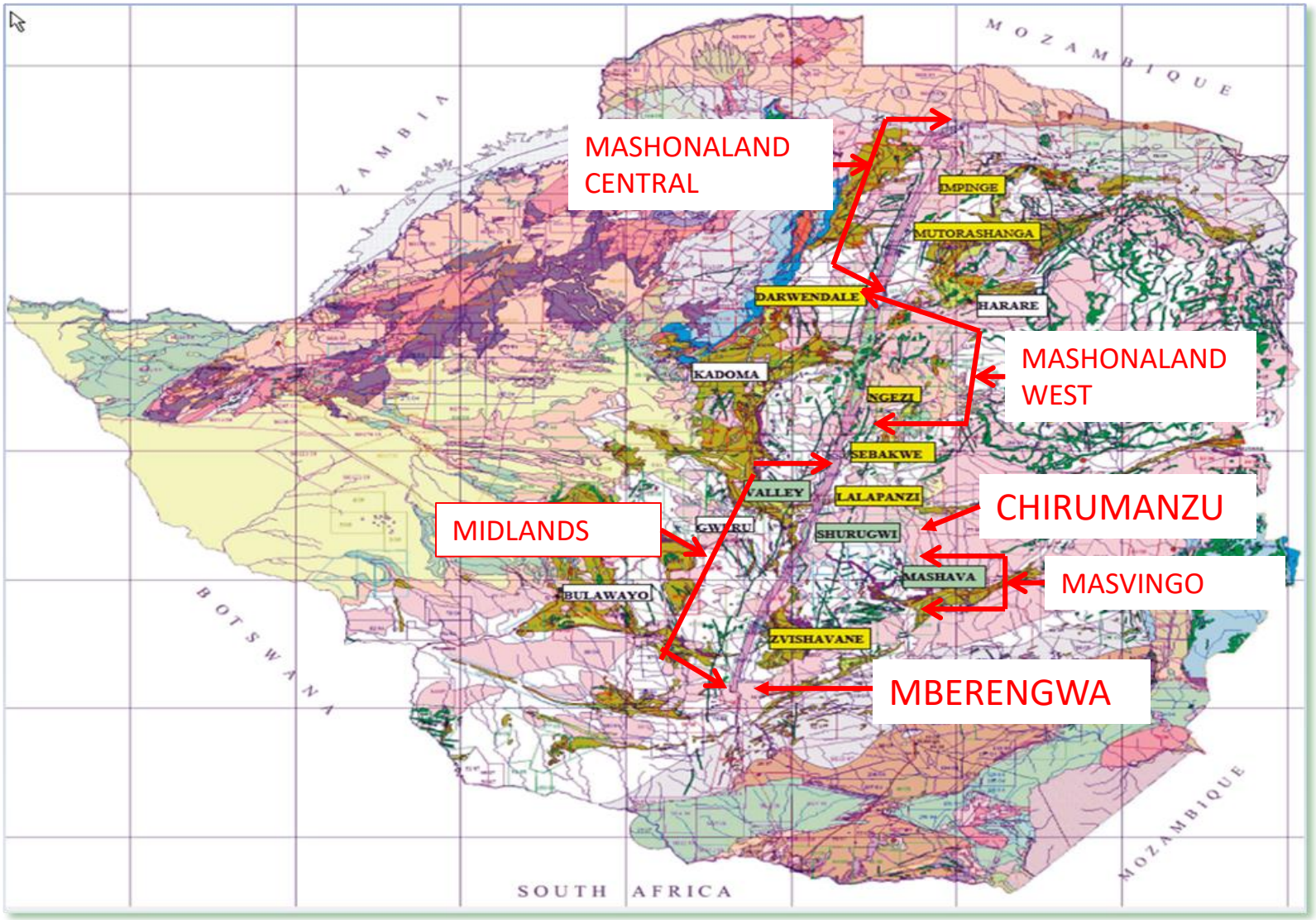
- South Africa : 72% of world Resource - Stratiform
- Zimbabwe: 12% -Stratiform & podiform
- Kazakhstan: 4% - Podiform
- Finland : 2% -Podiform
- India : 1% -Podiform
- Turkey and others : 9% -Largely podiform

But Zimbabwe companies producing at full capacity is not in the top 5 producing companies .

