

https://dspace.org/

The impact of increasing platinum supplies on the industry in South Africa

Odendaal, Nicolaas Johannes

1992
https://hdl.handle.net/10539/27839

Downloaded from a DSpace repository. https://dspace.org/

THE IMPACT OF INCREASING PLATINUM SUPPLIES ON THE INDUSTRY IN SOUTH AFRICA

Nicolaas Johannes Odendaal

A dissertation submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in fulfillment of the requirements for the degree of Master of Science in Engineering

Johannesburg, 1992

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.



11 day of June 1992

ABSTRACT

Platinum, the major metal recovered by the platinum mines in South Africa, is unusual among metals in that its commercial applications are limited to three major sectors, namely, autocatalysts, jewellery and investment. Hence, any degree of change in these sectors will either result in a rapid flooding of the market and a drop in the price, making it uneconomic for mines to continue to operate or, on the other hand, create a shortage.

The purpose of the study is to determine the future changes in the fundamentals, the effect thereof on the price of commodities produced by the platinum mining companies, and the consequent changes in the South African platinum industry.

The study was done mainly through literature research and empirical data. The latter were used to find correlations between prices, and supply and demand, in order to determine the price up to the year 2000. These price forecasts were used in calculating the revenue for each mine at a specific production rate.

Final evaluation of the mines was done by applying various techniques to determine the status of the mines.

It is concluded that future entry will be more difficult due to a moderate increase in the price of PGM. However, after the closure of certain new mines and prospects in South Africa, high cost producers who are able to implement effective cost saving measures to survive the recession periods, will be ensured of a flourishing future.

ACKNOWLEDGMENTS

At the completion of the dissertation, I should like to express my sincere appreciation to each one who made a contribution, in particular:

* to my supervisor, Dr M A von Below, for his guidance and assistance.
* the language editing by Mr D S Smit
* the Minerals Bureau for facilitating the completion of the dissertation.

A special thanks to my wife Rika for her inspiration and support in the years of study.

CONTENTS

		Page
DECLARATION		ii
ABSTRACT		iii
ACKNOWLEDGMENTS		iv
CONTENTS		v
LIST OF FIGURES		vii
LIST OF TABLES		viii
1	INTRODUCTION	1
1.1	Statement of the Problem	1
1.2	Purpose of the Study	2
1.3	Justification of the Project	3
1.4	Limitations of the Project	3
1.5	Preview of the Organisation of the Remainder of the Thesis	4
1.6	Resumé	4
1.7	Sources of Data	6
2	PRICE FORMATION	7
2.1	Introduction	7
2.1.1	Supply	10
2.1.2	Demand	11
2.2	Metal Price Forecast	14
2.2.1	Platinum	14
2.2.2	Rhodium	34
2.2.3	Prices of Other Metals	34
3	AN ANALYSIS OF FUNDAMENTALS OF THE PLATINUM INDUSTRY IN SOUTH AFRICA	38
3.1	The South African Platinum Industry	38
3.1.1	Progress of the Industry	38
3.2	The Mining Operation in South Africa	43
3.2.1	Mining Methods	43
3.2.2	Concentration, Smelting and Refining	45
3.3	Evaluation of the Mining Companies	46
3.3.1	Cost	47
3.3.2	Ore Grade and Revenue Distribution	49
3.3.3	Revenue	50
3.3.4	Profit	50
3.3.5	Profit/Revenue	56
3.3.6	Profit/Cost	57
4	SUMMARY AND CONCLUSION	65
4.1	Introduction	65
4.2	Platinum-Group Metal Supply, Demand and Price Forecast	66
4.3	The Platinum-Group Metal Industry	66

CONTENTS Page

APPENDIX 1 SOUTH AFRICAN MINE PRODUCTION - FORECAST 71

APPENDIX 2 RESULTS OF SUPPLY AND DEMAND FORECASTS 72

APPENDIX 3 METAL PRICE FORECASTS 73

APPENDIX 4 MINE EVALUATION PARAMETERS 74

REFERENCES 83

LIST OF FIGURES

Figure		Page
2.1	Percentage Contribution by Each Metal to the Revenue of Mines, 1991	9
2.2	South Africa's Production of Platinum-Group Metals, 1989-2000	18
2.3	Secondary Recovery of Platinum and Rhodium from Autocatalysts, 1982-2000	22
2.4	World Demand for Platinum by the Autocatalyst Sector, 1985-2000	25
2.5	Demand for Platinum by the Jewellery Sector, 1976-2000	27
2.6	Projected Demand for Platinum in the Fuel Cell Sector, 1980-2000	30
2.7	Price Forecast for Platinum, 1976-2000	33
2.8	Price Forecast for Palladium, Ruthenium, Iridium and Rhodium	35
2.9	Price Forecast for Gold, Nickel and Copper	36
3.1	Flow Diagram: South African Platinum Industry, 1991	44
3.2	Cumulative Tons Milled vs Cost/t & Cost/kg Platinum Produced	48
3.3	Contribution to Revenue by Platinum-Group and Base Metals, 1991	51
3.4	Cumulative Tons Milled % vs Revenue/t	52
3.5	Cumulative Tons Milled vs Profit/t	53
3.6	Relation Between Revenue, Cost and Profit	58
3.7	Influence of Revenue on the Profit/Cost-Factor and Consequent Change in Profit	63

LIST OF TABLES

Table		Page
2.1	World Production of Platinum-Group Metals	11
2.2	Western World Demand for Platinum, Palladium and Rhodium, 1990	12
2.3	Proportion and Recovery Grades of PGM + Au and Mineralized Layers of the Bushveld Complex	15
2.4	Linear Regression Analyses of Price of Platinum on the Supply-Demand Balance from 1976 to 1990	32
3.1	Profit/Cost-factors for all PGM Producers	60

CHAPTER 1

1 INTRODUCTION

1.1 Statement of the Problem

During the seventies and early eighties the Western market relied almost entirely on a single source of platinum-group metal (PGM) supply, controlled by an oligopoly of only three producers: Rustenburg Platinum Mines Ltd, Impala Platinum Ltd and Western Platinum Ltd. These mines accounted for almost all of the total South African production of 132 t in 1989.

The producers have generally been secretive about technical information such as ore grades, PGM proportions and working costs, probably as part of the companies' market strategy. This made it difficult for other companies to estimate the floor price and the revenue generated.

During the early 1980's, however, global demand for platinum increased dramatically, which led to a short supply of platinum. Increased demand from three sectors, namely autocatalysts, jewellery and investment demand (which accounted for nearly 86 per cent of the total Western World demand), gave rise to an increase in price. Demand for autocatalysts became important in the control of exhaust emissions from motorcars in America, Japan and Europe. As an investment, platinum enjoyed great popularity, especially in the East, where the Japanese developed a great affinity for the purity of the metal. This favourable climate led to worldwide exploration for platinum resources. Furthermore, research by MINTEK in South Africa, opened new grounds for the development of the UG2 Reef. Other mining companies

realised the opportunities that existed and since then several announcements of new ventures have been made by a diverse group of entrepreneurs.

In 1990, however, it was realised that demand was not enough to absorb all the platinum entering the market and at the end of that year an oversupply of 70 000 ozt was recorded. Drastic price declines of all metals occurred, aggravated by the world economies entering a recession period. Cash flows of mines were negatively affected, causing three new mines to cease development or production and established mines to scale down expansions.

1.2 Purpose of the study

The purpose of the study is to find ways of forecasting PGM and by-product prices and to determine the impact of these price changes on developments during the next few years until the year 2000.

This will be of the utmost importance to the investor who performs feasibility studies on producing and developing mines. Different opinions exist on developments in the platinum industry during the next decade. These range from a slight oversupply to more severe expectations of a negative platinum to gold premium and temporary suspension of expansion programmes and closure of mines.

If catastrophic events are excluded, a possible trend in the fundamentals of platinum could be determined in order to find a significant price-path which in turn will influence production.

1.3 Justification of the Project.

This project is much needed by the platinum industry at this stage, because of the lack of information that exists at a time when the market is in oversupply. It could play an important role in future planning by Government and could assist the mining companies in drawing up their market strategies during this lean period. The investor, in particular, finds it difficult to judge the financial positions of the platinum companies correctly, which acts as a negative stimulus for investment in the platinum market.

1.4 Limitations of the Project

A sound overview of production statistics was necessary, but these were not obtainable from some of the producing mines and were derived from previous research documents and recent publications.

The geographical isolation of South Africa from world markets and lack of prompt news, generally make it more difficult to estimate demand than supply. Reliable sources like Johnson Matthey's 'Platinum' and newsletters published by the Platinum Guild International and International Precious Metals Institute, acted as valuable sources of reference.

It is recommended that further investigation be undertaken to perfect a model of supply and demand, to act as a basic tool in the platinum industry to make better predictions on supply and demand balances.

1.5 Preview of the Organization of the Remainder of the Thesis

Platinum supply and demand and market share in the industry is discussed in Chapter 2. The South African producers and the price behavior of the different metals mined by these mines is emphasised. This is followed by a presentation of the South African Platinum Industry in Chapter 3, and a closer evaluation of the South African platinum mines. A summary and conclusion is presented in Chapter 4.

1.6 Resumé

During the last decade, figures released by research organisations were generally based on empirical data and research done by Wagner (1929), Von Gruenewaldt (1977) and Buchanan (1979).

In his publication, 'Platinum Deposits & Mines of South Africa', PA Wagner's main object was to describe the platinum-bearing deposits in the Transvaal and to draw attention to their enormous economic possibilities, which, at that stage, were not exploited to their full potential. This work by Wagner was used as reference by several researchers and is a primary source of information.

Wagner's geological description of the occurrence of the platinum-group metals is very detailed and is used later in the thesis as a criterion to determine the production of some of the platinum mines in the different localities of the Bushveld Complex. Valuable information regarding the grades and ratios recorded by Wagner, is found in the later work done by Von Gruenewaldt.

1.5 Preview of the Organization of the Remainder of the Thesis.

Platinum supply and demand and market share in the industry is discussed in Chapter 2. The South African producers and the price behavior of the different metals mined by these mines is emphasised. This is followed by a presentation of the South African Platinum Industry in Chapter 3, and a closer evaluation of the South African platinum mines. A summary and conclusion is presented in Chapter 4.

1.6 Resumé

During the last decade, figures released by research organisations were generally based on empirical data and research done by Wagner (1929), Von Gruenewaldt (1977) and Buchanan (1979).

In his publication, 'Platinum Deposits & Mines of South Africa', PA Wagner's main object was to describe the platinum-bearing deposits in the Transvaal and to draw attention to their enormous economic possibilities, which, at that stage, were not exploited to their full potential. This work by Wagner was used as reference by several researchers and is a primary source of information.

Wagner's geological description of the occurrence of the platinum-group metals is very detailed and is used later in the thesis as a criterion to determine the production of some of the platinum mines in the different localities of the Bushveld Complex. Valuable information regarding the grades and ratios recorded by Wagner, is found in the later work done by Von Gruenewaldt.

In 1977, Von Gruenewaldt, Professor and Director of the Institute of Geological Research on the Bushveld Complex, revealed some of his findings on the Bushveld Complex. He tried to identify the growth rate of production of platinum in the Bushveld Complex, in an effort to calculate the remaining life of the resource. His report contains information regarding the thickness of various seams, and the in-situ and recoverable grades of the platinum-group metals of the three platinum-bearing horizons of the Bushveld Complex namely, the Merensky Reef, UG2 and the Platreef.

More recently, Buchanan (1979), placed PGM production from the Bushveld Complex in relation to world markets. He calculated the revenue distribution from the Merensky Reef in the Rustenburg area, and pointed out the importance of the resource, being a source of primary platinum production, by contrast to other countries. In Canada and the USSR, platinum-group metals are by-products of nickel and copper mining. South African producers are thus in a position to adjust their production according to demand.

The above-mentioned studies reviewed the platinum industry as a whole and it is felt that some of the data used to calculate platinum production and revenue distribution are not suitable for use in current studies.

In view of the inadequacies of these investigations, this study is conducted in more detail to predict the outcome of developments in the platinum industry. The feasibility of several projects during the next five to ten years will depend on the final outcome of events, but the next few years could be very lean due to an oversupply in the market.

1.7 Sources of Data.

The sources of data consisted of literature searches (of which Johnson Matthey's 'Platinum' review is one of the leading journals on the subject), personal communication with management staff of the different mining companies, and empirical data gathered during employment as Mineral Economist at the Minerals Bureau of South Africa.

Information concerning production capacity and revenue was generally obtained from company annual reports and the media.

All metal prices were gathered from the Metal Bulletin, an American journal which publishes daily, monthly and yearly price fixings.

CHAPTER 2

2 PRICE FORMATION

2.1 Introduction

One of the important criteria in evaluating a project is the change in the income and expenditure of a mining company. The greater part of the income of mining companies, derived from the sale of mineral commodities they produce, is determined by the volume and the final market price received for the commodities. The market price of a commodity is determined, in turn, by the point of intersection of the market supply and market demand curves for this commodity (Van den Bogaerde, 1976 : 22).

However, instability in the mineral industry , as stated by Tilton (1977), occurs when an unbalanced state exists between supply and demand, leading to fluctuations in prices. The historic price changes for platinum in particular, have made it difficult to predict the price, due to large price fluctuations and uncertainty about output and demand.

Price elasticity of supply in the short-term is due mainly to substitution, expansion and distance of transport. Both an increase in supply and reports of substitution were responsible, to a high degree, for the drastic price decline of PGM from 1989 to 1991.

In the case of an oversupply, scaling down of output can occur within a reasonably short period by PGM producers in South Africa. However, when the market is in a state of under-capacity, it takes about 3 years or more to develop a new mine. The change in the price of PGM does not

have as much of an effect on demand in the short term, because of the intermediary status of a mineral commodity. In this case only a minimal amount is used in the final product, and the user is hesitant to use a substitute because of the expectancy of a decline in the price of the original product and the uncertain efficiency of a new product (as is the case with autocatalysts).

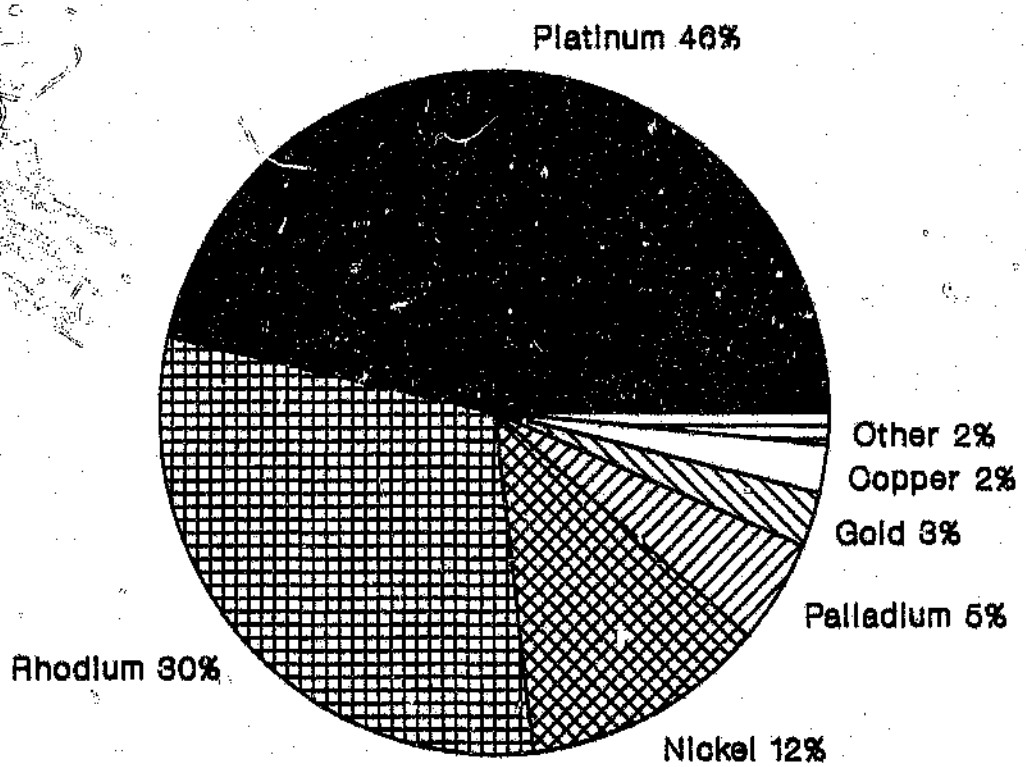
Models of price predictions are numerous. Theories concerning the supply and demand of PGM, are, however, not yet fully developed, by contrast to the many models developed for other minerals and metals. In order to calculate accurate revenue figures, each metal was treated individually. However, the primary role that platinum played in decision making when embarking on a new venture, diminished during the 1980's and early 1990's when the proportion and high price of rhodium in the ore shifted the attention from the Merensky Reef to the UG2.

Thus, to get a clear indication of movements in the market, price forecasts must be made for at least six PGM (platinum, palladium, rhodium, ruthenium, iridium and osmium), as well as gold and three base metals (nickel, copper and cobalt).

For the purpose of this study, the less important metals were eliminated by multiplying the volume of each metal produced in 1991 by its average yearly price for the same period, to determine the contribution of each metal to the revenue of mines (Fig. 2.1).

Three metals, namely platinum, rhodium and nickel were responsible for 88 per cent of mine income. Analyses of these metals were done in more detail, in order to determine supply and demand patterns from which prices were then determined. Price forecasts for the remainder of the metals were deduced by linear regression calculations, in order to determine the future trend.

Fig. 2.1 - PERCENTAGE CONTRIBUTION BY EACH METAL TO THE REVENUE OF MINES, 1991



This attempt was, therefore, not to predict or explain every short-term price movement of the metals, but to try to determine a relationship between certain variables and previous predictions, in order to forecast a price pattern for the metals to be used later in the final evaluation of the mines.

Where possible, this analysis is based on established evidence, but in cases where there are no data available, the study relies on analyses of previous studies and empirical data.

2.1.1 Supply

Primary Supply

Some 281 000 kg of PGM was produced in 1989. The largest single producer, South Africa, produced more than 48 per cent (131 592 kg) of the total world PGM production, followed by the USSR with 127 500 kg. The output from other countries is significantly smaller (Table 2.1). The three major producers, South Africa, USSR and Canada accounted for about 96,7 per cent of total world production.

Secondary Supply

A significant portion of supply of platinum-group metals each year originates from secondary sources, i.e., is recovered from scrap. Supply from this sector varies over time, partly in response to cyclical phases in the platinum price. In 1989 a platinum price of $500/ozt acted as a lower limit for feasible recycling; this, however, has changed. In 1990 and early 1991 the price of rhodium, another substance used in autocatalysts, experienced a sharp increase in price, which allowed for a reduced platinum price.

Table 2.1 WORLD PRODUCTION OF PLATINUM-GROUP METALS (kg)

Country	1988	1989	%	Rank
South Africa *	131 592	132 289	47,3	1
USSR	127 500	127 500	45,5	2
Canada	13 444	10 921	3,9	3
USA	4 970	6 280	2,2	4
Colombia	810	973	0,3	5
Australia	433	500	0,2	6
Other	2 217	1 538	0,6	
TOTAL WORLD	280 966	280 001	100	

Source: BGS, 1991, p212
* Minerals Bureau of South Africa

Scrap material, which accounted for about 6 per cent of total platinum supply in 1990, has been growing in importance over the past decade, and in 1990 was the third largest source of supply of platinum. Recovery of the other metals has also grown substantially. Large quantities of rhodium, first introduced in autocatalysts 1983, are likely to become more fully available for recovery in the 1990's, since the median age at which cars are scrapped is eight to ten years.

2.1.2 Demand

The biggest outlet for PGM in 1990 was for the use in autocatalysts. Demand from autocatalysts in the Western World during this period accounted for 39,3 per cent of the total demand for platinum and 84,4 per cent of that of rhodium. Demand for platinum in jewellery comprised another large consumption sector, which used 35,3 per cent of total platinum demand (Table 2.2).

It is thus clear that these sectors were consuming a large share of the total supply of PGM. Consequently, the irregular price behavior of rhodium, and in particular that of platinum, is subject to the change in demand from these sectors.

Table 2.2 WESTERN WORLD DEMAND FOR PLATINUM, PALLADIUM AND RHODIUM, 1990

Application	Platinum		Palladium		Rhodium	
	kg	%	kg	%	kg	%
Autocatalysts	47 277	39,3	9 642	8,8	10 575	84,4
Chemical	6 376	5,3	-	-	809	6,5
Dental	-	-	31 414	28,8	-	-
Electrical	6 376	5,3	52 098	47,8	373	3,0
Glass	4 199	3,5	-	-	280	2,2
Investment	6 221	5,2	-	-	-	-
Jewellery	42 456	35,3	6 065	5,6	-	-
Petroleum	3 732	3,1	-	-	-	-
Other	3 732	3,1	9 798	9,0	498	4,0
Total	120 369	100	109 017	100	12 535	100

Source: Coombes J.M., 1991, p6,10,59

Autocatalysts

Motor vehicles emit large quantities of carbon monoxide, hydrocarbons, nitrogen oxides and other toxic substances, such as fine particles of lead. Each of these can have adverse effects on the health and environment. In an effort to minimize the motor vehicle pollution problem, emission rates from cars have been limited by legislation in some of the industrialised countries for over two decades. Since then the motor industry has become the largest consumer of platinum and rhodium, and an important end user of palladium. In 1990, the autocatalyst industry accounted for 39,3 per cent of total platinum demand, 8,8 per cent of total palladium use and 84,4 per cent of total rhodium offtake (Table 2.2). Given this predominance, it is evident that the PGM industry pays a lot of attention to the worldwide trend towards adoption of PGM-based catalytic converters. Several countries have, during the

course of the late 1980's and early 1990's, adopted standards which will rely on these controls for the first time, including parts of the rapidly industrializing developing world.

During the 1980's, much time went into research to find alternatives to replace the two metals, platinum and rhodium, and in 1990 and 1991 several announcements were made of alternative compounds to replace them. None of these substitutes, however, seemed to be competent enough to meet all standards but did, on the other hand, depress the prices of rhodium and in particular that of platinum, and harmed investors' confidence in platinum.

