"RESERVES" AS A LEADING INDICATOR TO FUTURE MINERAL PRODUCTION

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Abstract

The definition and classification of mineral reserves and resources are discussed, and the factors which control their magnitudes and values analyzed. The reasons for the confusion in the use of these terms are explained.

The extent to which reserves and resources of minerals can be as leading indicators of future mineral production is examined and examples of the dangers of over-reliance on this factor are described.

Key aspects, such as confidence limits, differences in the economic exploitability, the dynamic nature of reserves, and their variability in grade, are examined in some detail.

Introduction

Generally speaking, minerals are non-renewable resources. This means that once depleted a mineral deposit no longer represents a source of material. By contrast agricultural, forestry and fishery resources are renewable, in that they provide an annual or periodic harvest.

It is therefore clear that the first indication of an area or country's mineral potential is given by its resource endowment. However. concepts such as "mineral endowment" or "mineral potential" are highly complex, and it is very difficult to describe even what minerals are in the ground. Exploration is generally the first step which is necessary to transform a speculative storehouse of mineral resources into an actual storehouse, but merely finding mineral deposits does not transform them into reserves. To adequately define the mineral endowment of an area we must show not only what the resources and reserves are at a given moment, but should provide an image that can accommodate changes in the future.

It is known that the endowment of unknown deposits in some areas may be estimated in a semi-quantitative manner at least insofar as minerals occurring in deposits which are exploited in a conventional manner are concerned. However, many parts of the world have been so poorly explored that no realistic assessment of their mineral potential can be made.

When talking about "world resources" or "world reserves" of any particular mineral it is important to note that new discoveries are being made continuously, while known deposits are being progressively depleted. Our information is therefore by definition incomplete.

As more exploration and development takes place our knowledge of mineral deposits increases, and it becomes possible to re-classify resources into reserves. The conversion of resources into reserves has been discussed by Beasly et al (20).

Mineral reserves are dynamic. Higher prices or improved technology may allow the exploitation of deposits which may previously not have been considered as reserves. Higher prices and improved technology therefore tend to increase the mineral reserves of an area, whereas inflation (leading to higher costs), higher power, water and freight rates and increases in taxation tend to decrease reserves.

There is great confusion about the definition of concepts such as "reserves", "resources", "mineral endowment" and "mineral potential". For instance, estimates made during the past decade of the amounts of coal mineable in the United States at current prices have ranged from 20 to 380 billion tons. It is clear that the higher figures do not describe the same concept as the lower ones. Zwartendyk (2) make the point that " ...... if we do not know what the figures really mean, they are not merely useless; they are worse than useless, because they tend to mislead".

Despite this confusion several reputable organizations in South Africa and overseas have used estimates of "world reserves" of minerals as a key element in their forecasts of future mineral production, without attempting to assess the accuracy of these estimates or appreciating that such "reserves" are dynamic.

The purpose of this paper is to explain what is meant by some of the above terms, and to indicate to what extent estimates of "reserves" may be used as a leading indicator of future mineral production, particularly insofar as long-term forecasts of mineral production and exports are concerned.

The need for mineral reserves estimates in mineral policy formulation in mineral forecasts

In classic economic theory national output is considered to be a function of capital and labour. However, it is not always appreciated that capital, far from being mere money, represents accumulated raw materials and things made from them, usable energy and accumulated knowledge, whereas labour includes not only muscle power, but also the skills and ingenuity of people.

Per capita incomes of people are closely related to their per capita consumption of steel, energy, sulphur and many other minerals. Because of the importance of minerals and fuels in economic growth and in economic and strategic security, the extent of a nation's mineral resources is of great importance to governments. For instance, the magnitudes at various price levels of coal and uranium reserves are important considerations in planning a country's future energy policy. At the regional level decisions related to land-use involve appraisal of the distribution, amount and value of resources in an area.

On the international level one may point to such questions as the need for an international regime to govern the development of seabed resources, the character such a regime should have, the area to which it should apply, and the steps needed to protect producers from land-based deposits; all of which require adequate knowledge of the magnitude and value of sub-sea mineral resources.

The recent revival of the Malthusian theory by organizations such as the Club of Rome reflects a popular awareness of the importance of natural resources in supporting the continued well-being of the world's population. It also reflects wide-spread concern that the availability of non-renewable resources may be the limiting factor to future growth.

In countries such as South Africa, whose economics are highly dependent on the performance of their mineral industries, the need for a national inventory of their mineral resources is even more apparent. Without such an inventory it would not be possible to establish an optimum geological, metallurgical or mining research programme. It would also be impossible to plan the necessary infrastructure for the optimum development of mineral resources, to decide which minerals should be conserved, for which substitutes should be developed, or to forecast the future output of the mineral industry.

Such a national minerals inventory could therefore indicate what the potential of the mineral industry is and what research, taxation, legislation or other policy actions are necessary. It must therefore be regarded as one of the essential pre-requisites for the formulation of a comprehensive minerals policy and is also essential in the preparation of a consolidated forecast of a country's future production, exports, imports and consumption of minerals. In this latter regard it should, however, always be appreciated that the inventory is incomplete and dynamic, and that the inventories of other nations will have a continuous effect on its magnitude and values.