STRATIFORM & PODIFORM

GEOLOGY

LOCATION GEOLOGY MAP - ZIMBABWE



LOCATION OF STRATIFORM CHROMITE RESOURCE

- **Mashonaland Central**: **North Dyke**
  Tengenenge
  Impinge
  Birkdale
  Mutorashanga

- **Mashonaland West**: **Middle Dyke**
  Ngezi
  Darwendale
  Maryland
  Lembe/Mapinga
  Mutorashanga

- **Midlands**: **South Dyke**
  Lalapanzi
  Mapanzure
  Bannockburn
  CSC

LOCATION OF PODIFORM CHROMITE RESOURCES

- **Midlands**: Valley
  Nhema
  Chirumanzu
  Mberengwa
- **Masvingo:** Mashava

THE GREAT DYKE AND PODIFORMS GEOLOGY

Location

- **THE GREAT DYKE**
- Tengenenge to Mberengwa,
- Stretches for 550km and is 4-11km wide.
- **PODIFORM**
- Isolated chrome resources in Shurugwi,Mashava ,Nhema ,Valley, Chirumanzu and Mberengwa

Host Rock

- **THE DYKE : STRATIFORM**
- Chromite hosts rocks are :Harzburgite, dunite, serpentinite and pyroxenite
- **PODIFORM**
- Chromite host rocks are: Serpentinite ,Silicified Talc Carbonate and Talc Carbonate

Chrome Seams

- 10 known seams, The 11 th seam is poorly exposed in the North Dyke
- 8cm to 40cm thickness
- Average vertical spacing of seams is 30-40m
- Geotechnical Parameters considered fore seams are: Seam Widths, quality, dip, friability, & continuity

Known Minerals in the Dyke

- Platinum Group Metals
- Chrome
- Asbestos
- Nickel

CHROMITE RESOURCES

STRATIFORM (DYKE)

- The dyke intruded as an ultramafic sill ,estimated age 2.7 Ga .
- 11 seams are known to exist on the Great Dyke, but not evenly distributed through out the dyke.
- Dyke has been geographically sub-divided into North, Middle and South Dyke has approx. 85% of claims holding and 97% of Resource/Reserve

PODIFORM

- Podforms are estimated at 3 Ga.
- Podiform known resources are off the Dyke in Shurugwi, Mashava , Valley, Nhema, Chirumanzu and Inyala(Mberengwa).
- They constitute approx. 3% of Zimbabwe's chromite resource.
- Areas with chromite resources are scattered in the Southern side of Zimbabwe, mostly concentrated in the Midlands.

ELUVIALS

- Chrome fines generated from seams by a natural process of weathering.
- Eluvials chromite concentrations vary between 3 and 30% Cr_2O_3 in the soils where they form an anomaly. Depth of eluvials vary by area but maximum recorded is 2.5m.
- Eluvial are located along the margins of the Dyke or in the transverse valleys or along watercourses

GEOLOGY OF THE GREAT DYKE

(STRATIFORM)

EMPLACEMENT SEQUENCES

Karoo System

- Sedimentary rocks
- Unconformity
- Dolerite dykes

Great Dyke

- MAFIC SEQUENCE: Host to Nickel and PGMs
- Gabroic & Pyroxenite host rocks.
- ULTRAMAFIC SEQUENCE: Host to chromite
- Serpentine, & Harzburgites host rocks.

Basement complex

- Shamvaian: Sedimentary Rocks
- Bulawayan: Sedimentary and Ultramafic rocks
- Sebakwian: Silicified Ultramafic and sedimentary rocks