Jewellery

Demand for expensive jewellery pieces in Japan, the largest consumer of platinum for jewellery purposes, continued during the late 1980's to early 1990's. The market size of jewellery gifts, according to a Platinum Jewellery Fair press release in 1991, is anticipated to expand further in the future. There are signs of a shift in preference from combination jewellery of platinum and gold to pure platinum, while combinations of the two metals have a tendency to emphasize platinum.

Further growth is expected as fashion and expertise in jewellery making, spread to other countries.

Fuel Cells

In spite of the relatively high cost of generating power using fuel cells in 1990, the environmentally friendly nature of operation is resulting in their adoption in a number of

markets that will lead to lower cost of production. In 1990, at least five companies, in Japan and the USA, were close to offering phosphoric fuel cells commercially, in sizes ranging from 10 kw to tens of megawatts. The phosphoric acid technology, which requires platinum coated electrodes for satisfactory performance, is now sufficiently advanced for commercial operation.

Fuel cells, in particular the platinum, solid polymer cell or Proton Exchange Membrane technology could have a significant future as a mobile power source, especially in cars, trucks and busses with a 10 kw power unit.

Fuel cells look set to become a major consumer of platinum over the next decade, with the market growing to 1,2 million ozt by the year 2000 and to 2,8 million by 2010 (Nurdin, 1991: 103).

2.2 Metal forecast

2.2.1 Platinum

Supply

This section surveys the probable increase in mine supplies of PGM during the next ten years, up to and including the year 2000. The main focus is on South African mines, as these will provide the bulk of new metal to come onto the market.

Future supply calculations were made on the assumption that current mining development will commence as originally planned in 1990.

South Africa is by far the largest producer of PGM. Due to the high ratio of platinum to other PGM in South African ore, the country's share of world platinum production substantially exceeds its share of world PGM production (Table 2.3).

Table 2.3 **PROPORTIONS AND RECOVERY GRADES OF PGM+Au AND BASE METALS IN THE MINERALIZED LAYERS OF THE BUSHVELD COMPLEX.**

	Merensky Reef	UG2 Reef	Platreef
Proportions:			
Pt	59	41	42
Pd	25	34	46
Ru	8	12	4
Rh	3	9	3
Ir	1	1,9	0,8
Os	0,8	1,7	0,6
Au	3,2	0,4	3,4
Recovery Grade PGM+Au g/t	5,5	6,0	3,4
Ni			
Content %	0,18	variable	variable
Recovery Grade kg/t	1,3	0,7	3,6
Cu			
Content %	0,11	low	variable
Recovery Grade kg/t	0,8	-	1,8

Source: Von Gruenewaldt, 1977, p88

In 1990, South Africa accounted for 74,5 per cent of the total world supply of platinum, which stresses the important role the country plays in any price move due to changes in supply.

In order to obtain a realistic scenario for supply of the PGM and by-products, the analysis of each mine was done on a Quatro Pro spreadsheet by feeding in different parameters obtained from company reports and other relevant publications.

The parameters are as follows:

Tons milled: The tonnage received at the mill, less waste rock sorted on surface, plus or minus ore taken from or added to mill bins and stockpiles, after adjustment for the moisture content (Storrar, 1981: 230).

In-Situ Grade: Term used to distinguish material eg. rocks or minerals found in their original position of formation, deposition or growth, as opposed to loose, disconnected or derived material.

Overall Mining Recovery (OMR): The ratio of mill head grade to the in-situ grade. Reduction takes place due to:

* Losses which are brought about by geological disturbances made up of potholes, displacements and intrusions.

* Dilution due to shortfall and gullies. Both increase the tonnage but reduce the grade. Shortfall is tons unaccountable by survey measurement and is explained by inaccuracies of stope width measurement underground.

Metal Proportions: Table 2.3 gives an indication of the average metal proportions in the different layers. These proportions do change, however, throughout the Bushveld Complex, so that mines were treated on an individual basis, each with its own grade and proportions.

Percentage Recovery or Extraction at treatment plant: The ratio expressed as a percentage of the mass of the specific mineral product actually recovered from ore treated at the plant to its specific mineral content before treatment (Storrar, 1981: 225).

Developments in the South African platinum industry and the future outlook are discussed in more detail in Chapter 3.

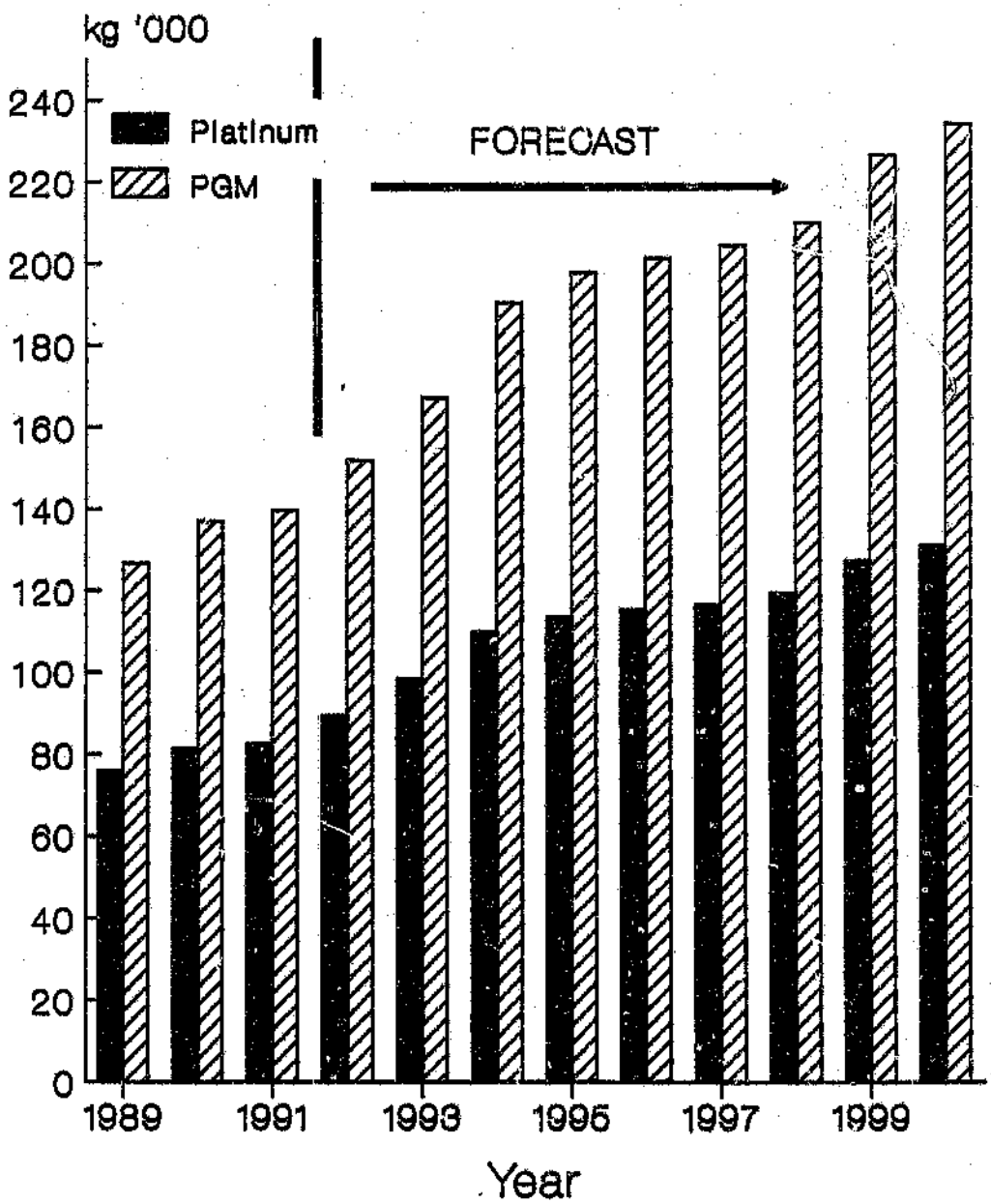
Projected output of PGM in South Africa is expected eventually to rise sharply to reach a peak between 1993 and 1994, due to the commencement of several planned mines and the expansion of existing mines, after which it will level off.

A further sharp increase is expected after 1997 due to the commencement of other new mines like the Southplats, Kennedy's Vale and Severin prospects, to meet increased demand for platinum in fuel cells (Figure 2.2, Appendix 1).

North America is the second largest producer of PGM in the Western World. There are currently about 30 exploration projects in the USA and Canada. However, in **Canada**, exploration activity at potential PGM-producing sites was subdued during 1990/91 as risk capital became less readily available due to the slowdown in the economies of the world. Increased output is, however, expected from the Madeline Mines' Lac des Ilses prospect in Ontario. Established production of PGM in Canada is limited by nickel output.

Mine capacity at the Stillwater Mine in the **USA** is 27 500 tons per month with a ratio of platinum to palladium of 1:3,5 (Coombes , 1991, p17) and only minor amounts of nickel and rhodium as by-products. Recovery by flotation is over 92 per cent. According to Coombes

Fig. 2.2 - SOUTH AFRICA'S PRODUCTION OF PLATINUM-GROUP METALS, 1989-2000



(1990, 17), plans to expand mining at Stillwater have been put on hold for the time being. It was, however, assumed for the purpose of this study, that further expansion could take place by 1997. Expansion of the project could double capacity to about 5 287 kg platinum and 12 441 kg palladium per annum. According to Mancusso (1990) development of a second mine is expected to commence at East Boulder, adjacent to the Stillwater Mine in 1993, and will produce 3 421 kg platinum and 11 508 kg palladium per annum by the end of 1998. The Stillwater mine is, however, vulnerable to any pronounced weakness in the platinum and palladium price. However, with a grade as high as 27g/t platinum and palladium in some places (Coombes , 1991, p17) high prices of these two commodities will assure the company's continued existence.

The USSR supplies a large percentage of PGM to the Western World. The largest output of PGM by far in the USSR, comes from the Noril'sk-Talnakh and Kola Peninsula deposits as by-products of massive disseminated Ni-Cu sulphide deposits. According to Von Gruenewaldt (1991:24), PGM production originates from the Noril'sk area, which amounts to close on 95 000 kg, and other producers in the USSR, notably the Pechenga area on the Kola Peninsula where grades are only 0,04 - 0,4 ppm.

A representative of Inco, who visited the Noril'sk deposit in 1990 has given the following approximate grades:

Nickel	3%
Copper	5%
Platinum	2,2 ppm
Palladium	11,0 ppm
Rhodium	0,6 ppm

Supply of the USSR to countries in the West is expected to increase, but availability would be affected by increasingly volatile political conditions during the period under study and change in domestic requirements. If the Soviet indusury were eventually to be restructured as part of a market orientated economy, increased output of consumer goods, to make up for the present scarcities, might result in increased internal demand for platinum. The application of emission control for the 1,3 million cars produced each year in the USSR, would further erode the export allocation of platinum.

Zimbabwe will probably also become a large producer of PGM in the Western World within the next few years. The platinum deposits along the Great dyke in Zimbabwe are probably the largest outside South Africa. Within the Great Dyke is the Hartley Complex, which is 100 km long and 10 km wide. A $193 million (capital cost, mid 1990 value) investment to bring a mine on stream is envisaged by Delta Gold, an Australian company and BHP-Utah International. Recent expenditure at the developing mines in South Africa would however, suggest that this may be too conservative, especially in Zimbabwe. Production of PGM is expected by 1996.

Secondary Recovery of PGM, according to Saville (1988) falls into two broad classes:

(i) Industrial recycling, which follows normal business principles of maintaining minimum inventories of high value scrap. This is done by recycling promptly under refining terms, which fairly reflects services supplied, processing costs and profit requirements of refiners.

(ii) Scrap industry recycling with a speculative motive, especially if the scrap arises as a low cost by-product. Recyclers then tend to hoard and release PGM scrap according to their assessment of market price trends and their cash flow requirements. Here

autocatalyst recycling is the most likely growth area for PGM recycling, because of the regular large input of PGM into this market.

By 1995, 14 789 kg of platinum and 1 088 kg of rhodium are likely to be available from spent catalysts. By the year 2000, these figures are expected to reach 22 938 kg platinum and 3 241 kg rhodium (Figure 2.3).

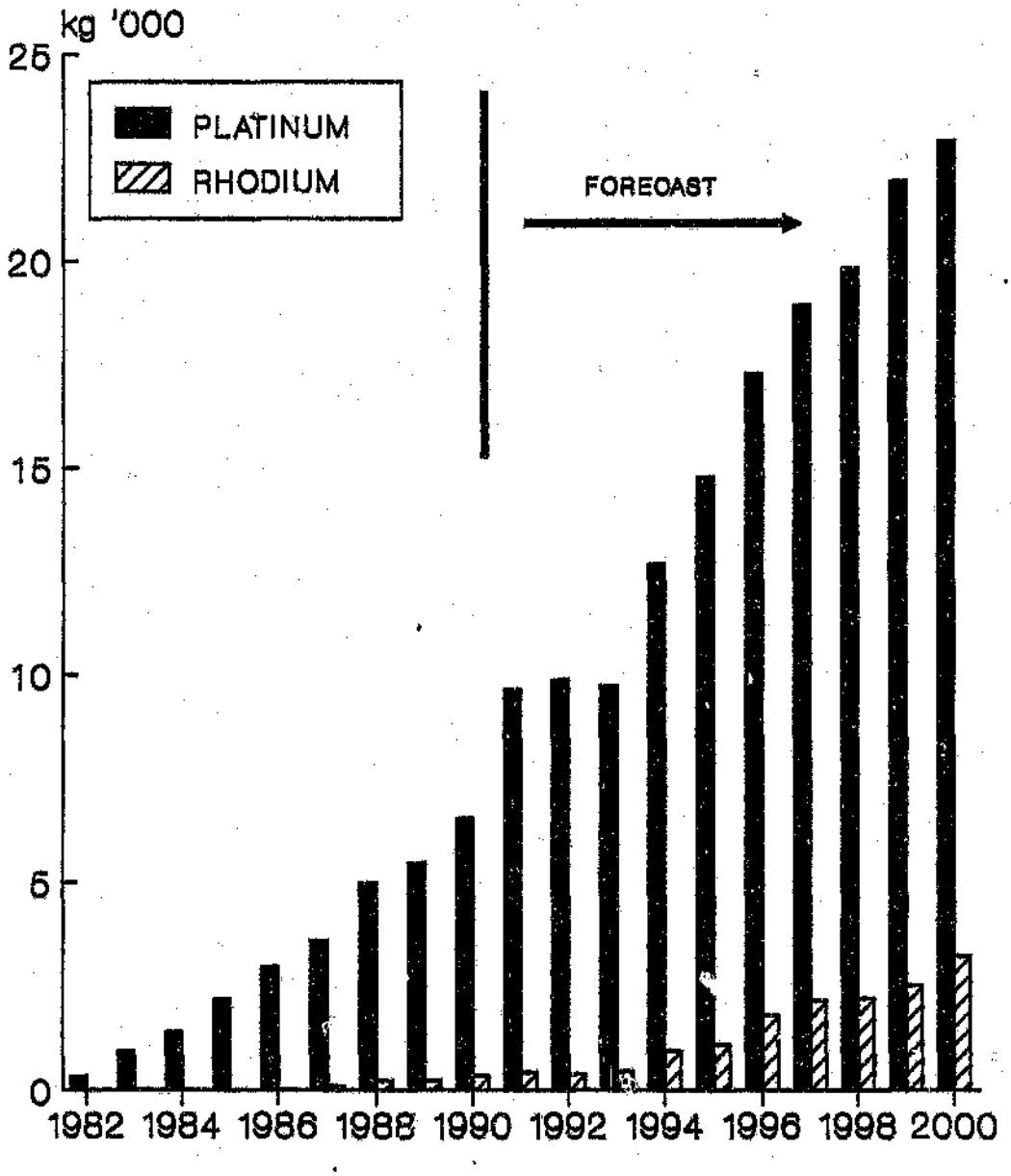
These figures are based on the following assumptions:

* 15% loss of the PGM in place
* 60% of scrapped converters being recycled
* Platinum and palladium recovery of 95 per cent and recovery for rhodium varying from 60 to 75 per cent.
* Life expectancy of 10 years for autocatalysts.

The application of platinum-group metals in the petroleum and chemical industries is well known. These industries are also comparatively mature industries, with well developed patterns of recycling. Spent catalysts are returned to the refiner on a changeout credit basis, where new catalysts are supplied and the consumers charged for the refining and metal losses in refining. Typical refining terms give PGM returns of 97-99,5 per cent. External supply from this sector is thus negligible.

Between 1990 and 1995, annual supplies of platinum could increase by about 43 030 kg, or 38 per cent. The overwhelming majority of these extra kilograms will originate from South Africa.

Fig. 2.3 - SECONDARY RECOVERY OF PLATINUM AND RHODIUM FROM AUTOCATALYSTS, 1982-2000



World supply of platinum is projected to 194 652 kg in the year 2000 which means a weighted average growth of 5,17 per cent from the 122 547 kg produced in 1990 (Appendix 2), depending on:

* The success of the first phase expansions by the established South African producers and the success of the new ventures
* Whether any of the South African producers embark on any second phase expansion
* Level of sales emanating from the USSR
* The success of the projects in Zimbabwe.

Platinum Demand

The analysis and development of demand is based on a number of publications. Most of the historic data comes from the widely regarded Johnson Matthey publication, 'Platinum'. This, combined with models and theories published by economic journals and stockbroking companies, provides a chronology of the PGM market.

Increased demand is expected from three major demand sectors namely autocatalysts, jewellery, and fuel cells. However, the big unknown factor is the investment sector, which has the capacity to absorb well in excess of 9 000 kg, as was demonstrated during the period 1984 to 1988.

Autocatalyst demand is expected to remain the largest consuming sector of platinum. A worldwide trend is continuing towards adopting PGM-based catalytic converters to reduce vehicle emissions.

Figure 2.4 depicts the growth trend in the demand for platinum in autocatalysts. Sales of cars equipped with autocatalysts is expected to grow from approximately 50 per cent of all cars in 1991 to over 75 per cent in 1993.

According to Walsh (1991) the annual growth in vehicle registrations around the world since 1950 has averaged 5,9 per cent for motorcars and 5,6 for trucks and buses. More recently, the trend has slowed down. Since 1970, annual car registration growth averaged 4,7 per cent per annum while truck and bus registrations averaged 5,1 per cent per annum.

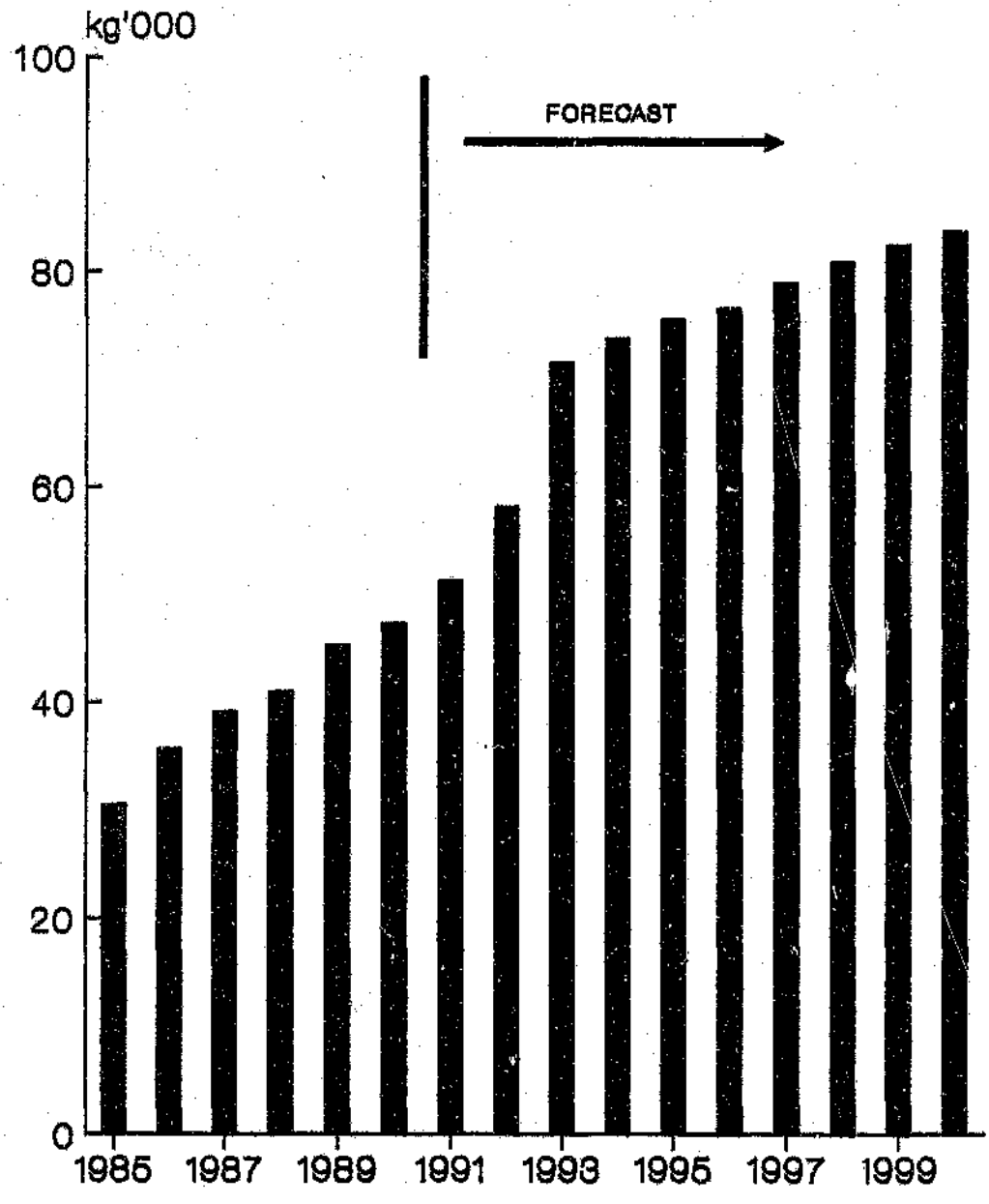
The world vehicle population has been growing faster than the overall number of people, indicating that there may not be a natural limit or at least that it has not been reached yet.

