CHAPTER 1: INTRODUCTION

1.1 GENERAL INTRODUCTION

The six platinum group elements (PGEs); platinum (Pt), palladium (Pd), rhodium (Rh), iridium (Ir), ruthenium (Ru) and osmium (Os), together with gold (Au) and silver (Ag) are classified as precious metals. Also referred to as “noble”, due to their lack of reactivity with mineral acids and oxygen [1], these metals have played a role in the development of society which, for gold and silver in particular, can be traced back to ancient times. Gold and silver were well known to the Greeks and Romans and were used in jewellery and extensively in trading.

Although officially platinum was first discovered in America in 1735 in the Pinto River, New Granada (or Colombia as it is known today) and christened “Platina del Pinto”, more surprisingly, ornaments forged from platinum by Indians native to Ecuador and Columbia, dating from considerably before 1735, are on display in museums in Denmark and Columbia [2].

Excluding gold and silver and exhibiting unique properties, platinum and palladium are the most widely used in today’s modern society and are considered as the most important precious metals followed by rhodium, ruthenium and iridium and to a lesser extent osmium. The special properties of platinum and palladium (and rhodium to a degree) include high density, strength, durability, high melting points, resistance to corrosion and catalytic qualities which have enabled these metals to be exploited in a series of diverse industrial applications such as diesel and petroleum autocatalysts, electronics, glass manufacturing and the chemical sector. The relative scarcity thereof, only around 185 (one hundred and eighty five) tonnes of platinum are mined and refined worldwide per annum [3], also make these metals progressively sought after for jewellery and for Exchange Traded Funds (ETF’s) for investment.

America, the world’s first producer of platinum lost its position as the major producer of precious metals to Russia who then lost it to South Africa after the discovery of the Merensky Reef by Hans Merensky in 1924. South Africa today supplies over 80% (eighty percent) of the world’s platinum needs, followed by

Russia, which remains the world's second largest supplier of platinum and is the world's largest producer of palladium. Canada the world's third largest producer of platinum, produces the metal as a by-product from nickel-copper mining. [2,4]

1.2 BACKGROUND OF THE STUDY

1.2.1 Sources of precious metal deposits in Southern Africa

The world's largest known deposits of Platinum Group Metals (PGEs) are concentrated in the Bushveld Complex (BC), which extends for more than 400 km in the northern parts of South Africa. The BC is divided into eastern, western as well as northern and southern limbs and includes two major PGM bearing narrow-seamed reefs, namely the Merensky and Upper Group 2 (UG2) Reefs. The Merensky Reef, which is estimated to contain some 17 000 tons of PGMs has been successfully exploited since its discovery by Hans Merensky in 1924 and until the late 70's comfortably met the larger percentage of the world's demand for platinum. [5]

All, that however, was to change in the 1980's when growth in the PGM market driven by expanded use in jewellery and autocatalyst fields, required that new sources of PGMs be found and developed. By then, most Merensky ores that could be accessed were either too deep or patchy in grade, or were in areas where the development costs were likely to be high. It was an obvious step therefore to look more closely at the shallow UG2 Reef (which plays host to the precious metal components which are the subject of this dissertation) that could be accessed from the existing Merensky mine infrastructure.

1.2.2 Multidiscipline – Challenges and opportunities of the UG2 Reef

While this dissertation focuses on challenges to the chemistry discipline presented by continued exploitation of the UG2 Reef, it is well understood that quality assurance is fundamental to commercial evaluations of data, be it in the fields of geology, mining or the metallurgical extraction processes. As such it is essential to illustrate just a few of the early challenges presented to the latter disciplines following the first exploitation of the UG2 Reef in its own right by Lonmin at

Western Platinum in 1983 [6]. Not surprisingly these were as a result of the physical and the mineralogical differences between the UG2 and Merensky Reefs the most notable of which are as follows:

- The UG2 Reef underlies the Merensky Reef by almost 150 m in the western and 400 m in the eastern limb of the BC [7].
- The relative density of UG2 ore is much higher than Merensky ore [6].
- The UG2 Reef generally has a much higher chromite and a much lower base metal content [6].
- Whereas PGM grades are similar in both reefs, the UG2 Reef contains typically four times the rhodium grade [7].
- The particle or grain size of PGMs in UG2 ore is generally much smaller than the equivalent in Merensky ore [7].