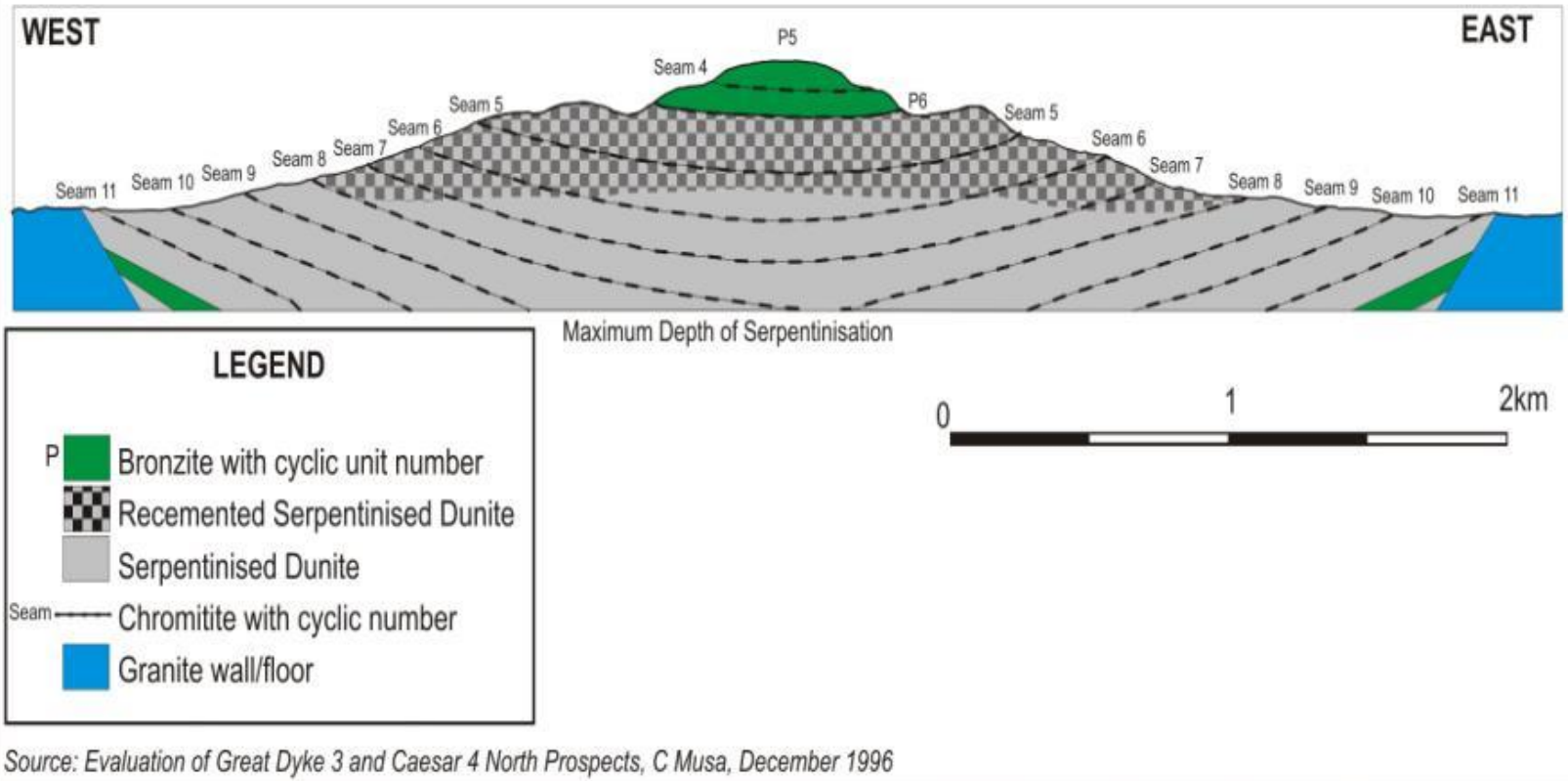
MAGMA SOURCE

- The Great dyke intrusion come from 4 magma chambers namely:
- Musengezi chamber
- Chegutu chamber
- Shurugwi chamber &
- Wedza chamber

Great Dyke Geology

- On cross section the dyke is a syncline structure and its strike length running North-South
- The seams follow the syncline structure out-cropping on both the Eastern and Western limp.
- The dyke is heavily faulted resulting in seams displacements and seam blanking.
- The outcropping dip for upper seams is shallower than that of lower seams.