According to Walsh (1991), anticipated new car sales for the different regions of the world indicate that while North America is not forecast to grow, the Asia Pacific region will grow rapidly. Furthermore, while the next few years are expected to be economically difficult for Eastern Europe, rapid growth in this region from the year 1995 to 2000 is likely. Coombes (1990: 24), recently gave the forecast growth figures for this region. New car registrations are expected to rise from 700 000 in 1990 to 1,2 million in 1995 and 1,6 million in the year 2000, which means a substantial potential for the application of autocatalyst technology.

The tougher standards of emission control set worldwide, ruled out the use of the lean burn engine with a simple platinum-palladium catalyst as a means for the small car to meet legislative requirements. Consequently, platinum-rhodium catalysts, in the ratio of 5:1 (already the favoured configuration for larger cars in North America and the EEC), are likely to be the universal choice of carmakers in Europe for emission control.

Another large outlet is in the motorcycle industry. In Taiwan, where emission control on motorcycles was implemented in July 1991, 1 000 motorcycles are produced every year.

Fig. 2.4 - WORLD DEMAND FOR PLATINUM BY THE AUTOCATALYST SECTOR, 1985 - 2000



With a 5g PGM load per motorcycle, this area could become another large outlet for PGM when implemented later in all countries where these vehicles are used.

Jewellery is an area of demand which has been a mainstay of the platinum industry since the mid 1960's.

In 1990, 87 per cent of platinum consumed in the jewellery industry was accounted for by Japan. It was then assumed that the outlook for the jewellery industry largely depended on the continuing growth of consumer spending and favourable reception for new designs by Japan's younger set.

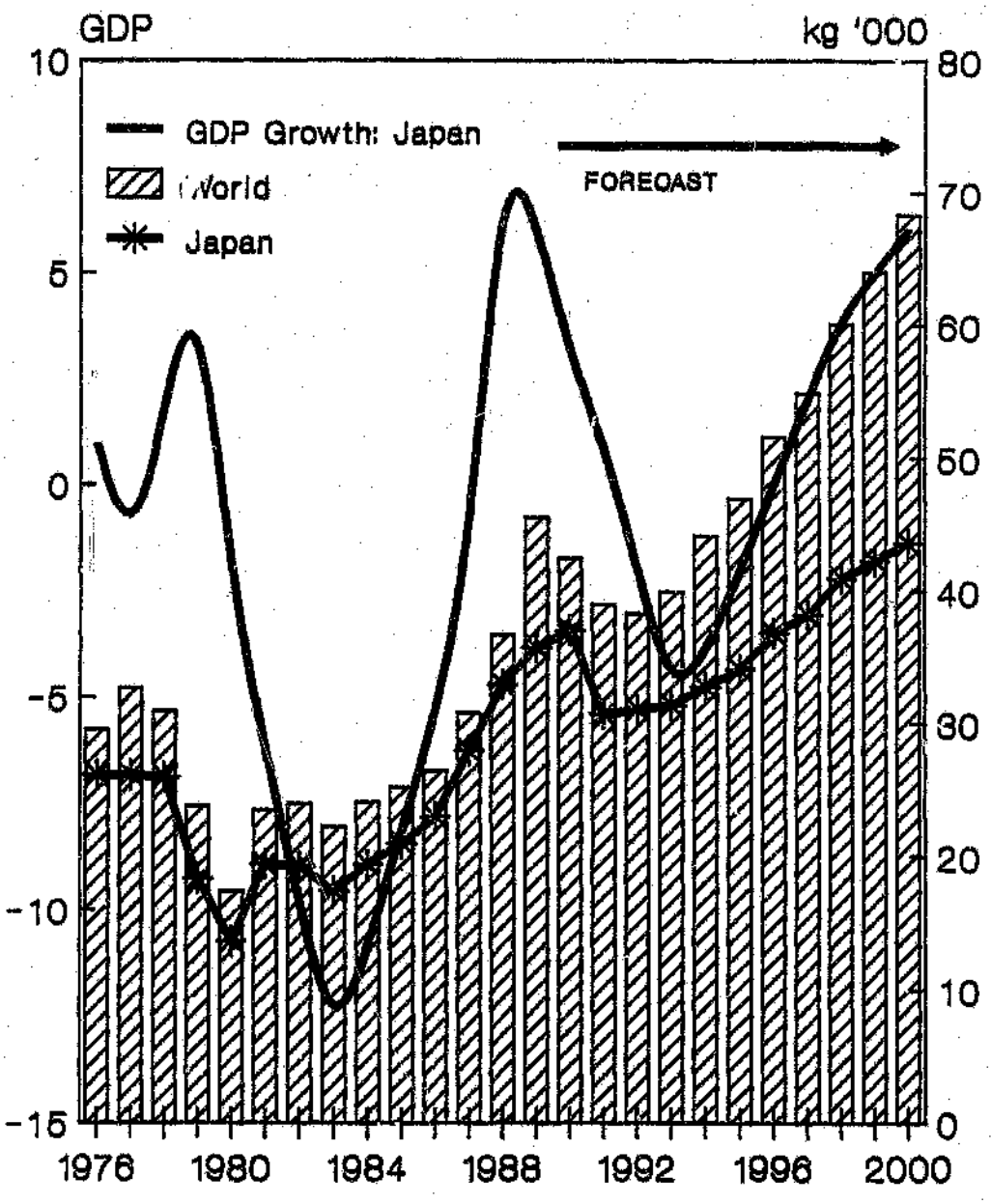
This ratio is illustrated in Figure 2.5 where a relation between the deviation of GDP from its long term trend and the demand for platinum for jewellery is evident.

It is thus intuitively assumed that, under normal conditions, the demand for platinum increases when per capita income rises. To check this possibility, the historical GDP and platinum demand were used to calculate a linear regression of jewellery demand on the business cycle of Japan. The result was a correlation coefficient of 0,86, which indicates a very good correlation between the two parameters.

A growth cycle was then determined by taking GDP from 1965 and deflating it using the CPI of Japan. A path of the business cycle was then calculated by substracting the long term trend from the actual values, to get a positive and negative deflection of each following year (Lombaard and Stadler, 1981:46).

By using this information, the trend in the economy was then deduced and drawn for the next ten years, under the following assumptions:

Fig. 2.5 - DEMAND FOR PLATINUM BY THE JEWELLERY SECTOR, 1976-2000



* The Japanese economy was at its peak in 1989 resulting in high demand for platinum in jewellery consumption. This demand continued in 1990, although a slowdown in the economy already existed.
* A trough would be reached by the economic cycle by 1992 - 1993, but not as deep as the previous slowdowns, because economies are better geared for recession periods.

A growth-trend for jewellery demand was also calculated, with a resultant average yearly growth of 3,24 per cent.

Both these factors were then used to establish growth.

Fuel cell development is the most promising development for platinum in the next ten to fifteen years.

The US Public Utility Association plans the establishment of 15 000 kw of fuel cell capacity in the Western USA early next century. In Japan the New Energy and Industrial Technology Development Organisation published a forecast that by the year 2000, phosphoric acid technology will have an installed capacity of 1 900 megawatts in Japan, which will be 85 per cent of all alternative technology installed. This alone will account for 300 000 ozt of platinum. In the year 2010, this will rise to 5 800 megawatts, which would account for almost one million ounces of platinum (Nurdin, 1991: 102).

Forecasting of platinum application in fuel cells was made under the following assumptions:

* Large scale commercialisation no later than the mid-1990's (American Public Power Association, 1988: 9).

* Consumption of 1,2 million ozt platinum in fuel cells by the year 2000, and 2,8 million by the year 2010 (Nurdin, 1991: 103).

* Loading of 5 g platinum for each kilowatt of electrical capacity (Coombes, 1991: 44).

* The substitution of one technology for another according to Martino (1972: 110) shows an S-shaped curve.

The new technical approach, such as the case with fuel cells in 1990, has not yet proved to be economically viable, but as the new approach continues to prove itself in an ever widening variety of applications, the older approach is abandoned. The new technology will also not be adopted at once. There will always be some risk involved in adopting it. This approach was used to fit a Pearl curve on the data available.

Figure 2.6 shows the expected growth in demand for platinum in fuel cells.

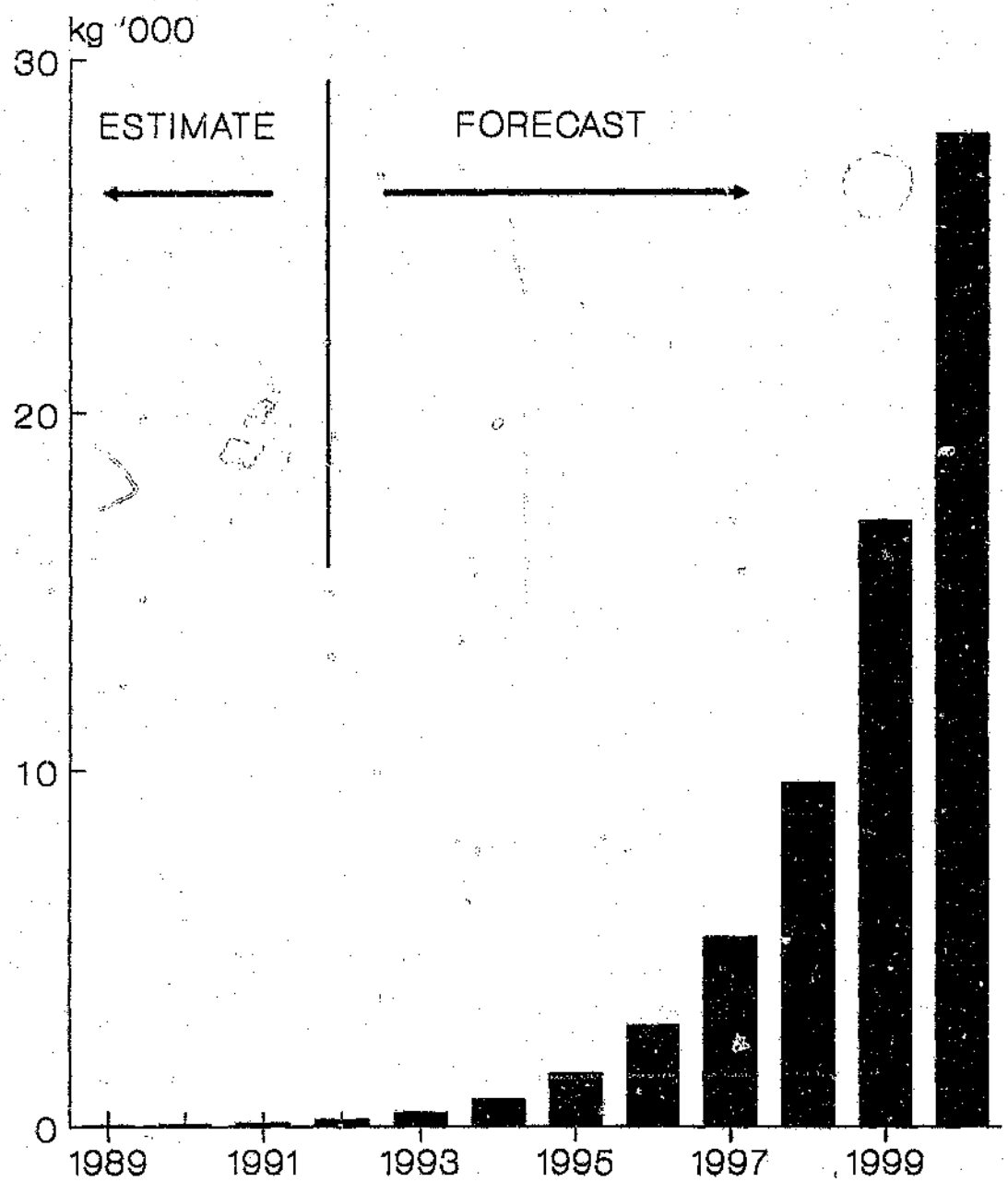
Some 80 per cent of the platinum is recovered when the cells are replaced after four years.

Other sectors in the platinum industry which absorb about 25 per cent of total Western World platinum demand, include investments, petroleum, chemical, electrical and glass industries.

Due to the expected lacklustre performance of platinum from 1991 to 1993, investors are expected to turn to alternative investments during this period, but renewed interest is expected in 1993 and the remainder of the decade.

The new drive to lead-free petrol is causing petroleum refiners to use higher platinum catalyst loadings. Projections agree that if new source refineries in the Pacific Rim come to fruition,

Fig. 2.6 - PROJECTED DEMAND FOR PLATINUM IN THE FUEL CELL SECTOR, 1989-2000



this will mean an increase in demand for new catalyst installations of up to 8 per cent by the mid-1990's.

The other sectors are set to remain small. Further demand in the **chemical sector** will merely be to top the existing catalyst installations. Over-capacity in the fertiliser industry will cause a gradual de-activation of plants in the 1990's. This is due to pressure within the EEC for farmers to use natural dressing instead of fertiliser. Platinum and palladium use in the **electronic sector** will remain limited due to the ongoing move to miniaturise electronic components. Other end-uses in the **glass-fibre, paint and pharmaceutical industries** are not seen as significant growth areas.

In order to predict the demand for platinum in these sectors, a regression analysis of demand over time was done (Fergusson, 1976: 115).

> **World demand for platinum is projected to 206 674 kg in the year 2000 which means a weighted average growth of 5,54 per cent from the 120 423 kg produced in 1990.**

Platinum Price

For the purpose of determining the price of platinum, the above-metioned factors were investigated to find means to forecast the price. Firstly, a correlation between the actual historic data of the supply and demand balance and the yearly price for the commodity was investigated. On visual estimation, a correlation was evident between the changes in the balance, negative or positive and the change in the price of platinum, but the linear regression correlation of price with balance was very poor. The assumption was made that some difference or lag must exist because of expectations of market players, which could influence any correlation. Data were smoothed by applying a three year moving average on the two

sets of data in order to attempt a better correlation. A much better negative correlation was then achieved, which fits with the assumption originally made (Table 2.4).

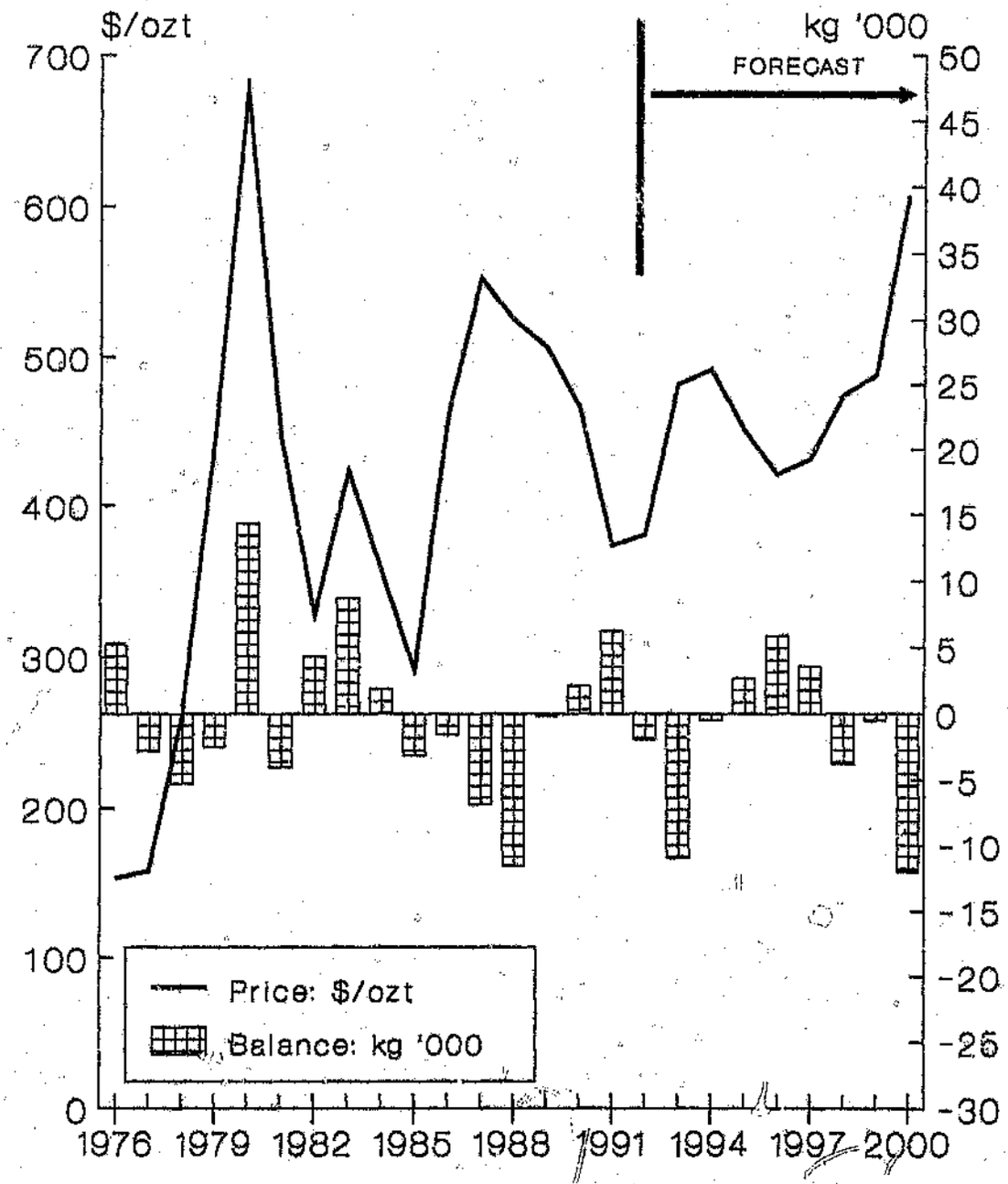
Table 2.4 LINEAR REGRESSION ANALYSES OF PRICE OF PLATINUM PLATINUM ON THE SUPPLY-DEMAND BALANCE FROM 1976 TO 1990.

Applying five year moving average:	
	Correlation Coefficient (r^2)
Before	0,064743
After	-0,51486

These criteria were then used to calculate the price of platinum. The slope of the increase in the price of platinum was determined by the linear correlation of historic performance of the price.

The price of platinum is expected to improve in the second half of 1992, to reach a peak in 1993 when demand for autocatalysts reaches its full swing in Europe. During 1994 to 1997, the price is again expected to decline. In recent years Japanese investors have accumulated platinum following the sustained rise in the price. During 1990 and 1991, the Japanese have encountered losses on the stock market which will have to be offset by way of selling platinum stocks. Furthermore, secondary supply is likely to increase to 18 939 kg per annum, and the developing South African mines will reach full production while the demand for platinum in Europe moderates to stay in line with annual production of motorcars. By 1998 the negative situation is expected to be offset by the increase in demand for the use in fuel cells, and the price is expected to reach $600/ozt (Figure 2.7).

Fig. 2.7 - PRICE FORECAST FOR PLATINUM 1976-2000



2.2.2 Rhodium

Rhodium is produced as a by-product by all the platinum-producing mines, which means that supply is inelastic to changes in price. This was tested by applying a regression analysis of supply on price, which resulted in a very low correlation coefficient. Keeping in mind that the autocatalyst sector absorbed 84 per cent of the total demand for rhodium in 1990, the dependance of price on autocatalyst demand was calculated and a correlation of 0,78 was obtained. Demand for autocatalysts was then used to obtain the future price of rhodium (Figure 2.8). This price is expected under the assumptions that:

* future production will be stable, without any disruption, as happened in 1990 when Rustenburg Platinum Mines experienced refining problems
* there is no disruption of supplies from the USSR

2.2.3 Prices of other metals.

The price trends of gold, copper, palladium, ruthenium and iridium were calculated using linear regression analyses to get the best fit line. Price forecasts are represented in figures 2.8 and 2.9 (Appendix 3). The gradual weakening of ruthenium and iridium prices conforms to the supply and demand situation in 1990, where supply was able to cater comfortably for the demand for both metals. A further increase in platinum production will inevitably result in increased supply of both ruthenium and iridium in an already saturated market, and will result in lower prices.