Commercially this meant:

- That by-product revenue from copper and nickel would be much lower for UG2 as compared to Merensky ore [6, 7]. However, growth in autocatalyst demand, referred to above, also created a rising demand for rhodium, an essential component of the autocatalyst "washcoat" mix. According to the Johnson Matthey annual report [3], the rhodium price is consistently higher than the other PGM market prices which periodically would mean increased revenues for rhodium may outweigh the associated loss in revenue for nickel and copper.
- Obvious cost-of-mine savings from utilising existing Merensky mine infrastructure to access shallow UG2 reserves which would be further enhanced by the higher relative density of UG2 ore resulting in improved tonnage to volume ratios [6].

In accordance with the processing route, the early UG2 challenges and opportunities were as follows:

1.2.2.1 Mining operations

- Mine support would be complicated and challenging as a result of the three pyroxenite bands above the UG2 Reef [6].
- The width, depth and greater regularity of the UG2 Reef would provide more opportunity for mechanised mining thereby reducing the degree of manual labour required [7, 8].
- The greater predominance of PGM fines in the UG2 ore would mean during mining that friability of the ore would result in some of the PGM minerals being liberated into the fines. As such, some of the UG2 mines made use of industrial cleaners for final clean-up. However in the flotation concentrating step to follow, floatability decreases below a minimum particle size and as a result the use of mining methods to minimize the production of fines had to be given due consideration [7].

1.2.2.2 Mine Concentrators and the flotation process

Chapter 3 provides a detailed summary of the mineralogy of the UG2 Reef and its component PGMs and explains the process of concentration. It is sufficient therefore to say that the flotation circuits as existed in the early 80’s were designed to recover the PGM minerals associated with base metal sulphides in Merensky ore. The challenge therefore was to design flotation circuits for the very different characteristics of the UG2 ores. The objectives were to:

- maximise PGM recoveries despite the much reduced grain size of both the base metal sulphides and single grain PGMs.
- minimize chrome recovery as significant quantities of chrome in the resultant Concentrate would present problems to the downstream smelting processes as then existed [8].

On a positive note, the absence of significant talc minerals, which have a detrimental effect on Merensky Concentrate grades, presented an opportunity for much higher UG2 Concentrate grades [9] thus together with much lower nickel and copper grades would reduce Concentrate volumes which in turn would result in significant savings in smelting costs [6].

1.2.2.3 The smelting process

The six-in-line rectangular electric furnaces as existed in the early 80's were ideal for the smelting of Merensky Concentrate where the substantial density differences between PGM rich base metal sulphides and oxide minerals (gangue) facilitated the formation of distinct matte and slag phases. In the absence of substantial base metal sulphides in UG2 Concentrate, the challenge was to achieve complete coalescence of the small amount of dispersed matte which would be formed [6, 7]. Secondly, as referred above, recognising the presence of higher chrome content in the UG2 Concentrate it was expected that this would create three basic problems for the smelting operation: [5]

- Since chromium has a limited solubility in slag, increased feed concentration was expected to lead to the formation of crystalline chromite spinel. As spinels have high melting points and are dense, they were likely to settle on the furnace hearth resulting in reduced furnace volume. And as these species are of intermediate density (between matte and slag) they would form a mushy layer at the matte-slag interface [10].
- The high melting point due to the refractory nature of spinels would lower the fluidity of the slag which would lead to furnace tapping problems.
- Higher chrome concentrate would also result in decreased electrical conductivity which would lead to electrical control problems in traditional furnaces.

In response, higher temperatures coupled with judicious mixing of high sulphide low chrome Merensky Concentrate meant that, satisfactory coalescence was achieved with acceptable dissolution of the chrome present in the slag [6]. Higher temperatures implicitly meant higher unit power consumption, but this was ameliorated by the much reduced volume of higher grade UG2 concentrate.

1.2.2.4 Laboratory operations

The function of laboratories within the mining industry is to report quality results that are traceable to international standards such as ISO 17025. The platinum mining laboratories make use of Lead Fire Assay (Pb-FA) and Nickel Sulphide (NiS-FA) fusion techniques in order to remove the matrix of complex ores and to pre-concentrate the PGMs prior to analysis. While, these methods are very expensive, tedious, time consuming, labour intensive and of old technology, they are still the most reliable methods for precious metal analysis today.