CHROMITE OCCURRENCE IN THE GREAT DYKE SECTIONAL VIEW

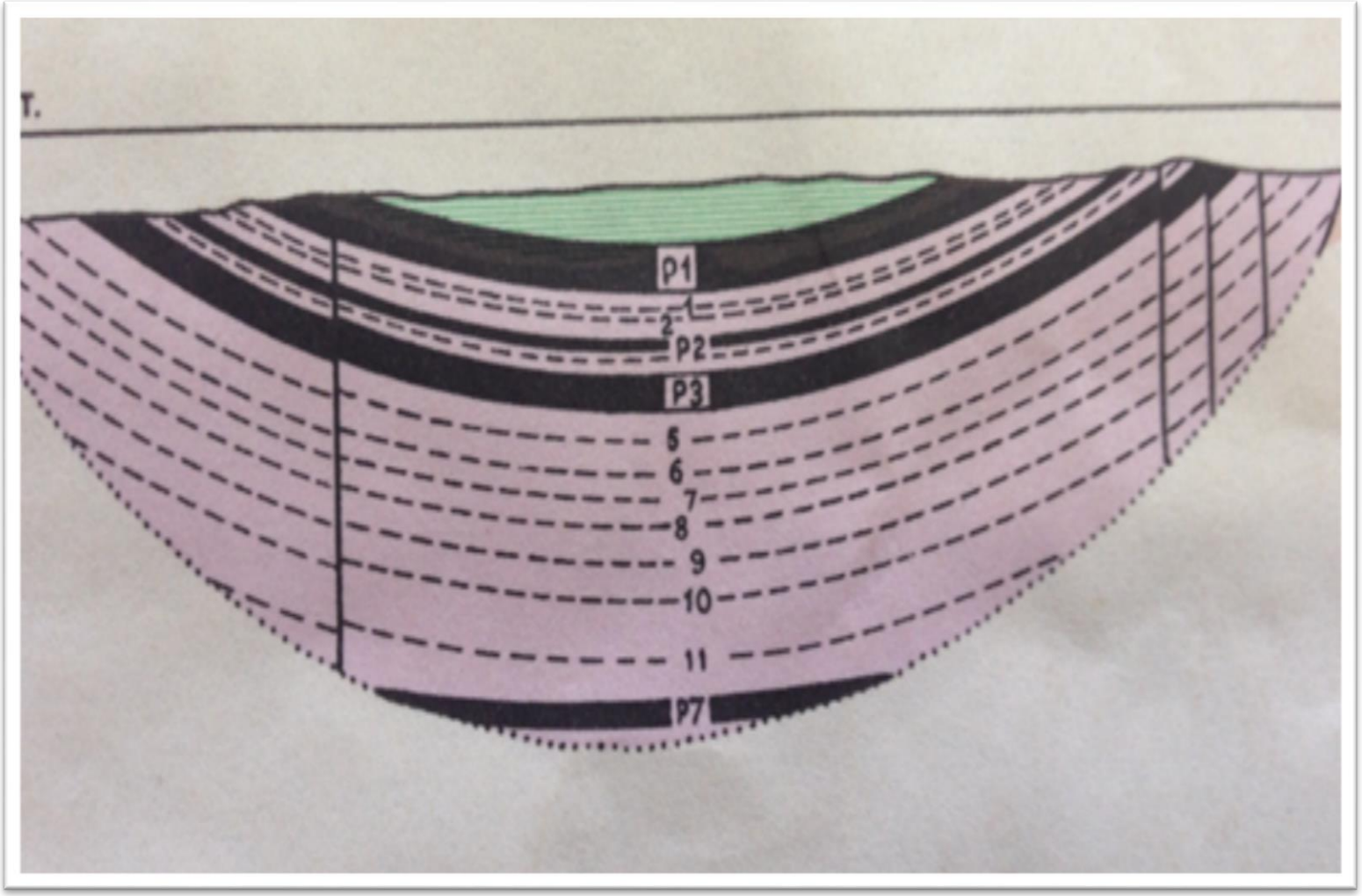


Source: Evaluation of Great Dyke 3 and Caesar 4 North Prospects, C Musa, December 1996

Cross Section Illustrating the Chromitite Seams of the Great Dyke

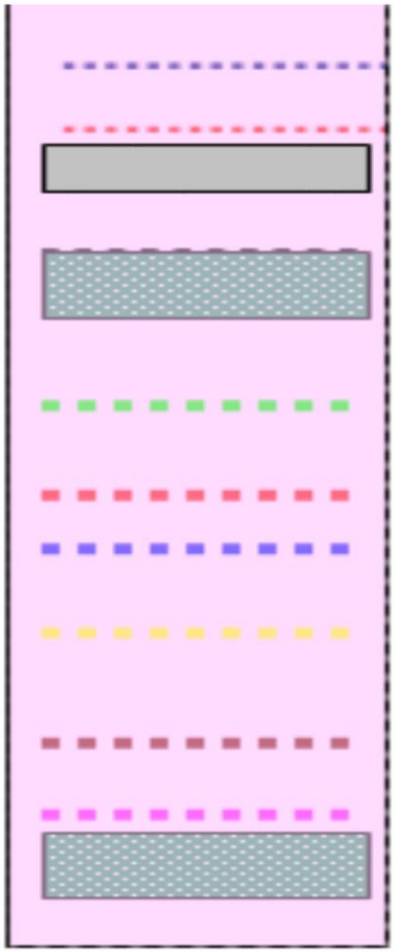
Date: July 2010

Dyke cross section



CHROMITE OCCURRENCE IN THE GREAT DYKE
PLAN VIEW

Seams Sequences



Seam 1

Seam 2 Pyroxene layer below seam

Seam 3 in some areas poorly developed in Harzburgite

Seam 4 in Serpentine
Pyroxenite band 6

Seam 5 in Harzburgite

Seam 6

Seam 7

Seam 8

Seam 9

Seam 10 in Harzburgite

Pyroxenite band 7
Seam 11 poorly developed
Harzburgite

SEAMS DISTRIBUTION

- NORTH DYKE: Tengenenge to Maryland
  Seams 4-10
  Seam 11 poorly developed
  Seam 1-3 eroded after faulting
  and uplifting
- MIDDLE DYKE: Ngezi-Darwendale (&Lydiates)
  Seams 1-4
  Seams 1-2 well developed but seam 3-4 localized in the
  Westen Limp
- SOUTH DYKE: Lalapanzi
  Seams 1-2 well developed.
  Seams 3-4 poorly developed
  South of Shurugwi
  Only seam 1

Critical Geotechnical Parameters for seams

- Quality: Cr_2O_3, Cr/Fe (S,SiO_2)
- Seam Thickness
- Seam continuity
- Dip
- Friability