The price of nickel was determined by finding a relationship between the production of stainless steel and the demand for nickel in this application. A correlation of 0,76 was calculated. A Gompertz curve was applied onto stainless steel growth to forecast growth

Fig. 2.8 - PRICE FORECAST FOR PALLADIUM, RUTHENIUM IRIDIUM AND RHODIUM

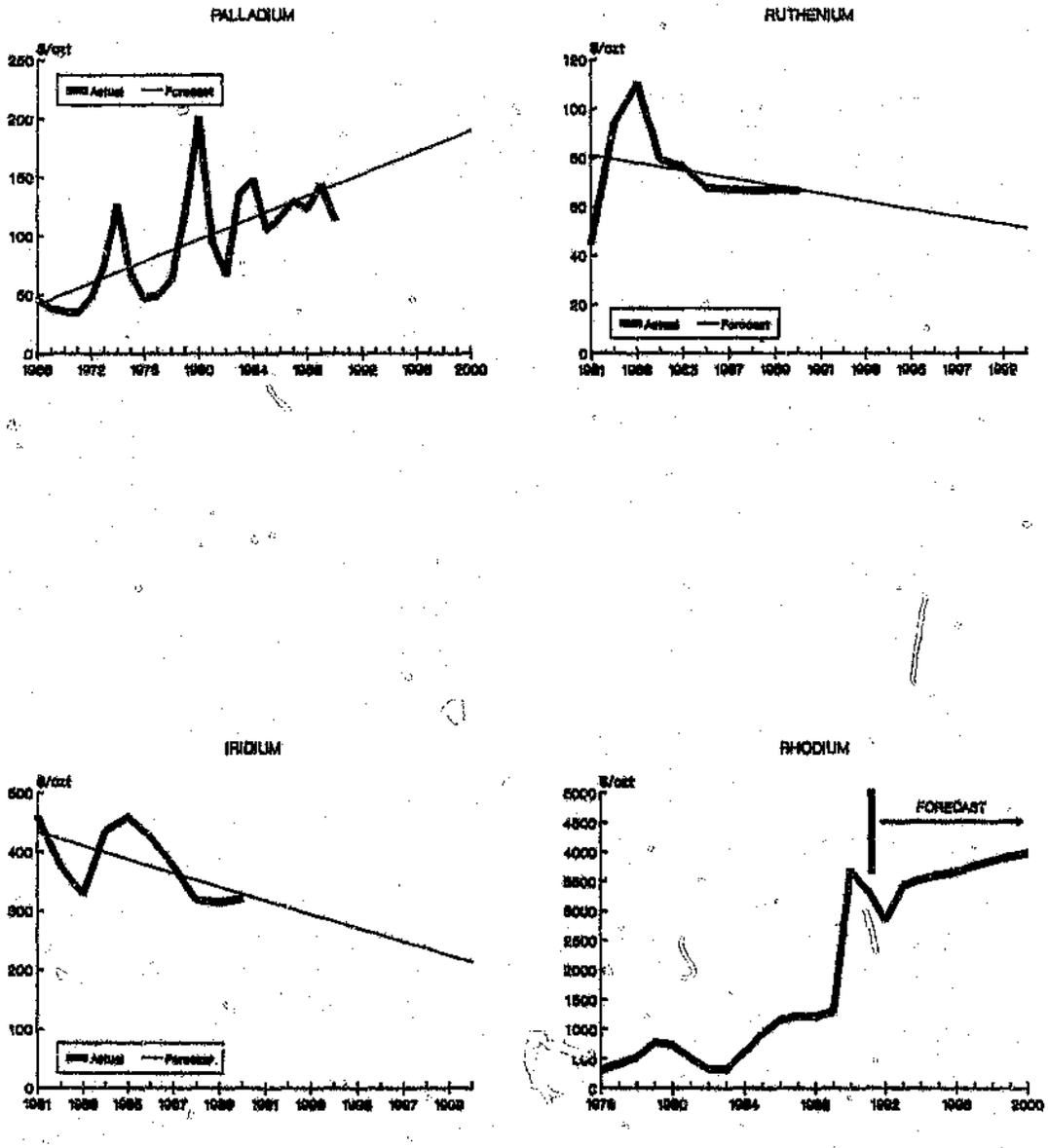
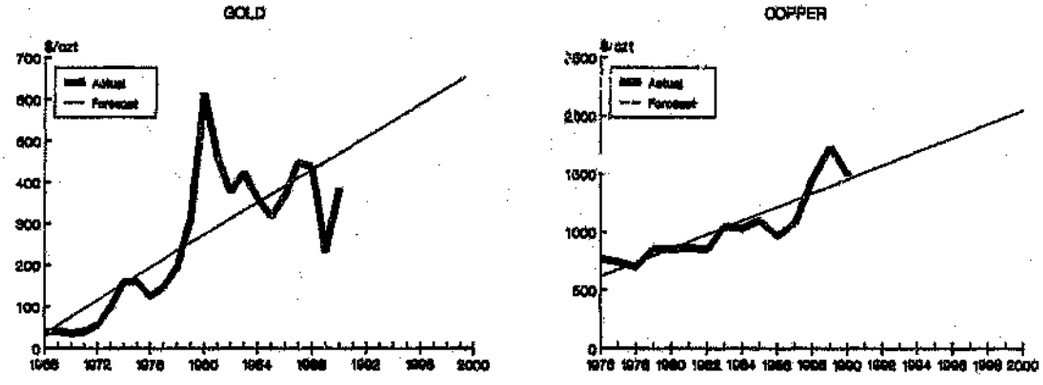
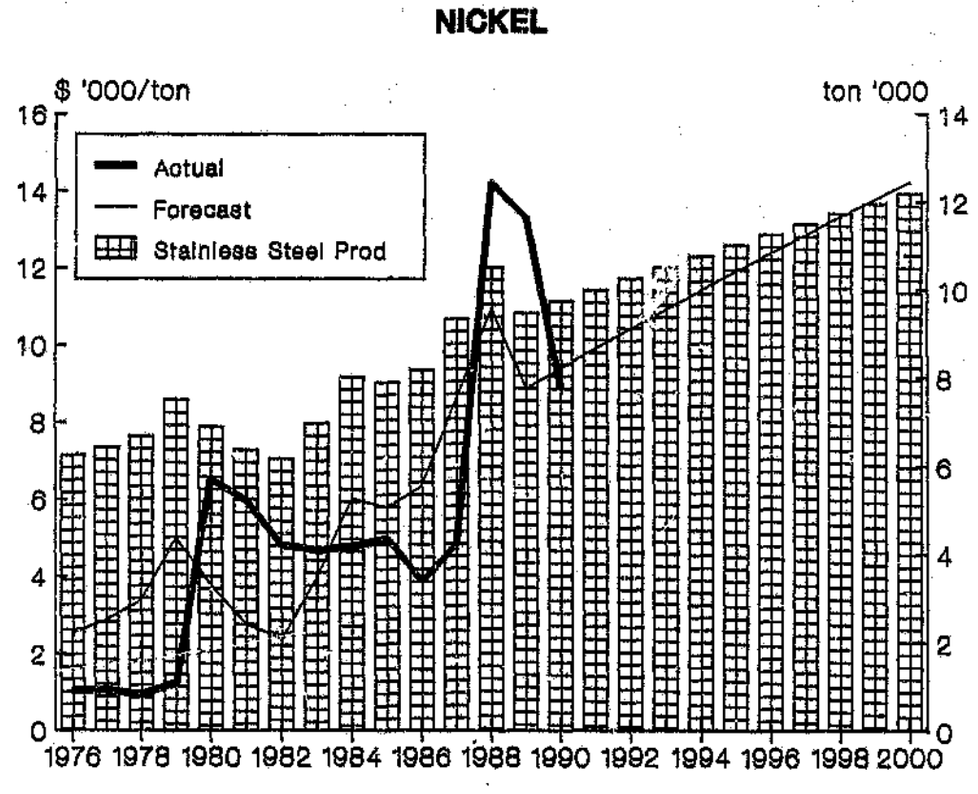


Fig. 2.9 - PRICE FORECAST FOR GOLD, NICKEL AND COPPER





to 2000. These calculations were fitted on the linear regression calculations to find the price for nickel.

CHAPTER 3

3 AN ANALYSIS OF FUNDAMENTALS OF THE PLATINUM INDUSTRY IN SOUTH AFRICA

The aim of this chapter is to determine finally the influence of the circumstances given for the period 1990 to 2000 on each of the South African platinum mining companies.

Mine evaluation consists of the physical aspects of the mine, which are also linked intimately with the economic conditions prevalent during that specific period and which were dealt with in Chapter 2. Although the true value of a mine is never known until such a mine is completely worked out, the value can be determined either through an estimate or an informed guess.

3.1 The South African Platinum Industry.

3.1.1 Progress of the Industry

The first report of platinum in South Africa was made in 1892 by William Betel who identified PGM-bearing concentrate from the Witwatersrand gold-bearing ores. These ores contained mainly two platinum-group metals, namely osmium and iridium, in alloy form, commonly known as osmiridium. Sixteen years later, Drs A.L. Hall and W.A. Humphrey

reported the occurrence of PGM-bearing ore in the Rustenburg districts, but all deposits were found to be uneconomic.

In June 1924, Dr Hans Merensky received concentrate panned from alluvial deposits on the farm Maandagshoek, from Andries Lombaard, a farmer in the Lydenburg district. To Merensky it was clear that the concentrate originated from a nearby 'mother lode'. Soon afterwards, dunite pipes were discovered at Mooihoek, Driekop and Onverwacht. In addition, Andries Lombaard had discovered a 12 metre-thick band of platiniferous rock on Maandagshoek which proved to be a platinum-bearing magmatic layer. Merensky was able to trace the horizon north and southwards for a distance of 100 km. In September 1924, Merensky proposed that the layer be known as the Lombaard Reef, but soon afterwards it was acknowledged as the Merensky Reef.

The **Merensky Reef** is found between the Main Zone and the Critical Zone of the Bushveld Complex. As it persists downdip for several kilometres, the resource is beyond calculation and the economic, measured reserve calculation is defined merely by heat gradient and the technology to overcome it. The Reef attains its typical development in the Rustenburg and Lydenburg districts, where it has the characteristics of well-bedded, sedimentary strata, dipping inwards towards the centre of the Complex at between 6 and 25 degrees. According to Wagner (1929:101), the horizon attains its greatest importance in the Rustenburg district. PGM grades in the Lydenburg district, average about 3,42 g/t compared to the Rustenburg area, where the average tenor exceeds 10,26 g/t over a stoping width of 762mm.

A prospecting programme was started in March 1925 in the Potgietersrus district. Activity was concentrated on a pyroxenite layer, which proved to be the main platinum carrier and which is now known as the Platreef.

In June 1925, attention was focused on the western section of the Bushveld Complex, and the Merensky Reef was located soon afterwards by way of trenches, on the farms Waterval and Turffontein.

Despite the attention given to the discoveries at Waterberg, Lydenburg and Potgietersrus, the focus was centred on the Merensky Reef near Rustenburg.

A rapid and sustained weakening in the price of platinum in the early 1930's, led to the closure of several operations, except at Eerstegeluk and Waterval, near Rustenburg.

During this depressed market, rationalization of the platinum industry took place, which resulted in the formation of Rustenburg Platinum Mines (RPM) in September 1931, by the amalgamation of two operations, namely Potgietersrust Platinum and Waterval Platinum.

After World War II, an upsurge in demand occurred in the chemical industry. Platinum, formerly used only for jewellery, was then used by the chemical industry, as a catalyst for nitric acid and sulphuric acid production, and for hydrogeneration and synthesis of hydrocarbons and hydroxylates.

This led to the start of new mines, and renewed competition. In 1949, The Union Platinum Mining Company Limited, administered by the Anglo Rand Mining and Finance Corporation, commissioned a plant near Northam. Steps were taken by RPM to absorb the Company and it became what is known today as the Union Section of RPM.

An additional outlet for platinum realized in 1950, when platinum came to be used as a catalyst for the production of high-octane petrol from low-grade and natural crude oils.

Further mine development was, however, hampered by a fall in the price of platinum in 1958 to almost half its original level. This was caused by a sharp reduction in offtake by the end industry and the dumping of excessive USSR stocks on the Western Market.

The next development came in 1966, when Union Corporation announced its intention to establish a new mine on a property held by the Bafokeng tribe north of Rustenburg. This became known as **Impala Platinum Limited.**

The renewed activity and competition, hastened RPM's exploration activities in other areas. The company recommenced its prospecting of the Potgietersrust leases and of its property north of the Union Section, on the farms Middellaagte and Amandelbult. In 1972, a decision was taken to open the Amandelbult Section, with the intention that its plant would produce 225 000 ozt platinum per annum, and act as lever to provide RPM with the flexibility to react promptly to any changes in demand. This was followed by Anglo Transvaal's decision to mine at Atok, in the Pietersburg area. In 1977, Atok Platinum was acquired by RPM.

Western Platinum Limited, managed by the Lonrho group in association with Falconbridge Nickel of Canada, was commissioned in 1971, on the farms Middelkraal and Wonderkop, near Brits. In February 1987, Lonrho purchased Falconbridge's 49 per cent stake in Westplats, bringing its share in Westplats up to 99,44 per cent.

Although the UG2 chromitite horizon was identified in the 1920's, at first no attention was paid to its potential. RPM, however, conducted studies on the UG2 ore since 1976, while Impala Platinum has been mining UG2 ore and processing it as a blend with the run-of-mine Merensky Reef ore. Mining at Western Platinum was initially concentrated on the Merensky Reef, but in January 1983, milling of the UG2 commenced.

Thereafter, during the period 1985-1989, several announcements on developments of new mines were made. In 1985, the London price of platinum rose sharply from $291,47/ozt to over $552/ozt. The mining houses then realised the opportunity that existed and feasibility studies and development at different prospects started.

However, in the late 1980's, a collapse in the price occurred, which led to the closure of mines and the suspension of several prospect developments.

In 1987, plans by Severin to develop a 50 kt/month mine were abandoned, when the company failed to raise the required capital.

In 1989, operations of the companies Lefkochrysos Ltd and Rhodium Reefs Ltd were affiliated to the holding company Barplats Mines Ltd. The Lefkochrysos mine at Brits was renamed Crocodile River, and the Rhodium Reefs development near Steelpoort changed its name to Kennedy's Vale. The Crocodile River Mine was, however, plagued with problems throughout 1990. The ensuing delays in reaching production targets reduced the planned output of all metals, after difficulties in underground extraction of ore, mechanical failure at the milling plants and arsenic contamination at the refinery, accentuated the lock-up of semi-refined PGM in the refining pipeline. As a result, operations at Kennedy's Vale were deferred until such time that Crocodile River reached its production and generated a positive cash flow. However, the ill-fated Crocodile River Mine soon run into cash-flow problems and was acquired by Impala Platinum in the third quarter of 1991. A month later, Impala decided to mothball the operation, due to the high-cost mine layout which made the mine unviable at the prevailing low platinum and rhodium prices.

Western Platinum acquired the Karee mine from Impala platinum in January 1990, in terms of which the Impala Group acquired a slightly greater than 25 per cent equity share

and a 27 per cent profit participation in the future earnings of the merged Western Platinum/Karee mine.

Despite all closures and restructuring in the industry, by October 1990, RPM, backed by strong financial reserves, continued to increase output and raised output of UG2 ore by 30 000 tpm at the Union section. This was scheduled to be followed in September 1992, by an additional output at the Amandelbult Section, further to the north, comprising 100 000 tpm from the UG2 Reef and 40 000 tpm from the Merensky Reef. Atok Mine, with a mining and milling capacity of 70 000 tpm, undertook a 100 000 tpm expansion programme, due to be in place by August 1992.

Future increases in output could also stem from the start of the Southplats project (Southern Witwatersrand Exploration Company (Pty) Ltd), the Sevplats project (Severin and Anglovaal) and from the copper-nickel prospects of Anglo American and Anglovaal in the Eastern Transvaal.

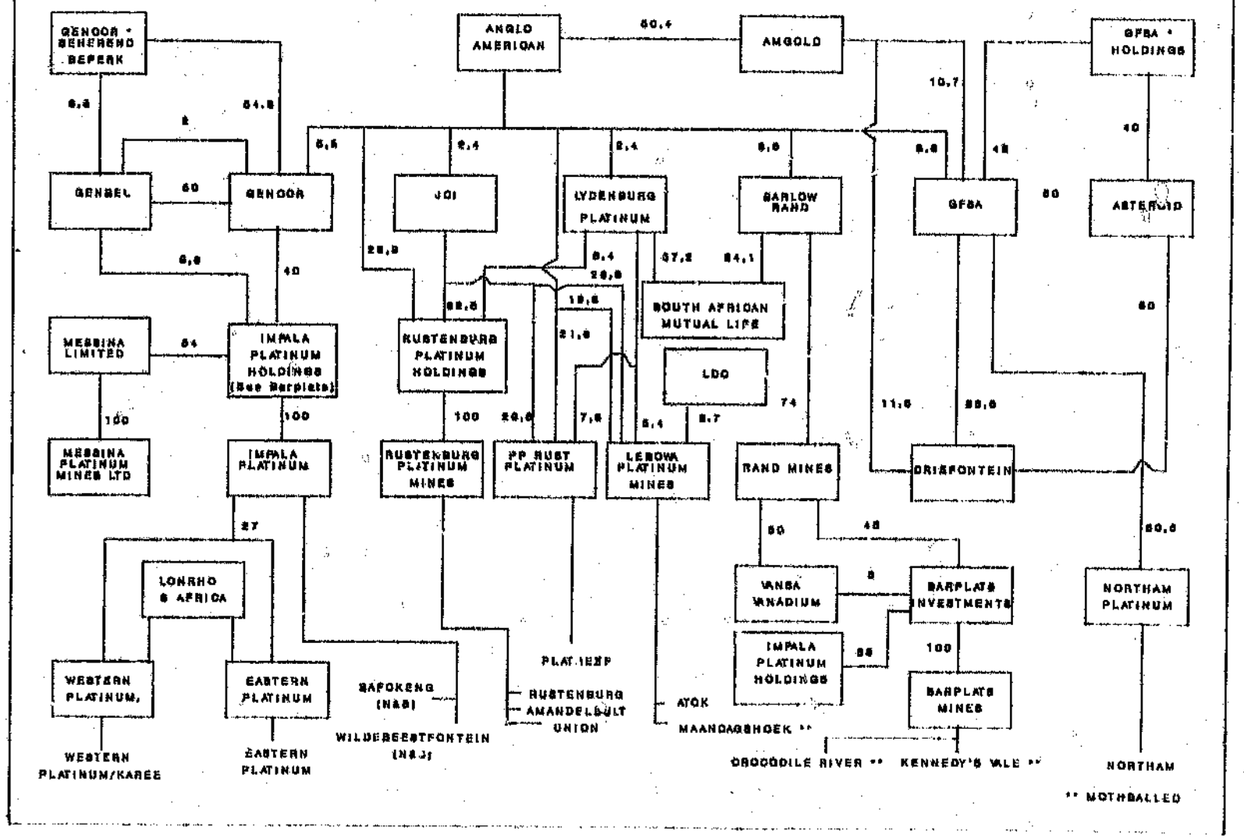
The expansion by existing mines and the advent of new producers, have made the platinum business environment more competitive.

The structure of the South African platinum industry in 1991 is depicted in Fig. 3.1.

3.2 The Platinum Mining Operations in South Africa

3.2.1 Mining Methods

Fig. 3.1 - FLOW DIAGRAM: SOUTH AFRICAN PLATINUM INDUSTRY 1991



In South Africa, the mining of PGM ore is similar to gold mining, inasmuch as it occurs in layers in the Bushveld Complex, which enables a progressive mining method in stopes. Platinum mining, however, differs from gold mining in several respects. PGM reefs are igneous in origin whereas gold reefs are sedimentary. This results in a much higher heat gradient in PGM mines. One of the main features of the platinum reefs is potholes in the plane of the reef, varying from 30 to 500 metres in diameter and causing rapid sinking or rising of the reef. These potholes disrupt the smooth cycle of drilling, blasting and stope clearing, which results in geological losses. Further dilution of the ore takes place through inaccurate blasting and the inclusion of waste rock, and during the blasting of gullies. In both cases, an increase in tonnage but a reduction in grade takes place. Dilution was therefore taken into account during the calculation of the overall mining recovery, which is the ratio of mill head-grade to the in-situ grade, expressed as a percentage.

3.2.2 Concentration, Smelting and Refining

The treatment of platinum-group metals is a complex process. The main source of ore has traditionally been the Merensky Reef, which is relatively amenable to processing. However, the UG2 Reef, lying below the Merensky, poses significant metallurgical problems. The high chromite content of this reef accumulates as a solid deposit within the furnace. It is only with recent interest in the UG2 Reef due to its higher ore grade and rhodium content, that new processing routes to extract PGM from this ore, have been developed. Recovery is further complicated by the occurrence of PGM, not as a separate mineral type, but in chemical combination or solid solution, either with base metal sulphides or within a silicate mineral matrix. In some areas, as in the proximity of dykes and other intrusions, the base metal minerals have been altered geologically, and this affects their response to the extraction methods used.

Crushing of the ore to particle size is done to promote the metals' chemical and physical separation or concentration processes. It is during this stage that a percentage of PGM is lost in the different processes. Metal recovery during concentration is usually in the range of 71-93 per cent (S Allison, 1982 and Mining Mirror, 1988). Froth flotation, whereby selected chemical reagents induce bubbles, and create an affinity for the metals to adhere to the surface of the froth from which they can easily be gathered, is used.

During smelting, the flotation concentrate is mixed with limestone (to act as flux) and is then heated in a furnace to produce copper-nickel matte which absorbs the PGM. The product of smelting is treated in a base metal refinery to extract the metals, copper, nickel and cobalt and PGM concentrates.

Finally, the PGM metals are refined by essentially confidential processes, to separate the six constituent metals.

3.3 Evaluation of the Mining Companies

Several techniques exist to determine the status of a mining operation. These techniques were used for evaluation, and to demonstrate the impact of variables on the present and future status of the mines (Appendix 4).

A brief description of the variables in the final equation, which combines profit, cost and revenue, follows.

3.3.1 Cost

Costs are obviously involved in any mining operation and are one of the most important criteria in the evaluation of the platinum industry, and an important measure of the future feasibility of an operation. The problem of keeping day-to-day running costs within bounds, is a difficult task. It is aggravated in times of high inflation in a country like South Africa, when extra efforts have to be made either to increase production, to mechanize, or to introduce new operating techniques. The cost factor was the main reason for the closure of the Crocodile River Mine, mentioned in section 3.1.1.

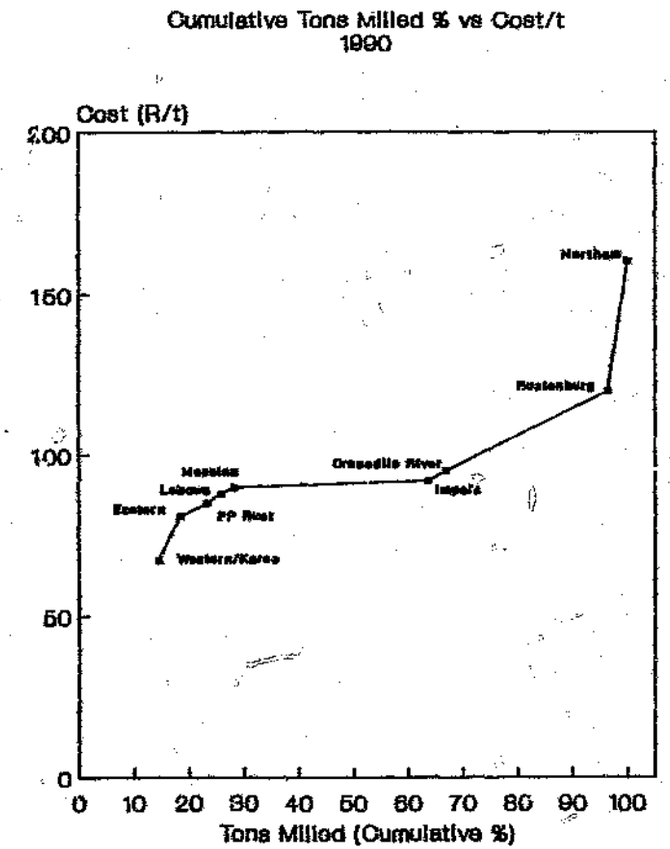
In 1990, D Russel (1990: 14) estimated the average cost per ton to be around R130. The author, however, estimates this figure to be more in the region of R100/t. In the average cost breakdown, on-mine costs account for 82 per cent of total expenditure, treatment and refining 12 per cent and other expenses 6 per cent. Operating cost over and above on-mine cost, add around R19/t to the costs of existing producers. These costs comprise milling - 37 per cent, smelting - 21 per cent, base metal refining - 32 per cent and PGM refining - 10 per cent.