The complete dissolution of the UG2 Reef material has been a challenge from the early days of UG2 mining. The flux used in NiS-FA fusion techniques is effective for sulphide and silicate minerals, but is less effective for the complete dissolution of chromitite crystals, which are more refractory in nature resulting in viscous slag which contains chromitite crystals or grains. [11] Much progress has been made in optimising fluxes and techniques used for the existing processes. For the analytical chemist to develop methods they require a thorough understanding of the composition of the material to be evaluated.

1.2.3 Multidiscipline – Future challenges and opportunities of the UG2 Reef

The success of all disciplines within the mining industry is borne out by the rapid change in mining mix between Merensky and UG2 ore for all the major platinum producers: Anglo Platinum, Impala Platinum, Lonmin and Northern Platinum since the initial exploitation of the UG2 Reef in 1983 with the percentage of UG2 ore being mined increasing at the expense of Merensky ore.

As a result, it is well documented that the greater volume of new PGM production which is currently coming on stream and that which is planned for the future shall come from the UG2 Reef [8]. None-the-less, a future where UG2 platinum mining shall be dominant shall present further challenges and opportunities.

Future challenges shall include:

1.2.3.1 Concentrators and the flotation process

Although much success has been achieved in establishing economically acceptable PGM Concentrate recoveries from UG2 ores, such recoveries still remain variable from region to region and still in general lag recoveries achievable for Merensky ores. There remains considerable scope for UG2 recovery improvements, be that through specialised milling and grinding processes and/or through other processes to further liberate PGMs (indirectly the subject matter of this dissertation) or through additional scavenging circuits.

1.2.3.2 Smelting process

As above, some of the issues associated with the smelting of UG2 Concentrate have been addressed by smelting with Merensky Concentrate. However, as the volume of the latter systematically reduces there may be a need for processes which can comfortably smelt UG2 Concentrate in isolation. Considerable work by the major producers and others has already gone into alternate furnace design and into alternate processes, the most recently being “Conroast” technology. The Conroast process does not follow the traditional matte smelting route. It consists of a two-stage process: a dead-roast sulphide Concentrate with complete sulphur capture and a reduction smelt with an iron alloy collection.[12,13] Whilst, it is more environmental friendly as it involves no SO_2 emissions and while it can process material with higher chrome content than is possible in traditional furnaces, its primary product is an iron alloy requiring of specific downstream processing. Such alternate processes remain in their infancy, by way of comparison, the current “Conroast” furnace has a processing capability of around 2000 tonnes per month of Concentrate as compared to the larger 38 MVA six-in-line processing copper cooled furnaces at Impala and Anglo Platinum which each have a processing capability of up to 35 000 tonnes per month of Concentrate. [12]

Future opportunities shall include:

1.2.3.3 Platinum mine tailings Retreatment

It would be fair to say that commercial focus during the initial exploitation of the UG2 Reef was on the development of processes which would generate acceptable PGM recoveries. However, PGM prices in particular the platinum price, have been rising from $ 250/oz in 1983 to typically $ 1500/oz in 2010 [3]. As a result, companies such as Sylvania Resources Limited (SRL) have began to target the platinum mining Tailings dams (which contain about 2.6 g t^{-1} PGM) held by the major producers as a means to grow Sylvania's PGM production profile through retreatment. [14, 15]

1.2.3.4 Ferrochrome operations

In parallel to rising PGM prices, chromium prices have also risen considerably. Chromium, a mineral which was as first, at least by the PGM producers, considered of nuisance value, has become a valuable by-product. The world market for chromite ($FeO.Cr_2O_3$) is driven primarily by the world's demand for ferrochrome used in stainless steel. South Africa remains the world's largest single producer of ferrochrome and supplies much of the world's stainless steel demand and thus the growing market for their product [16]. South African chromite reserves are also part of the BC where several chromite seams represent probably more than 75% of the world's economic resources. [17] Chromite seams which have been exploited specifically for ferrochrome are the LG6 and MG1/2 seams which have a higher Cr/Fe ratio than that in UG2 Reef. Nevertheless, as the cost of mining deeper LG6 and MG1/2 ores increases, the availability of up to 20 million tonnes per annum of UG2 chrome Concentrate from UG2 tailings, containing 40-42% chrome oxide (as by-product of PGMs mining), shall become more attractive to ferrochrome producers and as a result, more and more UG2 sourced chromite shall ultimately be utilised in ferrochrome production. [16]