Estimated Friability Parameters

Friable	25-60% fines generation
Lumpy	< 15% fines generation

Estimates from Zimasco exploration and mining data

CHROMITE RESOURCE IN DYKE

Type of Ore	Location	Area	Geology
Stratiform	(North Dyke) Mashonaland Central	Impinge D23	-Seams 4 to 10 are available in the North Dyke -All seams are being mined but seam 9 is the most preferred seam because of favourable geotechnical parameters. -Mineable seams have high quality ore , Cr2O3> 46 , Cr/Fe > 2.6 but average seam thickness 11cm (unfavourable). Average friability is 30% .Seam dip 27-35 degrees. Continuity around 87 %. - Most mining in the area is underground by incline shafts, winces and adits. Unit cost of mining is high. -**Additional Resource:Eluvial** Resource in localised flat areas
		Mutorashanga D25	-Seams 4 to 10 are available in the North Dyke, in Harzburgite -Mineable seams have an average thickness 11cm. - Seam qualities is same as in Impinge but Friability is > 90%. - Seam dip 27-35 degrees
		Shiela and Arthur's luck D23	-Seams 4-10 are available for mining, - Current mining is on seam 6 and 7 -Mineable seams have low seam thickness averaging 11cm. - Ore quality and dips is the same as in Impinge. -Areas have got Eluvial resources localised in flat areas.
		Maryland D23	-Mineable seams have high quality Cr2O3 >47% seam thickness averaging 11-12cm. Seam dip 27-35 degrees.- Seams 4-9 have been identified but the most preferred seams for mining are 5,6,7. Eluvial Resource localised in flat areas.