Cost/ton of Ore Milled depends on mining depth and haulage method. Increasing depth will raise cost, while the method of haulage can vary from labour intensive on the one hand to completely mechanised on the other. These differences result in the cost/ton of ore milled varying from one mine to another.

The South African mining industry is undergoing a period where increasing labour-cost and inflation play a major role in the accumulation of costs.

In figure 3.2 the expected **cost per ton of ore milled** and the **cost per kg of platinum produced** is plotted against cumulative tons milled, by the existing and developing platinum mines in South Africa.

Figure 3.2


Cumulative Tons Milled % vs Cost/t
1990
Cost (R/t)
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90 100
Tons Milled (Cumulative %)
Northam
Rustenburg
Crocodile River
Impala
Lebowa
PP Rust
Western/Kroo

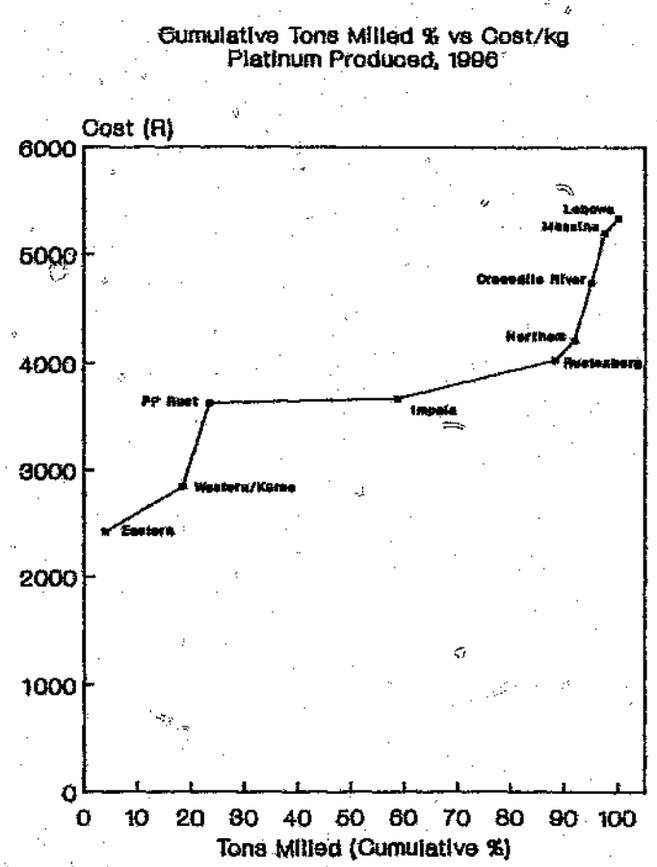
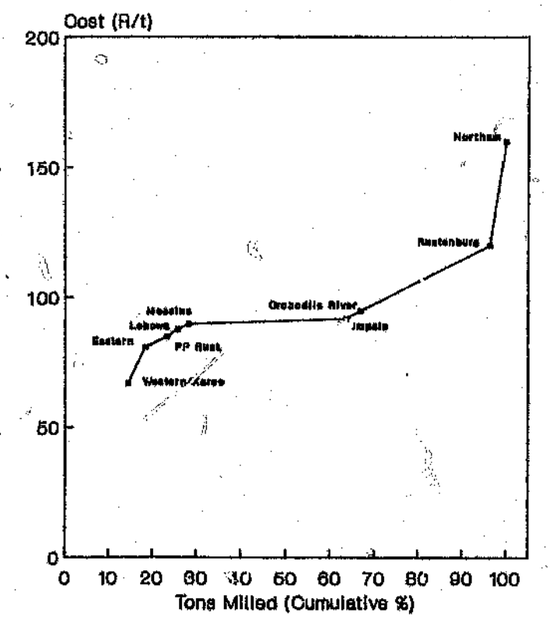
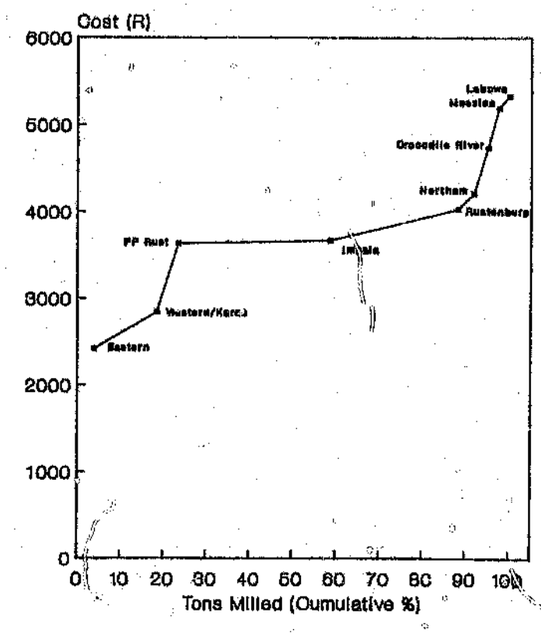

Cumulative Tons Milled % vs Cost/kg
Platinum Produced, 1996
Cost (R)
6000
5000
4000
3000
2000
1000
0
0 10 20 30 40 50 60 70 80 90 100
Tons Milled (Cumulative %)
Lebowa
Crocodile River
Northam
Rustenburg
PP Rust
Impala
Western/Kroo
Eastern

Figure 3.2

Cumulative Tons Milled % vs Cost/t
1990



Cumulative Tons Milled % vs Cost/kg
Platinum Produced, 1996



Interesting to note is the change in ranking order when the cost/kg platinum produced is taken into account.

High cost producers include Lebowa, Messina, Crocodile River and Northam. These mines will, in future, have to find alternative means to counter ever increasing costs. RPM, for instance, is experiencing increasingly difficult mining conditions at certain shafts of the Rustenburg section with increasing mining depth. However, in future, trackless mining methods at RPM and the introduction of a chrome recovery circuit, will help to lower the cost of production. Expansion at Amandelbult and Union sections, results in marginally lower cost, due to shallower deposits at Amandelbult, combined with higher grade. Mines in the Lonrho group are expected to improve profit/t dramatically after 1992, when teething problems at their mines are sorted out.

The deteriorating effect of increasing cost is, however, accelerated by the forecast decline of the platinum price from 1994 to 1997, whereafter an improvement in some mines is expected. The importance of cost was demonstrated with the closure of Crocodile River Mine. On the other hand, Western Platinum enhances cost effectiveness at its shafts through the participation of employees in certain decision-making. This contributes to labour productivity and better cost figures.

3.3.2 Ore Grade and Revenue Distribution

At 1991 metal prices, the average value of the Merensky Reef was R303,42/t, (about R10 more than that of the UG2 Reef), and that of the Platreef was R210,23/t.This indicates the advantage of high grade Merensky Reef ore, as is the case with Rustenburg Platinum Mines and Northam Platinum. However, the UG2 has an advantage over lower grade Merensky Reef operations, due to the high value of rhodium, which is more abundant in the UG2. The

fact that it can be exploited from existing underground shafts by some mines, makes it even more attractive.

Figure 3.3 indicates the revenue contribution of each metal in the different layers.

3.3.3 Revenue

Revenue calculation was derived from five PGM, gold, copper and nickel. Although other products like silver, cobalt sulphuric acid and ammonium sulphate are also produced by the larger mining groups, for simplicity, they have not been included in the calculations. Furthermore, revenue was based on the calculated quantities produced and the expected prices received for the metals during each year under review.

Northam Platinum is by far the highest revenue/ton mine in the industry, followed by the combined mine output of Rustenburg Platinum (Fig 3.4). This can be ascribed to the high grades which originate from the Merensky Reef. Worthy of note is the fact that both of these mines were also classified as high-cost producers, which has a negative effect on profit (Fig. 3.5).

3.3.4 Profit

Profit/t received by the individual mines gives an indication of the control of mining costs by each mine. Figures 3.5 a,b,c show the forecast profit/t of companies. Despite lower revenue/t figures at the mines of the Lonrho Group, cost control by these mines contributes to the better

Fig.3.3 - CONTRIBUTION TO REVENUE FROM PLATINUM-GROUP AND BASE METALS, 1991
Rand/ton milled

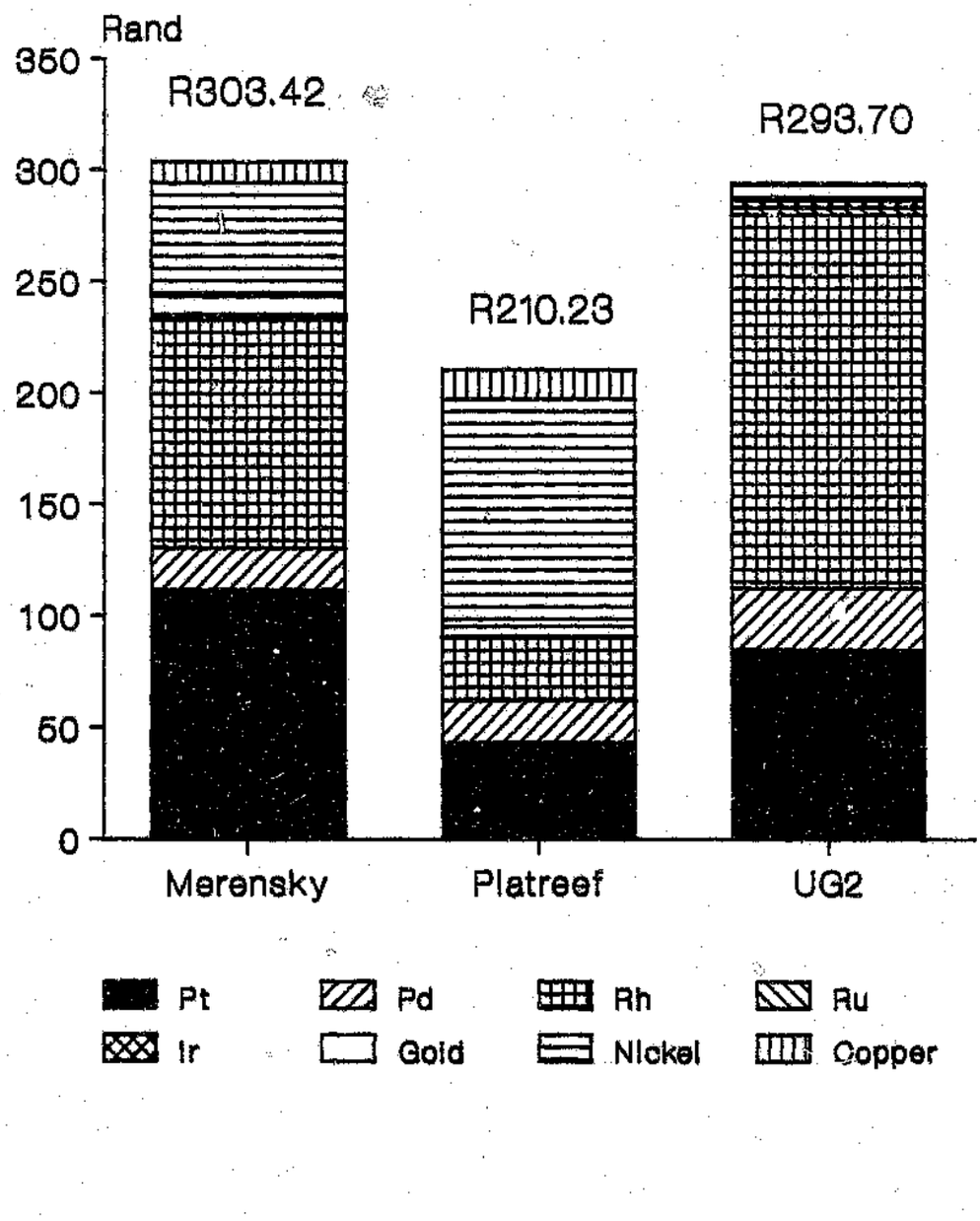
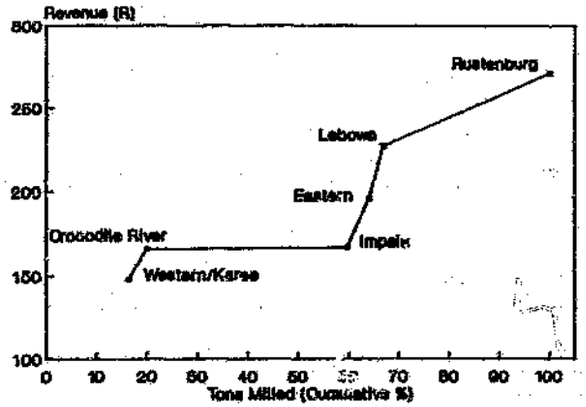
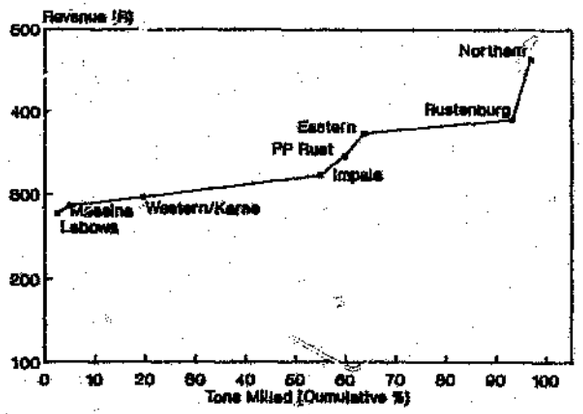


Fig. 3.4 - Cumulative Tons Milled vs Revenue/t

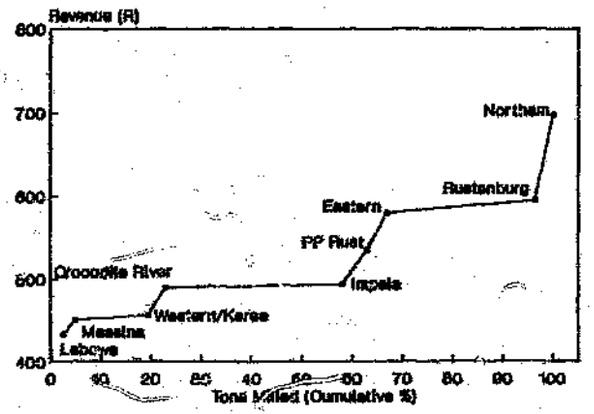
1991



1994



1997



2000

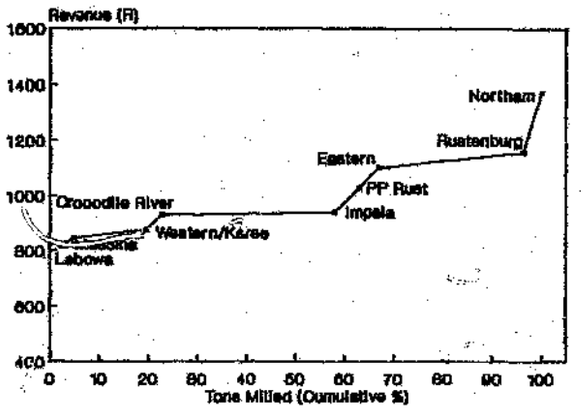
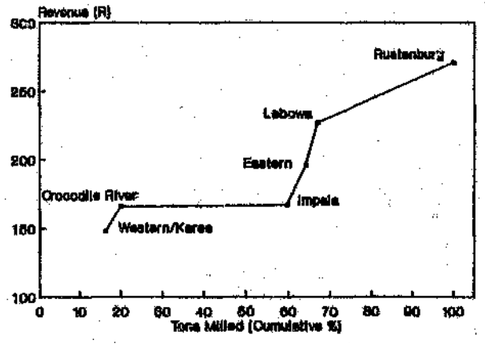
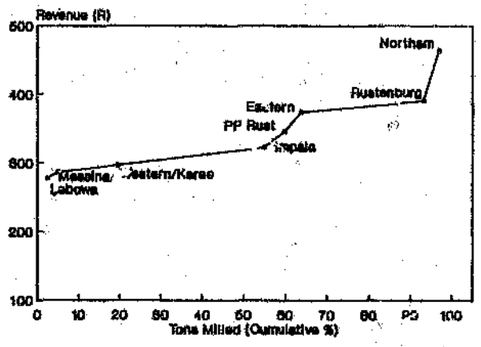


Fig. 3.4 - Cumulative Tons Milled vs Revenue/t

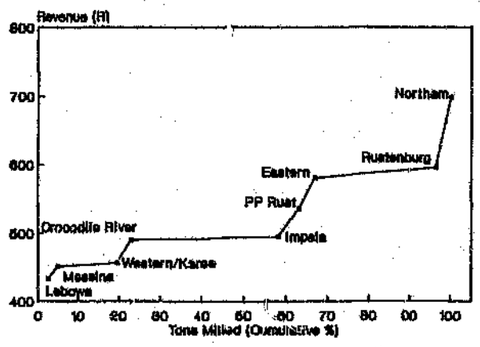
1991



1994



1997



2000

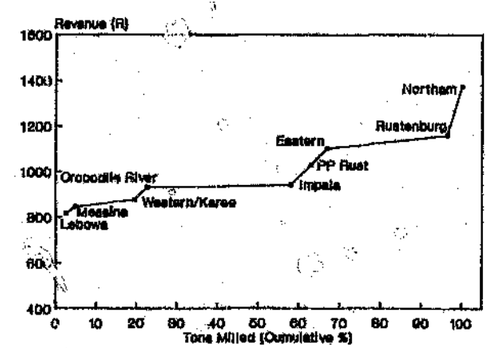


Fig. 3.5a - Cumulative Tons Milled vs Profit/t

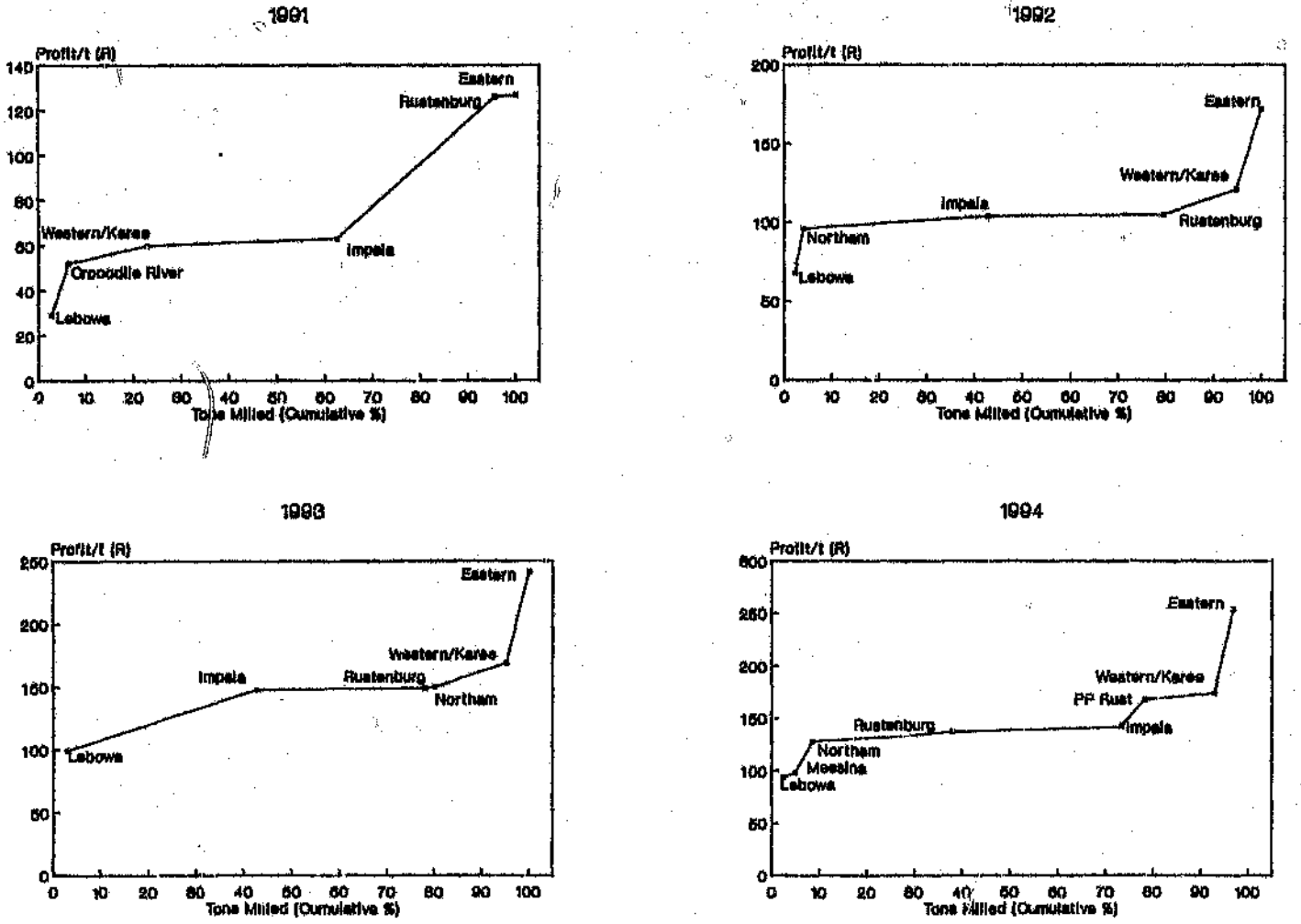


Fig. 3.5b - Cumulative Tons Milled vs Profit/t

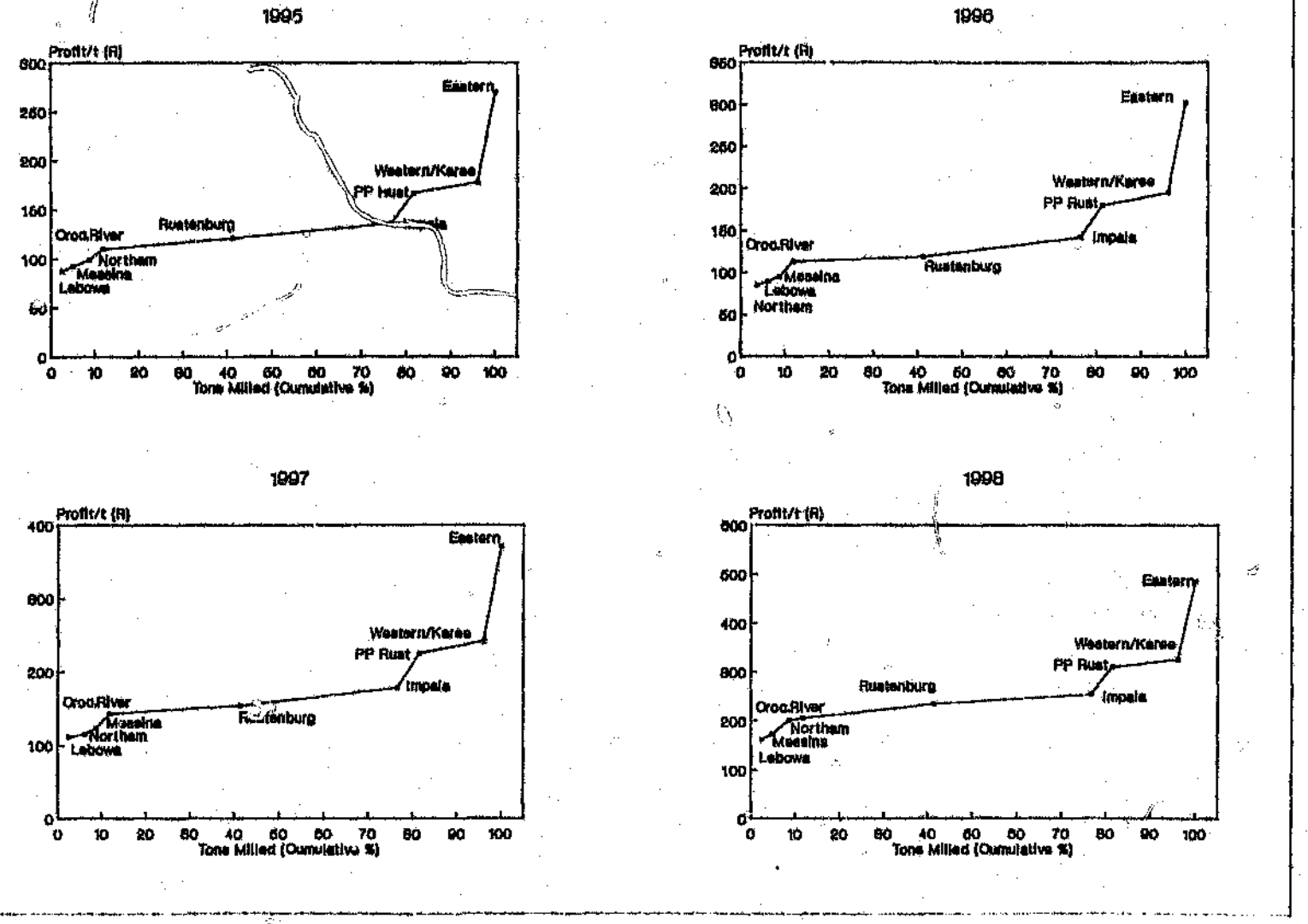
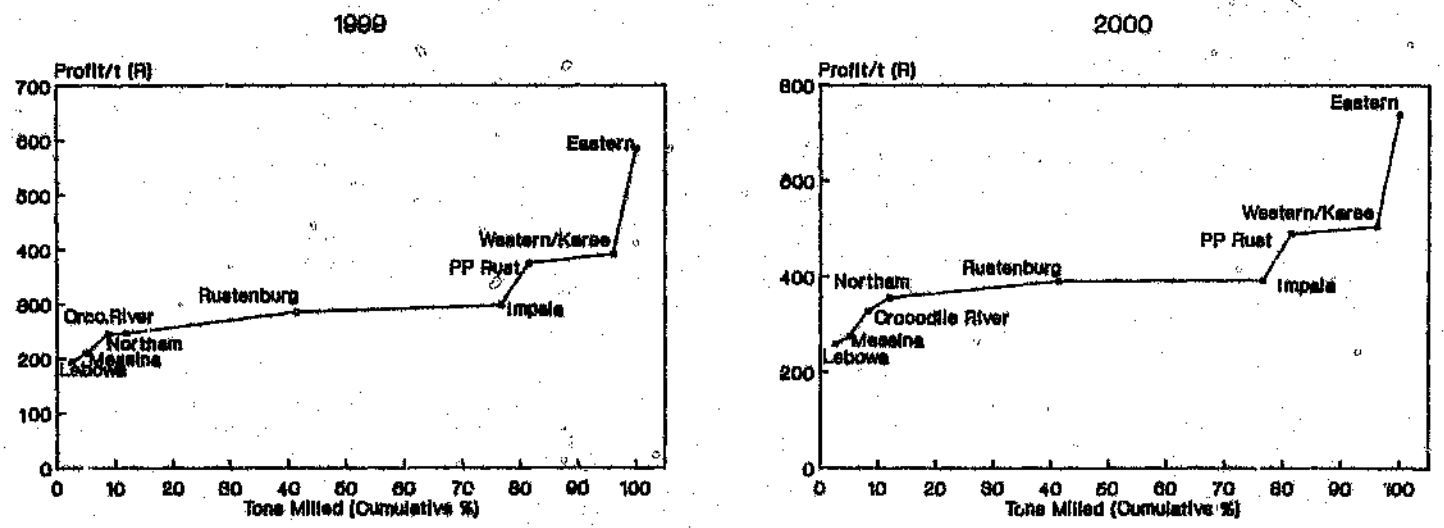


Fig. 3.5c - Cumulative Tons Milled vs Profit/t



performance, for example, Western/Karee, which are now better placed in the ranking order. It is also clear from figure 3.5 that opencast operations are highly profitable. Compared to underground operations they also have the advantage that income is generated more quickly at the start of mining operations. The less profitable mines are Messina, Lebowa, Northam and Crocodile River. The first two of these have additional cost associated with economies of scale, while Northam has extra cost due to the depth of the mine. All three companies have the disadvantage that refining is done either by a sister/parent company or toll refining overseas, which lengthens the refining pipeline of PGM. This is a drawback for new mines, because time is of the utmost importance during the refining of a high value commodity like the platinum-group metals.

If prices perform as assumed in Chapter 2, distinctions between the different mining companies for the period under review are possible. As indicated by the profit/t calculations, the companies most hardest-hit by the low platinum price in 1991-1993 will be Lebowa, Crocodile River, Western Platinum, and Northam with its entry in 1992. There should be, however, a notable recovery of Northam in 1993 and also a strengthening of RPM. This is due to the expected rise in the platinum price, which will benefit high-grade Merensky Reef exploiters. It is possible that during the next downturn, these companies will fall back in rank, due to their reliance on platinum production. Although the grades of Potgietersrust Platinum are lower than producers of other reefs, the company benefits from the high nickel content of the ore and the fact that costs of opencast mining is lower.

3.3.5 Profit/Revenue

Profit/revenue indicates the change in either price or control in cost. At each mine, costs are kept at a constant growth rate, which means that changes in the profit/revenue are due mainly to better metal ratios and initial cost. It is anticipated that Eastern Platinum could be a highly

profitable mine in years to come, followed by its stablemate, Western Platinum. The same applies to Potgietersrust Platinum.

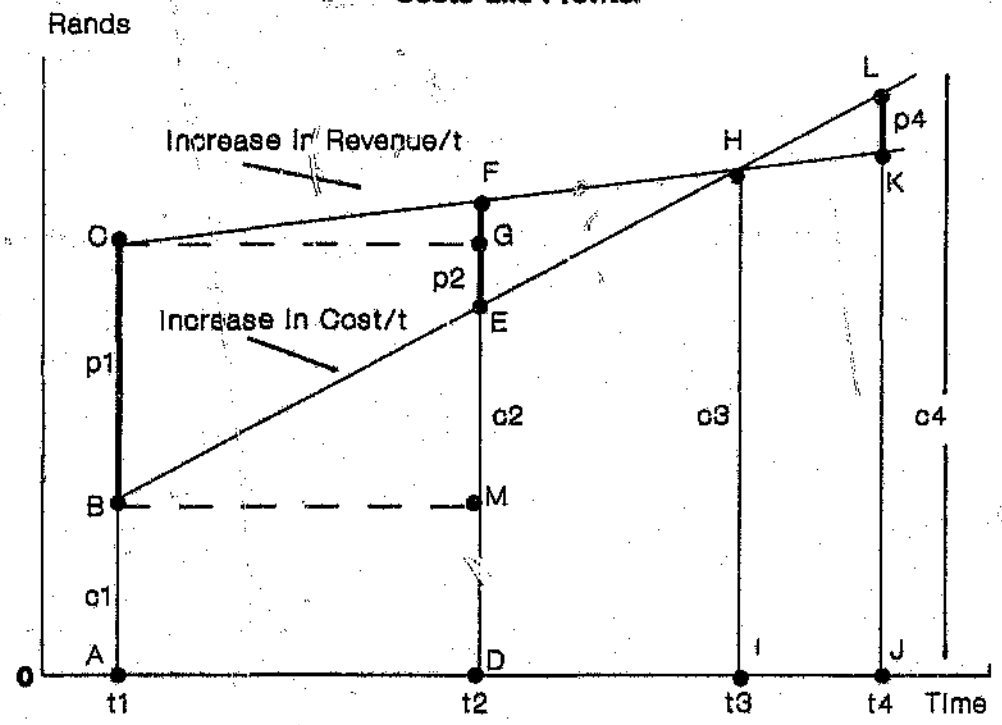
3.3.6 Profit/Cost

All the techniques used so far incorporate only one or two variables and might give an inaccurate mine ranking. An example is the case of Impala and Messina in 1995. It could be assumed that because of a constant cost/t rate of change for both companies, Messina, with the higher revenue/t rate of change, compared to Impala, will experience a less severe change in profit/t. However, this is not the case, as can be seen in Figure 3.6. The line AC represents the revenue/t received at t_1 and AB the cost/t, which means that profit/t equals BC. As time progresses, revenue/t and cost/t increase and since the rate of increase in cost/t is greater than that in revenue/t, the slope BL is greater than CK.

It could thus be assumed that profit/t ('p1') will decline over time to an amount equal to 'p2' at t_2, due to the increase in cost/t from 'c1' to 'c2' being greater than the increase in revenue/t from 'AC' to 'DF' . The project will eventually reach a time t_3 when the cost/t line crosses the revenue/t line at 'H', where profit/t equals zero. Note that at t_4 cost equals 'c4' and revenue equals 'JK', giving a negative profit 'p4' (loss).

It then emerges from the graph that, should no cost reduction measures take place, that the profitable period, 't_3 minus t_1'depends on the ratio between initial profit/t 'p1' and initial cost/t 'c1'. Should 'c1' increase at the expense of 'p1', the intersection 'H' will move to the left, that is, occur at a time earlier than t_3 (giving rise to a shorter profitable period).

Fig. 3.6 - Relation between Revenue, Costs and Profits.



t_1 = R/C-1 (Large Positive)

t_2 = R/C-1 (Small Positive)

t_3 = R/C-1 equal 0

and

t_4 = R/C-1 negative

where

JL = c4 and KL = p4

KL = KJ-JL

= -p4 (negative)

This statement is formulated as follows:

$$\frac{\text{Profit/t}}{\text{Cost/t}}$$

where Profit/t = Revenue/t - Cost/t

and Revenue/t = $\sum_{i=1}^{n}$ Price (R) x Ore Grade (g/t)

n = number of commodities

thus

$$\frac{\text{Profit/t}}{\text{Cost/t}} = \frac{\text{Revenue/t - Cost/t}}{\text{Cost/t}}$$

$$= \frac{\text{Revenue/t}}{\text{Cost/t}} - \frac{\text{Cost/t}}{\text{Cost/t}}$$

thus

$$\frac{\text{Profit/t}}{\text{Cost/t}} = \frac{\text{Revenue/t}}{\text{Cost/t}} - 1$$

This means that the higher the profit/cost factor, the better the performance of a company.

	Impala	Messina
Revenue/t Change	9,5%	11,14%
Cost/t Change	20,3%	20,1%
Profit/t Change	-4,5%	-6,42%
Profit/Cost	0,784	0,4

Table 3.1 indicates the profit/cost-factors for all PGM producers as calculated in this manner for the 10 consecutive years from 1989 to 2000.

Table 3.1 PROFIT/COST FACTORS FOR ALL PGM PRODUCERS

	1	2	3	4	5	6	7	8	9
1989	1,24	1,09	1,67	0,44	0,20	-	-	-	0,46
1990	0,98	0,56	0,19	0,38	0,01	-	-	-	0,94
1991	0,86	0,61	0,85	0,27	1,85	-	-	-	0,45
1992	0,60	0,83	1,42	0,54	2,08	0,42	-	-	-
1993	0,71	0,98	1,65	0,65	2,42	0,54	-	-	-
1994	0,54	0,78	1,41	0,51	2,13	0,38	0,52	0,94	-
1995	0,40	0,62	1,20	0,39	1,88	0,24	0,41	0,78	0,46
1996	0,33	0,54	1,10	0,33	1,74	0,18	0,44	0,70	0,39
1997	0,35	0,57	1,13	0,35	1,78	0,20	0,37	0,73	0,41
1998	0,44	0,67	1,20	0,42	1,94	0,29	0,37	0,83	0,49
1999	0,45	0,65	1,26	0,42	1,94	0,29	0,44	0,84	0,49
2000	0,51	0,72	1,35	0,46	2,04	0,35	0,48	0,91	0,54

1. Rustenburg
2. Impala
3. Western/Karee
4. Lebowa
5. Eastern
6. Northam
7. Messina
8. Potgietersrust
9. Crocodile River

It is clear that certain companies can expect to show a deteriorating profit/cost-factor. This is mainly ascribed to the high cost of production these companies will experience, due to high inflation and rapidly increasing labour cost. However, companies which are able to keep costs low and the mine-call-factor high, are able to out-perform certain higher grade mines. Also clear is the better than expected performance by the opencast operations, Eastern and Potgietersrust Platinum.

It is important to note that capital expenditure and taxation are not taken into account in these calculations. This will put Rustenburg Platinum in a better position with respect to the other producers, which are heavily burdened by capital outlay for the next few years.

Finally, an equation given by Posel (1989: 34), was used to determine the performance of the different mines over the whole decade, to indicate the overall increase or decrease in profit:

$$\text{Change in Profit/t} = \frac{(\text{Profit/Cost})e-h}{\text{Profit/Cost}}$$

where e = % increase predicted in the revenue/t

h = % increase predicted in the cost/t

The factor 'e' was calculated, in this instance, from the expected increase in revenue received from 1989 to 2000, from all the metals, and was found to be equal to 18,31 per cent.

The factor 'h' was calculated on the assumption that the platinum mines will experience the same increase in cost/t as the gold mines had over the past 10 years. This was found to be equal to 20,3 per cent. It is envisaged that 'e' will experience a lower growth rate than 'h' (Also demonstrated in Figure 3.6 by curve CK having a less steep gradient than curve BL).

These factors were calculated to obtain two scenarios:

Actual	e=18	h=20
Pessimistic	e=15	h=20

The point at which the graph crosses the x-axis, indicates the minimum value of the profit/cost-factor which is permitted under the assumption of the predicted values for 'e' and 'h' as indicated on Figure 3.7 a: point A=0,38 and 3.7 b: point B=0,10. An optimistic scenario was not necessary, because all the mines already satisfy the conditions as stated in the actual scenario.

Figure 3.7 shows the influence of the changes in the price of commodities on the different mines.

One mine, Northam, at the lower end might experience cash flow difficulties at a lower revenue growth rate. However, this mine is the first entry of Gold Fields South Africa (GFSA) into the platinum market, and with capital outlay already more than R-billion on this mine, it is virtually impossible to postpone development further. This mine will, however, benefit at a later stage, when other mines reach the same depths, some at a lower grade than Northam.

Two mines also at the lower end are Messina and Crocodile River. These two mines were closed as a result of long-term incapability to produce a positive cash flow, due to the low PGM prices at the start of the mines. Eastern, Western/Karee and Potgietersrust Platinum are well geared to withstand virtually any price decline, while Impala is not expected to experience much difficulty. It must be kept in mind, however, that Impala does have a heavy

Fig. 3.7 - Influence of Revenue on the Profit/Cost-factor and Consequent Change in Profits

Fig. a - Pessimistic Scenario where e=15 and h=20

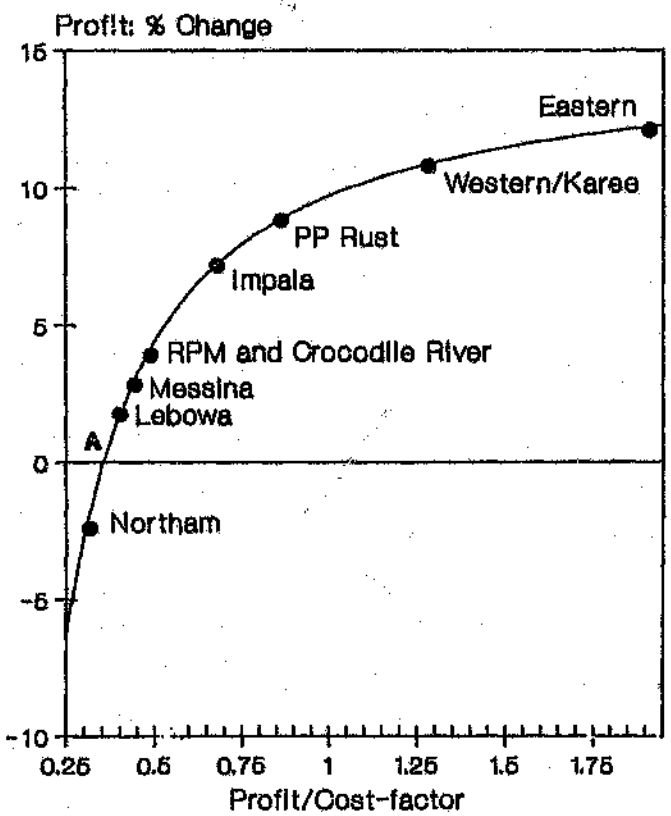
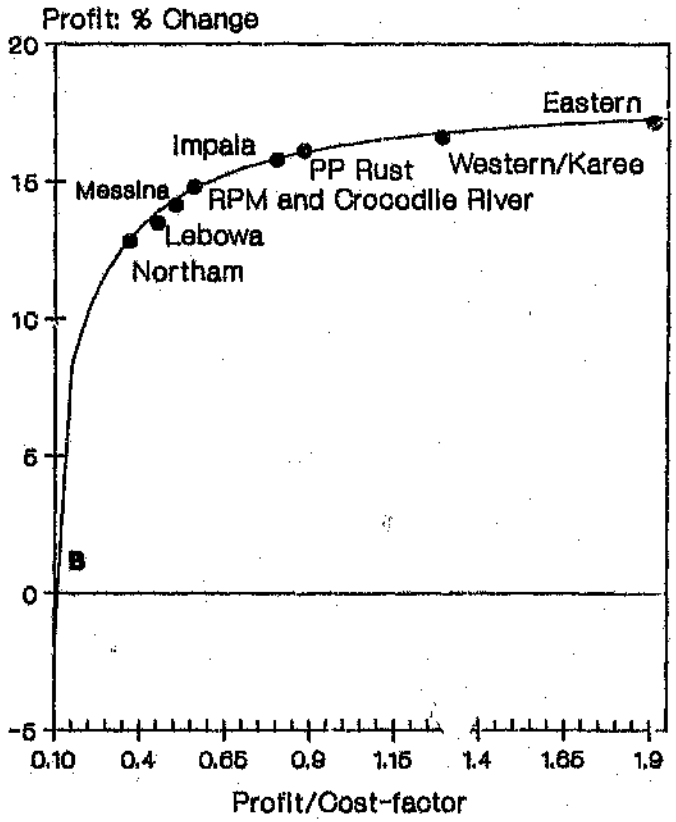


Fig. b - Actual Scenario where e=18 and h=20



capital expenditure burden which will have an influence on the final distributable profit. RPM is expected to fare better against the other companies during the period 1991/1992. Expansion at Amandelbult and Union sections will also result in marginally lower cost due to shallower deposits at Amandelbult, along with higher grade.

CHAPTER 4

4 SUMMARY AND CONCLUSION

4.1 Introduction

During the 1980's, platinum-group metal mining became a feasible alternative to gold mining for mining houses in South Africa, but increased exploration and exploitation created an oversupply of platinum which the market was unable to absorb. The conditions which are to blame for market disequilibrium were caused by various factors.

Prior to 1989, PGM producers' ability to adapt to market conditions was much greater than after the Ford announcement in that year, that it intended using palladium as a substitute for platinum in autocatalysts. After this announcement, consumers were in a position to manipulate the platinum market to a greater extent, in particular the autocatalyst market which is the biggest consumer of platinum. Also during this period, a third force became more apparent, namely the role of the investment sector. Investment plays a dual role in that it tends to stabilise the market in both directions.

PGM producers in South Africa need to take notice of these important signals,because they are a warning that future entry and the acquisition of market share is going to be more difficult than before 1989.

4.2 Platinum-Group Metal Supply, Demand and Price Forecast

A technical approach has been followed to forecast the fundamental changes in the PGM market for the next ten years, but the final results conform well with market expectations. The relationship between the world consumption of platinum and price is strong and forms the basis for price expectations over the next ten years.