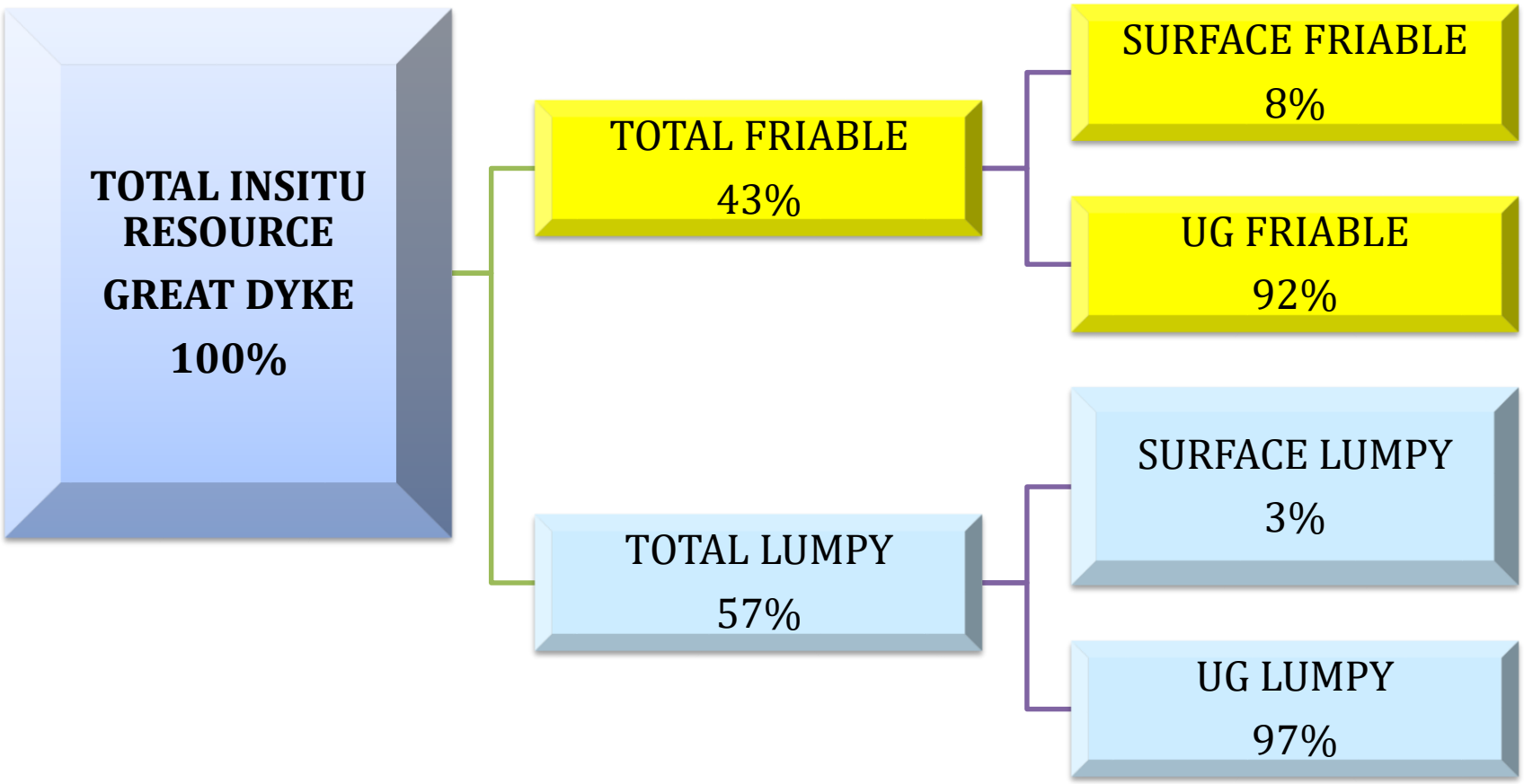
CHROMITE RESOURCE IN DYKE

Type of Ore	Location	Area	Geology
Stratiform	Middle Dyke	Ngezi D24	-Seams 1-4 are in Ngezi, Seam thickness ranging 18-24cm -Seams I and 2 are dominant and have favourable geotechnical parameters for mining. Seam 3 & 4 are localised and also have good quality Cr2O3>43%, Cr/Fe >2.4 - After years of mining the remaining resource is for underground mining operations. -The Northern side of Ngezi is characterised by high friability 25-30%. -Seam continuity is above 90% but dips range 18-22 degrees.
		Darwendale D30	-Seam 1 to 3 are dominant in Darwendale & Lydiates - Seam 1 & 2 are characterised by seam splitting. -Average seam thickness is 0.20 m with a quality of Cr2O3 =37-40 and Cr/Fe of 1.8-2.0. - Most of the open pittable resource has been mined. Seam continuity is greater than 88%. Dips range from 12-18 Degrees.

CHROMITE RESOURCE IN DYKE

Type of Ore	Location	Area	Geology
Stratiform	South Dyke	Lalapanzi D22	-Mining is on seam 1 and 2. Seam 3 and 4 are poorly developed. --Qualities average range Cr2O3,35-42 : Cr/Fe 2.0-2.2 - Seam thickness range 14-20cm. - Friability averages 20% with dips of 14 degrees - Seam continuity is around 80% because of blanking. There is high incidence of seam splitting on seam 1 - -There are Eluvials Resource in the area but of high iron content.
		South Of Shurugwi D22	-There is only seam 1. -Resource is both Lumpy and Friable ores -Quality ranges from 36-41% Cr2O3. Cr/Fe 1.9-2.2. -Dips range 5-15 degrees. Shallower ends being at the boat end. Seam is characterised by high magnesite content. Seam replacement by magnesite is common. - Seam continuity is greater than 85%

GREAT DYKE ESTIMATED RESOURCE SPLIT BASED ON FRIABILITY



GEOLOGY OF PODIFORM ORE BODIES

EMPLACEMENT SEQUENCES

Upper System	• Sedimentary rocks
Podiforms	• ULTRAMAFIC SEQUENCE: Host to chromite • Serpentine, Talc carbonates , Silicified Talc carbonates
Basement complex	• Gneiss and Tonalites

CHROMITE OCCURRANCE

Podiforms

- Ultramafic are the host rocks of chromite podiforms.
- Chromite layer was emplaced as a sill between the Sediments and Basement rocks
- After deposition the Ultramafic went through a series of structural deformation.
- This resulted in faulting and folding of the sill to form isolated chrome ore bodies (Pods)
- The significant pods are elongated (15-120m width) cigar shaped discontinuous lenticular ore bodies .
- Pods vary in shape , sizes and depth.
- They occur as dispersed pods in each area and some stretching in depth beyond 1.2 km

Critical Geotechnical Parameters for podiform are

- Quality: Cr_2O_3, Cr/Fe (S,SiO_2)
- Pod size
- Ore body orientation
- Friability
- Pod depth
- Shape of pod

ESTIMATED PODIFORM FRIABILITY

TOTAL INSITU RESOURCE PODIFORM

100%

FRIABLE RESORCE

3-6%

LUMPY RESOURCE

94-97%

FACTORS AFFECTING MINING

CHROME MINING IN ZIMBABWE

HISTORY

- Mining of Podiform resource has been for over 100 years.
- The known open pittable resource across the Great Dyke has almost been depleted. Isolated patches of mostly low grade and friable ores remain.
- The same applies for pods off the Great Dyke. World reknown Shurugwi ore bodies are almost depleted.

EXPLORATION

- In recent time there has been very little exploration in the country.
- For Zimasco less than 5% of the estimated resource has been explored
- Pods are inferred to be subsurface and require exploration through geophysical technics and diamond drilling.

CHALLENGES ASSOCIATED WITH NARROW SEAM UNDERGROUND MINING

PRODUCTIVITY CONSTRAINS

- The productivity of Shurugwi mines average 15t per man compared to 5t/man for dyke underground mines.
- Since the 1970s trials have been carried out to identify a high productivity and cost effective mining method for dyke narrow seam underground mining.
- To date no success has been registered
- This is an important project for the country as the future of chrome mining in Zimbabwe is, no doubt, underground.

REMAINING OPEN PITTABLE RESOURCE

- The remaining open pittable Resource lasts for less than 3 years.
- Future mining operations points towards underground mining which is costly in terms of initial Capex and unit costs.
- There is very little skill in the world on the cost effective Dyke narrow seam mining.

CHALLENGES ASSOCIATED WITH SEAM MINING

FRIABILITY

- The general trend and characteristic of chrome seams indicates that there is an increase in friability of chrome ores with depth.
- Friability of ores in the North dyke where, for Zimasco, the biggest resource is found is generally high, above 30%. This calls for investments in agglomeration and/or closed furnaces.
- Mining of ores with high friability is a challenge because of screening involved since the fines and lumpy ores are transported and consumed separately.
- Most operating furnace in Zimbabwe do not take fines as feed due to the dangers of furnace erruptions.
- Significant capital outlay is required by ferrochrome companies to invest in closed furnaces or Sinter plants that can utilise fines.

SEAM QUALITY

- North Dyke where the biggest dyke resource is has the high ore quality Cr_2O_3> 48% Cr/Fe >2.6.
- Middle and South Dyke where seam thickness is better, the quality is moderate Cr_2O_3 ranging 35-42% , Cr/Fe 1.8-2.2.
- Quality is variable for the same seam in different areas. Generally where the seam is thicker the quality is lower.

CHALLENGES ASSOCIATED WITH SEAM MINING

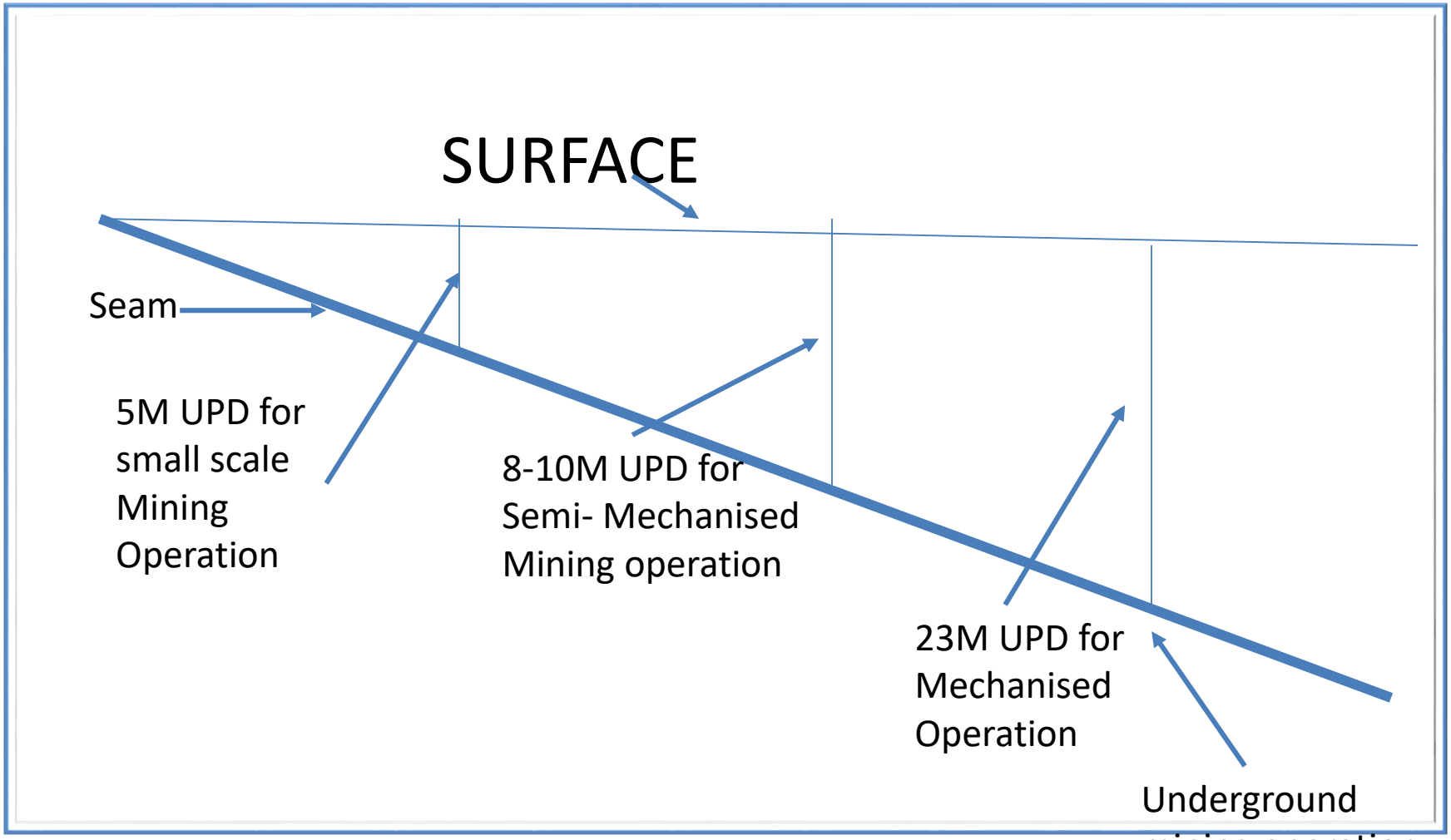
SEAM DIP

- In the Middle and South Dyke where seam dip is less than 22 degrees open pit mining can go up to a UPD of 23m depending on the market prices of Ferrochrome.
- There are some areas in the Middle and South Dyke where the dip is quite steep at 22-24 degrees resulting in high stripping ratios.
- In the North Dyke where the dips are above 24 degrees only underground mining is cost effective and practiced.
- Dips have got an effect on the unit mining cost, mining method, UPD achieved, Mining depth and productivity.