The forecast indicates that consumption will continue to be sluggish until the second half of 1992, when demand will start to increase. Production will have to be set accordingly, but will result in an oversupply in 1996 when demand is expected to moderate. A surplus of platinum will most likely be taken up by fuel cells, when expected large scale commercialisation takes place at the end of the decade.

The technical approach which has been followed to forecast the prices of commodities, give a expected longer term view, but it fails to identify short-term fluctuations. It is, therefore impossible to identify short term influences. It does, however, gives an clear indication of future cycles, which is needed for future planning.

4.3 The PGM Industry

PGM have many unique properties and as such have found many applications in industry. The high price of some of the metals, like all other expensive metals, has exposed it to substitution. Platinum, rhodium and palladium, however, will continue to be the important metals in autocatalysts, and many new and exciting uses are continuously being found for them through research.

Extraction methods have become very sophisticated, but the cost of production, as well as capital investment cost to start a new mine and refinery, have become very high. Up to 1989, many producers could afford to exploit several platinum deposits, but high cost, the lack of funds and low platinum prices, have forced less economic prospects temporarily out of business. Even the established producers, like Rustenburg Platinum Mines and Impala Platinum, have found it difficult at prevalent prices in 1990-1992.

The rising production cost and difficult economic milieu, have caused a shift backwards to an oligopolistic market, which existed before the expansion boom in the 1980's. It can also be argued that the closure of mines poses a threat to supply for the next three years. However, it can be expected that when that happens, the free market price will adjust itself to allow new producers to commence operations.

Chapter 2 identified the important fundamentals in the world PGM markets, and the interplay of oligopoly in the major producing country, namely South Africa. Until 1989, this market worked very efficiently in favour of producers who were able to adjust to changes in the fundamentals.

> **A drastic change has occurred since 1989, with consumers' influence on the price of the different commodities having a much greater effect on the price than before. This is because of the absolute necessity of platinum applications in expanding sectors. A third force, namely investment, has also came into play. By contrast to the one-sided flow which is demand orientated, the investment sector now started to play a dual role, i.e. on the one hand it tends to stabilise the market where investors buy at a low, thereby acting as support, and on the other hand tends to sell at any observable rise in the price.**

It is clear, however, that after the announcement made by the Ford Motor Company early in 1989, PGM joined the ranks of other metals with oversupplied markets at the beginning of the economic downturn in the early 1990's; a situation which has kept prices under pressure. The platinum price underwent a complete re-rating during 1990, and it is unlikely that the world will soon see platinum breaking the $1 000/ozt level again.

It emerges from the graphs that Westplats/Karee, Potgietersrust and Eastplats are highly profitable producers in the longer term, with Rustenburg Platinum Mines and Impala Platinum,medium profit mines. Northam, Messina, Lebowa Platinum and Crocodile River Mine are unequivocally low profit mines.

Rustenburg Platinum Mines is the market leader in terms of platinum production, and as such exhibits the most stability in the market. Geographically, it is better situated than Impala and Lebowa platinum, both of whom largely employ homogenous labour forces and experienced labour unrest in the past. To date the mining operations of RPM have not been plagued by serious incidents of labour unrest. In addition, RPM has a sound balance sheet, which enables them to withstand any short-term problem.

In terms of long-term growth, the company stands solid, due to the even spread of metals and the high grade of its lease areas. It is evident from the profit/cost-factor that the company will greatly benefit from the turnaround in the platinum industry in 1992/93 and again in 1997. Rustenburg Platinum Mines also has the advantage that Johnson Matthey, one of the world's largest platinum dealers, is marketing its products.

The sharp decline in the price of the commodities in 1989-1992 undoubtely had a negative influence on the performance of **Impala Platinum**. It came at a time when the company experienced labour problems, and when it was committed to expansions due to the shortening life of its existing areas. The company also faced major upgrading to its refineries due to

metal lock-up. Should the company overcome these problems, it is likely to perform better in the longer term. Impala also has the advantage of income from the Lonrho Group of companies (Fig. 3.1).

The Lonrho Group of companies, **Western/Karee Platinum and Eastern Platinum**, with the main advantage of shallow deposits and cost effective production, are in the best position to overcome the difficult times.

Four companies namely, **Lebowa, Messina, Northam and Crocodile River** are, however, facing difficult times. In the case of Northam and Crocodile River, which are higher revenue earners, reduction in cost could put these two mines in a better position.

> **Two of these mines, Messina and Crocodile River, were closed. It is doubtful whether any further closures will occur.**

Lebowa Mine is already an established mine that could adapt to a certain extent in the market, and as explained earlier, Northam Platinum is the first entry of Gold Fields into the platinum arena and they are expected to do everything in their power to remain the platinum industry.

> **All new underground operations on the Merensky Reef and UG2 Reef were to a large extent unsuccessful, which leads one to the conclusion that, provided there are adequate reserves at acceptable recovery grades on the Merensky Reef and UG2 Reef, it is easier and cheaper to expand existing operations than to start new, integrated platinum operations from scratch.**

However, South African producers must avoid adverse competition, which could lead to imbalances in market conditions and price volatility.

Although the future looks very gloomy for at least the largest part of 1992, the producers which survive the recession period, and can implement effective cost saving measures, will continue to make profits. Weaknesses in the local currency will be an additional bonus for producers.

APPENDIX 1

SOUTH AFRICA

METAL PRODUCTION (ozt)

YEAR	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Platinum	2440759	2614717	2652884	2873922	3158173	3531405	3646464	3704864	3746208	3836619	4094114	4213637
Palladium	1059699	1141192	1162572	1270687	1400476	1677026	1760440	1788764	1828392	1886851	2062743	2144570
Rhodium	189984	218499	228914	249976	277304	312035	326522	337063	342234	349612	385005	399951
Ruthenium	304477	346805	360111	392380	434258	485170	506180	520079	532750	550255	608218	636765
Osmium	24648	25138	25294	27816	30606	34077	34564	34637	35284	36228	39549	40705
Iridium	51913	54523	56055	62373	69958	78389	80736	81226	82537	84523	90984	92872
PGM	4071480	4400874	4485830	4877154	5370775	6118103	6354907	6466634	6567406	6744088	7280613	7528500
Gold	174426	180561	177896	187615	203382	224359	230266	231542	233112	236997	247609	250761
Nickel (T)	34477	35431	34764	37155	40476	45546	46865	46985	47629	48905	52045	52659
Copper (T)	22108	22726	22200	23800	26171	29739	30657	30708	31242	32208	34647	35051

METAL PRODUCTION (Kg)

YEAR	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Platinum	75916	81327	82514	89389	98230	109839	113418	115234	116520	119332	127341	131059
Growth		7.13	1.46	8.33	9.89	11.82	3.26	1.60	1.12	2.41	6.71	2.92
Palladium	32960	35495	36160	39523	43560	52161	54756	55637	56869	58688	64158	66704
Rhodium	5909	6795	7120	7775	8625	9705	10156	10484	10645	10874	11975	12440
Ruthenium	9470	10787	11201	12204	13507	15090	15744	16176	16570	17115	18918	19806
Osmium	767	782	787	865	952	1060	1075	1077	1097	1127	1230	1266
Iridium	1615	1696	1744	1940	2176	2439	2511	2526	2567	2629	2330	2889
PGM	126637	136882	139525	151697	167050	190294	197660	201135	204269	209764	226412	234152
Growth		8.09	1.93	8.72	10.12	13.91	3.87	1.76	1.56	2.69	7.96	3.40
Gold	5425	5616	5533	5835	6326	6978	7162	7202	7251	7371	7702	7800
Nickel (T)	34477	35431	34766	37156	40479	45546	46865	46985	47629	48905	52045	52659
Copper (T)	22108	22726	22204	23803	26181	29739	30657	30708	31242	32208	34647	35051

APPENDIX 2

WORLD PLATINUM PRODUCTION (kg)

Mine	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
TOTAL RSA PRODUCTION	81491	86468	82514	89389	96230	109839	113418	115234	116520	119332	127341	131059
USSR Sales	17107	21772	22268	14453	15152	15851	16550	17250	17949	18648	19347	20046
Zimbabwe	0	0	0	0	0	0	0	1361	3247	3247	3247	3247
North America:	6065	5754	7508	7526	8165	8185	8204	8223	8243	9553	15280	15300
CANADA: Other	4635	5781	5798	5816	5833	5851	5868	5886	5903	5921	5939	5957
Lac des Iles	0	0	0	0	622	624	625	628	629	631	633	635
USA:	1430	1710	1710	1710	1710	1710	1710	1710	1710	3000	8708	8708
Stillwater	1430	1710	1710	1710	1710	1710	1710	1710	1710	3000	5287	5287
East Boulder	0	0	0	0	0	0	0	0	0	0	3421	3421
Other	1866	2021	2025	2029	2033	2037	2041	2045	2049	2054	2058	2062
Secondary Supply	5443	6532	9658	9884	9734	12676	14789	17279	18939	19844	21957	22938
TOTAL PRODUCTION (kg)	111972	122547	123973	123281	133314	148588	155002	161393	166947	172677	189230	194651
TOTAL PROD ('000 ozt)	3600	3940	3986	3964	4286	4777	4983	5189	5367	5552	6084	6258

WORLD PLATINUM DEMAND (kg)

YEAR	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
AUTOCATALYST	45256	47277	51176	58072	71501	73679	75494	76521	78886	80833	82418	83698
JEWELLERY	40435	42456	38996	38270	39931	44131	46951	51579	54891	60079	64025	68344
INVESTMENT	4977	6221	6175	8213	12743	11610	10025	7308	7760	10025	11157	12290
CHEMICAL	5132	5376	5876	5375	4875	4374	3874	3374	2873	2373	1872	1372
ELECTRICAL	6065	6376	6231	6087	5942	5797	5652	5507	5363	5217	5073	4928
GLASS	4354	4199	3752	3710	3668	3627	3885	3543	3502	3460	3418	3377
PETROLEUM	2333	3732	1757	1894	2050	2215	2389	2578	2787	3010	3250	3512
FUEL CELLS	30	53	102	200	397	749	1446	2770	5232	9632	16967	27878
OTHER	3577	3732	3664	3399	3133	2868	2603	2337	2072	1806	1541	1275
TOTAL DEMAND (kg)	112158	120423	117719	125220	144230	149050	152319	155517	163366	176435	189721	206674
BALANCE	-186	2124	6254	-1939	-10916	-462	2683	5876	3581	-3758	-491	-12023

APPENDIX 3

METAL PRICES

YEAR		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Average Metal Prices:													
Platinum	$/ozt	451.4	423.48	373.62	457.84	556.74	491.59	410.18	372.4	395.28	473.96	487.66	553.49
Palladium	$/ozt	143.7	113.95	148.1	152.72	157.35	161.97	166.6	171.23	175.85	180.48	185.11	189.73
Rhodium	$/ozt	1300	3567	2528	2835	3434	3531	3612	3657	3763	3849	3920	3977
Ruthenium	$/ozt	67	66.45	65.3	63.74	62.17	60.6	59.03	57.47	55.9	54.33	52.76	51.19
Iridium	$/ozt	314.56	322.25	317.76	305.12	294.49	282.85	271.22	259.58	247.95	236.31	224.68	21.04
Gold	$/ozt	432.75	383.58	489.11	508.78	528.445	548.1	567.77	587.43	607.09	626.76	646.42	666
Nickel	$/t	13283	8860	9909	10417	10918	11412	11900	12380	12853	13318	13774	14223
Copper	L/t	1734.89	1496.71	1515.12	1574.91	1654.71	1694.49	1754.28	1814.08	1873.87	1933.66	1993.458	2053.25

APPENDIX 4

MINE EVALUATION PARAMETERS
MINE: Impala

Year		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Metals Produced:													
Platinum	ozt	1053061	1046153	976360	1024627	1172151	1225874	1225874	1225874	1225874	1225874	1291421	1291421
Palladium	ozt	466971	464318	437467	458889	520240	553848	553848	553848	553848	553848	606661	606661
Rhodium	ozt	88828	88391	83960	86038	99037	107045	107045	107045	107045	107045	121011	121011
Ruthenium	ozt	129768	130880	121757	127711	144591	154336	154336	154336	154336	154336	170000	170000
Iridium	ozt	22531	22402	21097	22130	25100	26699	26699	26699	26699	26699	29193	29193
Gold	ozt	77644	78120	71625	75182	86386	89559	89559	89559	89559	89559	92474	92474
Nickel	t	14152	14152	13035	13684	15744	16279	16279	16279	16279	16279	16706	16706
Copper	t	10894	10970	10025	10524	12119	12509	12509	12509	12509	12509	12786	12786
Tons Milled:		14520000	14640000	13575600	14241600	16173600	17160000	17160000	17160000	17160000	17160000	18660000	18660000
Exchange Rate:	R/$	2.8	2.59	2.86	3.23	3.82	4.12	4.8	5.83	6.62	7.79	9.17	10.78
	R/£	4.1	4.61	4.78	4.61	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Revenue/Ton Milled:	R	144	143	167	229	298	323	353	404	494	633	754	942
%			-0.86%	17.09%	36.79%	30.49%	8.25%	9.40%	14.29%	22.23%	28.25%	19.10%	24.93%
Cost/Ton Milled@20.3%	R	69	92	104	125	151	181	218	262	315	379	456	549
%			32.92%	13.31%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%
Profit/Ton Milled:	R	75	51	63	104	148	142	136	142	178	254	298	393
y%			-32.01%	23.91%	63.95%	42.61%	-4.02%	-4.50%	4.63%	25.80%	42.31%	17.31%	32.03%
Cost/kg Platinum	R	952.1766	1284.516	1446.085	1739.016	2076.822	2534.622	3049.151	3668.128	4411.758	5308.548	6591.947	7930.112
P/R ratio		52.05%	35.70%	37.78%	45.28%	49.56%	43.94%	38.36%	35.11%	36.14%	40.10%	39.50%	41.74%
Profit/Cost		1.085	0.555	0.607	0.828	0.982	0.784	0.622	0.541	0.566	0.669	0.653	0.716
Mining Revenue	R'000	2091100	2094900	2269200	3256332	4825760	5542344	6063553	6929945	8470644	10863876	14070065	17578124
Working Costs	R'000	1002700	1343800	1411900	1781843	2434349	3107127	3737874	4496563	5409485	6507611	8512979	10241114
Mining Profit	R'000	1088400	746100	857300	1474489	2391431	2435217	2325678	2433382	3061158	4356265	5557086	7337011

MINE: Rustenburg Platinum Mines Ltd

YEAR		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Metals Produced:													
Platinum	ozt	1162052	1167382	1183483	1242940	1302396	1302396	1302396	1302396	1302396	1302396	1302396	1302396
Palladium	ozt	486174	490159	496169	519475	542782	542782	542782	542782	542782	542782	542782	542782
Rhodium	ozt	74329	75165	77696	84891	92086	92086	92086	92086	92086	92086	92086	92086
Ruthenium	ozt	129608	130580	133251	141490	149729	149729	149729	149729	149729	149729	149729	149729
Iridium	ozt	25792	26149	27230	30276	33322	33322	33322	33322	33322	33322	33322	33322
Gold	ozt	82097	82143	82283	83387	84491	84491	84491	84491	84491	84491	84491	84491
Nickel	t	18114	18125	18159	18721	19282	19282	19282	19282	19282	19282	19282	19282
Copper	t	9609	9613	9628	9821	10014	10014	10014	10014	10014	10014	10014	10014
Tons Milled:		12259800	12349200	12619800	13459800	14299800	14299800	14299800	14299800	14299800	14299800	14299800	14299800
Exchange Rate:	R/$	2.6	2.59	2.86	3.23	3.62	4.12	4.8	5.63	6.52	7.79	9.17	10.78
	R/£	4.1	4.61	4.78	4.61	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Revenue/Ton Milled:	R	239	238	271	290	350	391	426	486	595	766	925	1139
Δ			-0.32%	13.88%	3.16%	20.50%	8.63%	8.96%	14.13%	22.39%	28.78%	20.67%	25.35%
Cost/Ton Milled:@20,3%	R	107	120	146	176	211	254	305	367	441	531	639	768
Δ			12.51%	21.23%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%
Profit/Ton Milled:	R	132	118	126	105	140	137	121	119	154	235	286	391
Δ%			-10.67%	6.41%	-16.60%	42.20%	-7.86%	-11.93%	-1.42%	28.82%	53.15%	21.51%	36.63%
Cost/kg Platinum	R	1126.446	1270.792	1352.874	1697.142	2314.003	2783.745	3346.846	4028.662	4845.48	5830.316	7013.87	8437.885
Profitability (P/R)		55.35%	49.80%	46.36%	37.44%	41.43%	35.14%	28.40%	24.53%	25.82%	30.70%	30.92%	33.70%
Profit/Cost		1.239	0.984	0.864	0.598	0.707	0.542	0.397	0.325	0.348	0.443	0.449	0.508
Mining Revenue	R'000	2931500	2943500	3425500	3768997	5146348	5589616	6091332	6952091	8506632	10957663	13222643	16574669
Working Costs	R'000	1309000	1483500	1837800	2358034	3013748	3625539	4361824	5246913	6312037	7593380	9134836	10989208
Mining Profit	R'000	1622500	1460000	1587700	1410964	2131599	1964077	1729826	1705178	2196595	3364283	4088007	5585462

MINE: Western/Karee

Year		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Metals Produced:													
Platinum	ozt	181598	247196	313633	355202	389600	426850	443959	443959	443959	443959	443959	443959
Palladium	ozt	76540	104438	136114	153931	168688	184880	191424	191424	191424	191424	191424	191424
Rhodium	ozt	19919	28081	36047	41147	46274	51903	54919	54919	54919	54919	54919	54919
Ruthenium	ozt	33396	47667	61851	70717	79176	88850	93807	93807	93807	93807	93807	93807
Iridium	ozt	2973	4433	5935	6823	7821	8488	8903	8903	8903	8903	8903	8903
Gold	ozt	13724	16946	20155	22181	24205	26426	27610	27610	27610	27610	27610	27610
Nickel	t	1837	2449	2870	3141	3306	3480	3516	3516	3516	3516	3516	3516
Copper	t	1232	1671	1976	2157	2270	2387	2402	2402	2402	2402	2402	2402
Tons Milled:		2844000	4271400	5217000	5616000	6160000	6792000	7080000	7080000	7080000	7080000	7080000	7080000
Exchange Rate:	R/$	2.8	2.59	2.86	3.23	3.62	4.12	4.8	5.63	6.62	7.79	9.17	10.73
	R/L	4.1	4.61	4.78	4.61	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Revenue/Ton Milled:	R	146	154	148	206	271	297	327	374	457	584	703	877
a			5.12%	-3.96%	39.37%	31.64%	9.45%	10.03%	14.39%	22.19%	27.82%	20.47%	24.73%
Cost/Ton Milled:@20,3%	R	52	67	71	85	102	123	148	178	215	283	311	374
b			29.60%	5.62%	20.33%	20.33%	20.33%	20.33%	20.33%	20.33%	20.33%	20.33%	20.33%
Profit/Ton Milled:	R	95	80	80	121	169	174	178	195	242	325	392	503
y%			-7.94%	-24.90%	102.17%	39.60%	2.85%	2.72%	9.46%	23.88%	34.46%	20.59%	28.21%
Cost/kg Platinum	R	942.8298	1283.648	1454.629	1345.07	1623.816	1960.034	2353.771	2844.326	3422.578	4118.308	4955.656	5963.141
P/R ratio		58.90%	51.75%	40.47%	58.71%	62.26%	58.51%	54.62%	52.27%	52.99%	55.75%	55.80%	57.36%
Profit/Cost		1.670	1.190	0.846	1.422	1.650	1.410	1.204	1.095	1.127	1.280	1.262	1.345
Mining Revenue	R'000	416569	657652	771313	1157173	1670296	2016336	2312548	2643417	3232374	4131540	4977425	6208234
Working Costs	R'000	171216	317312	469129	477771.7	632638.7	836740.4	1049418	1262764	1519484	1828395	2200106	2647390
Mining Profit	R'000	245353	340380	312184	679401	1043658	1179698	1263130	1380653	1712890	2303146	2777317	3560844

MINE: Labowa Platinum Mines Ltd

YEAR		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Metals Produced:													
Platinum	ozt	19206	19206	24608	42013	60019	60019	60019	60019	60019	60019	60019	60019
Palladium	ozt	18110	18110	23203	39615	56593	56593	56593	56593	56593	56593	56593	56593
Rhodium	ozt	2408	2408	3085	5268	7525	7525	7525	7525	7525	7525	7525	7525
Ruthenium	ozt	5718	5718	7326	12506	17869	17869	17869	17869	17869	17869	17869	17869
Iridium	ozt	409	409	525	895	1280	1280	1280	1280	1280	1280	1280	1280
Gold	ozs	418	418	536	915	1307	1307	1307	1307	1307	1307	1307	1307
Nickel	t	323	323	414	708	1011	1011	1011	1011	1011	1011	1011	1011
Copper	t	350	350	449	767	1095	1095	1095	1095	1095	1095	1095	1095
Tons Milled:		384000	384000	492000	840000	1200000	1200000	1200000	1200000	1200000	1200000	1200000	1200000
Exchange Rate:	R/$	2.6	2.59	2.85	3.23	3.62	4.12	4.9	5.63	6.52	7.79	9.17	10.76
"	R/L	4.1	4.81	4.76	4.61	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Revenue/Ton Milled:	R	178	202	227	196	252	278	309	356	433	548	660	818
a			13.14%	12.69%	-14.02%	28.97%	10.22%	11.09%	15.18%	21.77%	26.54%	20.38%	23.96%
Cost/Ton Milled:@20,3%	R	124	88	106	127	163	184	222	267	321	386	484	559
b			-29.16%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%
Profit/Ton Milled:	R	54	81	29	58	99	94	87	89	112	161	195	259
y%			-5.29%	-44.14%	137.96%	45.15%	-5.37%	-7.03%	2.03%	26.20%	44.39%	20.57%	32.66%
Cost/kg Platinum	R	2483.599	3009.476	3974.317	2546.3	3083.177	3686.002	4433.057	5332.967	6415.56	7717.918	9264.656	11169.44
Profitability (P/R)		30.36%	25.42%	12.60%	34.88%	39.25%	33.70%	28.20%	24.99%	25.90%	29.55%	29.60%	31.67%
Profit/Cost		0.436	0.583	0.271	0.536	0.646	0.508	0.393	0.333	0.349	0.419	0.420	0.464
Mining Revenue	R'000	68900	77500	111900	164266	302641	333586	370575	426705	519615	657510	791506	981134
Working Costs	R'000	47700	57800	97800	106977.7	183848.8	221170.1	266067.6	320079.4	386055.5	463221.7	557255.8	670378.7
Mining Profit	R'000	20800	19700	14100	57288	118792	112415	104507	106625	134559	194288	234250	310756

MINE: Eastern Platinum Ltd

YEAR		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Metals Produced:													
Platinum	ozt	2932	25280	94400	137309	137309	137309	137309	137309	137309	137309	137309	137309
Palladium	ozt	1282	11059	41295	60066	60066	60066	60066	60066	60066	60066	60066	60066
Rhodium	ozt	546	4709	17584	25577	25577	25577	25577	25577	25577	25577	25577	25577
Ruthenium	ozt	684	5899	22027	32039	32039	32039	32039	32039	32039	32039	32039	32039
Irridium	ozt	24	208	777	1131	1131	1131	1131	1131	1131	1131	1131	1131
Gold	ozt	63	541	2021	2940	2940	2940	2940	2940	2940	2940	2940	2940
Nickel	t	5	57	165	240	240	240	240	240	240	240	240	240
Copper	t	2	24	71	103	103	103	103	103	103	103	103	103
Tons Milled:		40992	504996	1320000	1920000	1920000	1920000	1920000	1920000	1920000	1920000	1920000	1920000
Exchange Rate:	R/$	2.8	2.59	2.86	3.23	3.62	4.12	4.8	5.63	6.82	7.79	9.17	10.78
	R/£	4.1	4.61	4.78	4.61	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Revenue/Ton Milled:	R	23	61	196	254	340	374	414	475	580	737	886	1102
%			165.93%	221.28%	29.94%	33.78%	9.97%	10.67%	14.69%	22.10%	27.03%	20.35%	24.30%
Cost/Ton Milled@20,3%	R	55	81	69	83	99	120	144	173	208	251	302	363
%			46.76%	-14.80%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.90%	20.30%	20.30%
Profit/Ton Milled:	R	11	1	127	172	241	254	270	302	371	486	585	739
y%			-89.50%	11167.64%	35.16%	40.27%	5.70%	6.13%	11.70%	23.14%	30.81%	20.38%	26.36%
Cost/kg Platinum	R	170.191	1194.343	961.3347	1156.486	1391.253	1673.678	2013.434	2422.781	2913.86	3505.374	4216.965	5073.008
Profitability (P/R)		46.86%	1.85%	64.87%	67.48%	70.75%	68.01%	65.22%	63.52%	64.06%	65.96%	65.98%	67.07%
Profit/Cost		0.195	0.014	1.847	2.075	2.419	2.126	1.875	1.741	1.782	1.938	1.939	2.037
Mining Revenue	R'000	939	30762	258334	488264	653180	718295	794905	911703	1113196	1414100	1701891	2115456
Working Costs	R'000	499	30193	90750	156796	191032	229611	276463	332585	400099	481319	579027	696570
Mining Profit	R'000	440	569	167584	329468	462148	488684	518442	579118	713097	932780	1122864	1418886

MINE: Potgietersrust Platinum Ltd

YEAR		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Metals Produced:													
Platinum	ozt	0	0	0	0	0	127653	170204	170204	170204	170204	170204	170204
Palladium	ozt	0	0	0	0	0	135616	180822	180822	180822	180822	180822	180822
Rhodium	ozt	0	0	0	0	0	9662	11550	11550	11550	11550	11550	11550
Ruthenium	ozt	0	0	0	0	0	10334	13778	13778	13778	13778	13778	13778
Iridium	ozt	0	0	0	0	0	2042	2723	2723	2723	2723	2723	2723
Gold	ozt	0	0	0	0	0	8060	10747	10747	10747	10747	10747	10747
Nickel	t	0	0	0	0	0	2359	3145	3145	3145	3145	3145	3145
Copper	t	0	0	0	0	0	1769	2359	2359	2359	2359	2359	2359
Tons Milled:		0	0	0	0	0	1800000	2400000	2400000	2400000	2400000	2400000	2400000
Exchange Rate:	R/$	2.8	2.59	2.86	3.23	3.62	4.12	4.8	5.63	6.62	7.79	9.17	10.78
	R/L	4.1	4,41	4.78	4,61	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Revenue/Ton Milled:	R	ERR	ERR	ERR	ERR	ERR	346	381	438	535	683	824	1029
e			ERR	ERR	ERR	ERR	ERR	10.22%	14.91%	22.11%	27.67%	20.65%	24.89%
Cost/Ton Milled@20,3%	R	ERR	85	102	123	148	178	214	258	310	373	449	540
h			ERR	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%
Profit/Ton Milled:	R	ERR	ERR	ERR	ERR	ERR	168	167	180	225	310	375	490
y%			ERR	ERR	ERR	ERR	ERR	-0.48%	8.01%	24.69%	37.82%	21.08%	30.38%
Cost/kg Platinum	R	ERR	ERR	ERR	ERR	ERR	2510.284	3019.872	3632.906	4370.356	5257.574	6324.862	7606.809
Profitability (P/R)		ERR	ERR	ERR	ERR	ERR	48.53%	43.82%	41.19%	42.06%	45.40%	45.57%	47.57%
Profit/Cost		ERR	ERR	ERR	ERR	ERR	0.943	0.780	0.700	0.726	0.832	0.837	0.907
Mining Revenue	R'000	0	0	0	0	0	622517	914960	1051413	1283854	1639083	1977624	2469927
Working Costs	R'000	0	0	0	0	0	320445.3	513994.3	618335.1	743857.2	894860.2	1076517	1295050
Mining Profit	R'000	0	0	0	0	0	302172	400966	433078	539997	744222	901107	1174877

MINE: Crocodile River

Year		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Metals Produced:													
Platinum	czt	21900	109500	58400	0	0	0	36500	94900	94900	94900	146000	182500
Palladium	ozt	10521	53107	28324	0	0	0	17702	46026	46026	46026	70810	88512
Rhodium	ozt	3953	19765	10541	0	0	0	6588	17129	17129	17129	26353	32941
Ruthenium	ozt	5212	26061	13899	0	0	0	8687	22586	22586	22586	34748	43435
Iridium	ozt	184	920	491	0	0	0	307	797	797	797	1226	1533
Gold	ozt	476	2391	1275	0	0	0	797	2073	2073	2073	3189	3986
Nickel	t	45	225	120	0	0	0	75	195	195	195	300	374
Copper	t	19	97	52	0	0	0	32	84	84	84	129	161
Tons Milled:		360000	1800000	960000	0	0	0	600000	1560000	1560000	1560000	2400000	3000000
Exchange Rate:	R/$	2.8	2.69	2.86	3.23	3.62	4.12	4.8	5.63	6.62	7.79	9.17	10.78
	R/L	4.1	4.61	4.78	4.61	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Revenue/Ton Milled:	R	139	184	166	ERR	ERR	ERR	390	401	490	622	749	931
e			33.06%	-10.04%	ERR	ERR	ERR	ERR	14.69%	22.11%	27.08%	20.36%	24.34%
Cost/Ton Milled:@20,3%	R	95	95	114	136	166	199	240	288	347	418	502	605
h			0.00%	20.33%	20.33%	20.33%	20.33%	20.33%	20.33%	20.33%	20.33%	20.33%	20.33%
Profit/Ton Milled:	R	44	89	52	ERR	ERR	ERR	110	113	143	205	247	327
y%			105.29%	-42.33%	ERR	ERR	ERR	ERR	2.39%	26.65%	43.51%	20.43%	32.50%
Cost/kg Platinum	R	1561.644	1561.644	1879.126	ERR	ERR	ERR	3939.395	4740.515	5704.261	6863.938	8259.376	9938.507
P/R ratio		31.42%	48.47%	31.07%	ERR	ERR	ERR	31.46%	28.09%	29.14%	32.90%	32.92%	35.06%
Profit/Cost		0.468	0.941	0.451	ERR	ERR	ERR	0.459	0.391	0.411	0.490	0.491	0.540
Mining Revenue	R'000	49870	331847	159216	0	0	0	209809	625612	763909	970795	1797672	2793954
Working Costs	R'000	34200	171000	109741	0	0	0	143795.2	449874.8	541334.4	651387.7	1205869	1813778
Mining Profit	R'000	15670	160847	49475	0	0	0	66014	175737	222575	319407	591803	980177

MINE: Northam

YEAR		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Metals Produced:													
Platinum	ozt	0	0	0	71832	96697	207208	207208	207208	207208	207208	207208	207208
Palladium	ozt	0	0	0	38710	52109	111662	111662	111662	111662	111662	111662	111662
Rhodium	ozt	0	0	0	5055	6805	14581	14581	14581	14581	14581	14581	14581
Ruthenium	ozt	0	0	0	7915	10655	22831	22831	22831	22831	22831	22831	22831
Iridium	ozt	0	0	0	1117	1504	3223	3223	3223	3223	3223	3223	3223
Gold	ozt	0	0	0	3909	4051	8680	8680	8680	8680	8680	8680	8680
Nickel	t	0	0	0	662	891	1909	1909	1909	1909	1909	1909	1909
Copper	t	0	0	0	419	563	1207	1207	1207	1207	1207	1207	1207
Tons Milled:		0	0	0	624000	840000	1800000	1800000	1800000	1800000	1800000	1800000	1800000
Exchange Rate:	R/$	2.8	2.59	2.66	3.23	3.62	4.12	4.8	5.63	6.62	7.79	9.17	10.78
	R/L	4.1	4.61	4.78	4.61	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Revenue/Ton Milled:	R	ERR	ERR	ERR	326	429	464	502	570	698	903	1090	1372
%			ERR	ERR	ERR	30.80%	8.07%	8.23%	13.63%	22.46%	29.37%	20.64%	25.90%
Cost/Ton Milled@20.3%	R	ERR	160	192	232	279	335	403	485	583	702	844	1016
%			ERR	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%
Profit/Ton Milled:	R	ERR	ERR	ERR	96	150	128	99	85	115	201	245	356
y%			ERR	ERR	ERR	56.04%	-14.58%	-23.29%	-13.68%	34.92%	75.50%	21.84%	45.17%
Cost/kg Platinum	R	ERR	ERR	ERR	2011.49	2419.82	2911.042	3501.964	4212.856	5068.102	6096.927	7334.603	8823.527
Profitability (P/R)		ERR	ERR	ERR	29.36%	35.05%	27.70%	19.64%	14	16.43%	22.29%	22.51%	25.96%
Profit/Cost		ERR	ERR	ERR	0.416	0.540	0.383	0.244	0.175	0.197	0.287	0.291	0.351
Mining Revenue	R'000	0	0	0	204506	360268	834320	902949	1026000	1256661	1625757	1961365	2469326
Working Costs	R'000	0	0	0	144489.3	233989.4	603191.2	725639	872943.7	1050151	1263332	1519788	1828305
Mining Profit	R'000	0	0	0	60117	126276	231129	177310	153056	206510	362425	441576	641020

MINE: Messina

YEAR		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Metals Produced:													
Platinum	ozt	0	0	0	0	0	44096	62995	62995	69124	81893	100792	100792
Palladium	ozt	0	0	0	0	0	31878	45541	45541	50891	59203	72865	72865
Rhodium	ozt	0	0	0	0	0	4655	6650	6650	7524	8645	10640	10640
Ruthenium	ozt	0	0	0	0	0	9172	13102	13102	14796	17033	20964	20964
Iridium	ozt	0	0	0	0	0	2204	3148	3148	3534	4092	5037	5037
Gold	ozt	0	0	0	0	0	2895	4135	4135	4374	5376	6617	6617
Nickel	t	0	0	0	0	0	985	1408	1408	1528	1830	2252	2252
Copper	t	0	0	0	0	0	654	934	934	1014	1214	1494	1494
Tons Milled:		0	0	0	0	0	840000	1200000	1200000	1320000	1560000	1920000	1920000
Exchange Rate:	R/$	2.8	2.59	2.86	3.23	3.62	4.12	4.8	5.63	6.62	7.79	9.17	10.78
	R/L	4.1	4.61	4.78	4.61	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Revenue/Ton Milled:	R	0	0	0	0	0	287	319	368	451	588	695	847
%			ERR	ERR	ERR	ERR	ERR	11.14%	15.30%	22.60%	26.04%	20.51%	23.69%
Cost/Ton Milled@20.3%	R	0	90	108	130	157	188	227	273	328	395	475	571
h			ERR	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%
Profit/Ton Milled:	R	ERR	ERR	ERR	ERR	ERR	98	92	95	123	173	210	275
y%			ERR	ERR	ERR	ERR	ERR	-6.42%	3.00%	29.22%	41.39%	21.00%	31.37%
Cost/kg Platinum	R	0	0	0	0	0	3590.75	4319.623	5196.506	6266.816	7520.476	9047.078	10883.63
P/R ratio		ERR	ERR	ERR	ERR	ERR	34.30%	28.88%	25.80%	27.19%	30.51%	30.63%	32.33%
Profit/Cost		ERR	ERR	ERR	ERR	ERR	0.522	0.406	0.348	0.373	0.439	0.442	0.482
Mining Revenue	R'000	0	0	0	0	0	240997	382620	441172	594973	886217	1314471	1625884
Working Costs	R'000	0	0	0	0	0	158337.7	272114.6	327353.9	433187.4	615874.4	911873.1	1096983
Mining Profit	R'000	0	0	0	0	0	82659	110505	113818	161786	270343	402598	528900

REFERENCES

1. Allison S.A. (1982) Verbal communication on *The Recovery of Platinum-group Metals from the Chromitite Reefs of the Bushveld Complex.*

2. American Public Power Association, (1988) *Notice of Market Opportunities for Fuel Cells*, Washington DC, pp.9-10.

3. *Breakthrough in UG-2 Development*, Mining Mirror,August 1988, pp.6-7,10.

4. British Geological Survey, (1990) *World Mineral Statistics 1984-88*, London: p.210.

5. Buchanan, D.L. *Platinum-Group Metal Production from the Bushveld Complex and its Relationship to World Markets*, Report No. 4, Bureau for Minerals Studies, University of the Witwatersrand, Johannesburg, November 1979, pp.1-11.

6. CPM Group, (1991) *Precious Metals - Platinum Group Metals*, New York, pp.3-104.

7. Edwards, A.M. and Silk, M.H. (1987) *Platinum in South Africa*, Randburg: Mintek, Special Publication no 12, pp.9-41.

8. Fergusson, G.A. (1976) *Statistical Analysis in Psychology & Education*, Kogakusha, McGraw-Hill, pp.113-127.

9. Giegerich, H. (1991) *European Autocatalyst Recovery*, Proceedings of a Seminar of the International Precious Metals Institute, Las Vegas, Nevada, January 1991.

10. Coombes, J.S. (1991) *Platinum 1991*, Johnson Matthey Public Limited Company, London, pp 64.

11. Lombaard, J.A. & Stadler J.J. (1981) *Ekonomiese Stelsels van Suid-Afrika*, 6th edition, Pretoria, Gutenburg, pp.43-47.

12. Mancusso, J.D. (1990) *Platinum Demand in the United States and Current and Forecast Production from the Stillwater Region, Montana*, Proceedings of a Seminar of the 7th Platinum Seminar at the Industrial Club of Japan, Nov, 1990.

13. Martino, J.P. (1972) *Technological Forecasting for Decisionmaking*, New York, American Elsevier Publishing Company Inc, pp.111-127.

14. Nurdin, M.A.B. (1991) *Fuel Cell: A New Significant Source for Platinum?*, Proceedings of a Seminar of the International Precious Metals Institute, Las Vegas, Nevada, January 1991, pp.99-104.

15. Posel, K. (1989) *Investing in Gold on the JSE*, 1st ed, Johannesburg, pp.3-94.

16. Russell, D. *South Africa's Sharpest Cutting Edge*, Metal Bulletin, 31 May 1990, p.14

17. Saville, J. (1988) *Reclaimed Platinum - The Future Market*, Proceedings of a Seminar of Metal Bulletin/Futures and Options World New York, Sept 1988.

18. Storrar, C.D. (1981) *South African Mine Evaluation*, Johannesburg, Cape and Transvaal Printers (Pty) Ltd, Chambers of Mines of South Africa, pp.4-10.

19. Tilton, J.E. (1977) *The Future of Nonfuel Minerals*, The Brookings Institution, Washington D.C. pp.64-79.

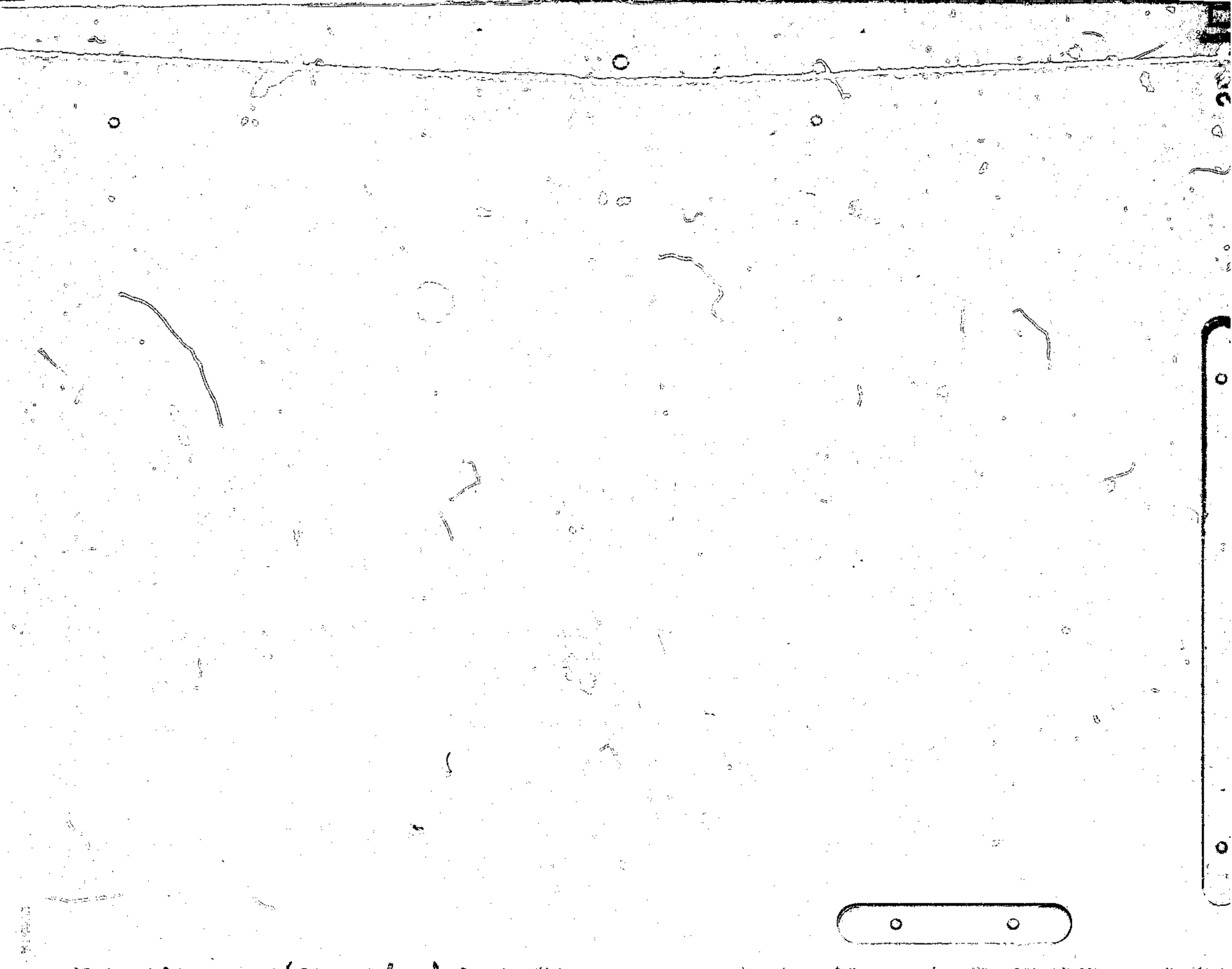
20. Van den Bogaerde, F. (1976) *Elements of Price Theory*, Pretoria, JL van Schaik Ltd, University of South Africa, p.22

22. Von Gruenewaldt, G. (1977) *The Mineral Resources of the Bushveld Complex*, Minerals Sci. Engng, vol.9, no2. April 1977, pp.83-95.

23. Von Gruenewaldt, G. (1991) *Report on a Visit to Noril'sk -Russia's Largest Platinum Deposit*, S.A. Mining World, February 1991, pp.20-25.

24. Wagner, P.A. *Platinum Deposits & Mines of South Africa*, 2nd ed. Cape Town: C Struik, 1973, 338pp.

25. Walsh, M.P. (1991) *Motor Vehicle Pollution Control: A Global Overview - 1991*, Proceedings of a Seminar of the International Precious Metals Institute, Las Vegas, Nevada, January 1991.



Author: Odendaal Nicolaas Johannes.

Name of thesis: The impact of increasing platinum supplies on the industry in South Africa.

PUBLISHER:

University of the Witwatersrand, Johannesburg
©2015

LEGALNOTICES:

Copyright Notice: All materials on the University of the Witwatersrand, Johannesburg Library website are protected by South African copyright law and may not be distributed, transmitted, displayed or otherwise published in any format, without the prior written permission of the copyright owner.

Disclaimer and Terms of Use: Provided that you maintain all copyright and other notices contained therein, you may download material (one machine readable copy and one print copy per page)for your personal and/or educational non-commercial use only.

The University of the Witwatersrand, Johannesburg, is not responsible for any errors or omissions and excludes any and all liability for any errors in or omissions from the information on the Library website.