SEAM CONTINUITY & SPLITTING

- Seams 1-4 in different areas suffer from seam continuity as a result of seam blanking, faulting and replacement.
- The seam mostly affected by seam low continuity is seam 1.
- Seam splitting is common on seam 2 in the Middle and South Dyke. It has waste middlings in between the upper & lower seam. The upper split is thinner less than 8cm but of high quality. Whilst the lower split is of low quality but thick >14cm.
- Both seam splitting and continuity have got an effect on unit mining cost and productivity.

SURFACE STRIPPING: REHABILITATION REQUIREMENTS



REHABILITATION

REHABILITATION

- The three stages of surface mining are: manual mining, semi-mechanised and fully mechanised mining.
- Open pit mining depths range from 3m to 23m.
- After the mechanised open pit mining the next stage leads to underground mining with the use of shafts and hoisting equipment.
- Full rehabilitation is carried out after fully mechanised strip mining.

CONCLUSION

- An estimated 95% of the country's chrome resource occurs in the Great Dyke
- Almost all of the resource suitable for surface mining has been mined over a period of over 100 years of mining chrome in and off the Great Dyke.
- So far efforts to identify the optimum method for narrow seam underground mining have failed.
- It remains a threat to the ability of the country to benefit from this huge resource.

THANK YOU

NORTH DYKE MINING CHALLENGES

ADIT MINE

- Ore has high Friability requiring lots of screening
- Seams dips ave 32 degrees are high/steep resulting in limited hoisting depth. Terrain is unfavourable for ores movements.
- Production is less than 100 tonnes per month.
- Mining is manual and labour intensive

WINCH MINING

- High friable ores requiring lots of screening .
- High seam dips and unfavourable working terrain.
- Mining depth is limited to a maximum of 80m because of steep dips.
- Production is less than 250 tonnes a month because of small seam thickness unfriendly geological parameters.
- Generator and a hoist required to power up.

UNDERGROUND MINING

- High friable ores requiring screening
- Seam continuity ranging 80-90% affecting productivity.
- Unit cost of Mining is high because of seam low thickness, faulting and the above parameters.
- Underground mining area is limited by Hoist capacity, claims boundaries and geological features.

MIDDLE DYKE MINING CHALLENGES

SMALL SCALE AND SEMI-MECHANISED OPEN PIT MINING

- High variation in Ore quality.
- Open pittable areas depleted.
- Low seam thickness in some areas affect productivity.

MECHANISED OPEN PITS

- High variation in quality.
- Open pittable areas almost depleted. Remaining can feed the 5 Furnaces configuration for one year
- The remaining areas have been mined to 12 m UPD.

UNDERGROUND MINING

- High friable ores requiring screening in some areas.
- Seam continuity ranging 90-95% affecting productivity.
- Unit cost of Mining is high because of seam low thickness, faulting and the above parameters.
- Underground mining area is limited by hoist capacity, claims boundaries and affected by geological features.

SOUTH DYKE MINING CHALLENGES

SMALL SCALE AND SEMI-MECHANISED OPEN PIT MINING

- High variation in Ore quality. Low quality seam 2 in Lalapanzi.
- Open pittable areas almost depleted. The significant open pittable resource is in Lalapanzi
- Low seam thickness in some areas affect productivity.
- The available open pittable resource can last for 2 Years on a 5 Furnace production.

MECHANISED OPEN PITS

- High variation in quality. Open pittable Resorce in the South of Shurugwi is friable.
- Open pittable areas almost depleted. Remaining can feed the 5 Furnaces configuration for 1.5 years
- The remaining areas have been mined to 12 m UPD.

UNDERGROUND MINING

- High friable ores requiring screening in some areas.
- Seam continuity ranging 80-90% affecting productivity.
- Unit cost of Mining is moderate- high because of seam thickness, faulting and the above parameters.
- Underground mining area is limited by Hoist capacity, claims boundaries and affected by geological features.

PODIFORM MINING CHALLENGES

OPEN PIT AND UNDERGROUND MINING

- Very little or no knowledge of the remaining resource because of lack of exploration information
- Known Open pittable resource was depleted.
- Exploration required is Geophysics and Diamond drilling.
- Current underground mining of pillars and deep seated ore bodies is expensive.