There have been several attempts recently at the establishment of national minerals inventories. The U.S. Geological Survey is working on their CRIB system (Computerized Resources Inventory Bank), while in South Africa the Commission of Enquiry into the Coal Industry, in co-operation with the Chamber of Mines, is engaged in the formulation of a national inventory of our coal resources. Some of these inventories have already had an influence on national minerals policies and have been used in estimates of future mineral production.

The concepts of reserves and resources

Zwartendyk (2), McKelvey [3] and Govett and Govett (21) have discussed many of the difficulties in defining the concepts of "reserves" and "resources".

Industry's concern over the extent of mineral resources is with the magnitude of supplies that are available or can be developed in the near future. This is also a matter of public interest. However, a national minerals policy and long-term forecasts of future mineral production must also take account of the extent of undiscovered deposits, as well as deposits that cannot be exploited under present economic and technological conditions, but which may become viable in future. McKelvey (3) points out that there are built-in problems in estimating potential resources that make an accurate and complete resource inventory impossible.

Most mineral deposits are hidden beneath the earth's surface and are difficult to locate and examine in such a manner than an accurate assessment of their extent and quality can be made, while the specifications for recoverable materials constantly change with changing economic and technological conditions, Recent developments have shown that political and social factors also have a marked effect on the size and value of the national minerals inventory [4].

It is therefore essential to revise our reserve estimates periodically. The British National Coal Board has, for instance, decided that it is necessary to assess Britain's economic coal reserves annually (5).

In order to reflect these changing conditions and the changing level of knowledge about the resources, any resource classification system must convey two prime elements of information, namely, the degree of certainty about the existence of the materials and the economic feasibility of exploiting them.

The degree of certainty about the existence of the materials is described and classified by using terms such as proved, probable, and possible (generally used by industry) or measured, indicated and inferred (generally used by Government). The use of these degree-of-certainty terms is not standard and they normally refer only to deposits which are known. In estimating South Africa's coal reserves it was found for instance that the definitions of measured, indicated and inferred reserves had to be different for vaious coal fields, because of differing geological conditions.

The basic parameter that was used in these definitions was spacing of exploration bore-holes.

The feasibility of economic exploitability of reserves changes with time, and is affected by geographical location, local and export demand, competition from alternative materials, available technology, government incentives, price, amenability to upgrading, available infrastructure and many other factors. Govett and Govett (21) have suggested the classification presented in Figure 1 and McKelvey(3) has suggested the classification of mineral reserves and resources shown in Figure 2. These classifications show the degree of certainty increasing from left to right and from right to left respectively, and feasibility of economic exploitation from bottom to top. Is should be noted, however, that McKelvey(3) defines "paramarginal resources" as those that are recoverable at prices as much as 1,5 times the prevailing ones. In recent times prices of several minerals have varied by more than 200 per cent over a period of months. This means that for some minerals certain deposits could, under this definition, change from recoverable to paramarginal to submarginal reserves and back, in the space of a year as a result of price changes only.

The United States Atomic Energy Commission uses a slightly different approach, reporting uranium reserves and resources in several cost-of-recovery categories. For the lower cost ones they make periodic estimates in two degree-of-certainty categories, called reasonably assured reserves and additional resources.

Another very important consideration, which is often over-looked, is that only a portion of the *in situ* reserves of many minerals is economically recoverable. The U.S. National Petroleum Council prepared a report in 1970[6], in which it reported estimates of crude oil reserves in the combined probable-possible class and in a speculative category. In addition they also showed the amounts of oil that would be available at the current average rate of recovery (30 per cent), at 42 per cent (which they estimated would be the rate in the year 2000) and at an eventual rate of recovery of 60 per cent.

Zwartendyk[2] has pointed out that, apart from all the other complications and variations which exist in the use of terms used to denote degree-of-certainty or feasibility-of-exploitation, many professionals are not aware of the existence of alternative interpretations, and thus never make allowance for the fact that for instance, "probable reserves" may *include* "proved" reserves, while in other classifications the proved reserves are *excluded*. As a final complication, he points out that the term "reserves" does not refer to the same exploitation stage for all minerals.

The terms "ultimate resources" and "mineral resource base" are used to denote a particular mineral's total source material in the earth's crust, essentially independent of cost or technology considerations. His classification of the various types of reserves and resources is shown in Figures 3 and 4.

Zwartendyk[2] also comments that mining engineers are mainly concerned with relatively well-known deposits that are either exploitable or nearly so, whereas geologists are usually occupied in trying to find unknown economic resources. Economists, on the other hand, are interested in the effects of cost price changes on the reserves. This may also lead to confusion in the use of terms. This is illustrated by Figure 5.

The Canadian Mineral Resources Branch has suggested the scheme for the classification of resource endowment shown in Figure 6. However, they stress the fact that such an endowment picture is not a definitive portrayal, but that it changes continually over time, because our knowledge changes and so do mineral production technologies and prices. If an endowment estimate or a "national reserve" estimate for any mineral is expressed as one figure only it tosses together so many fundamentally different categories that it loses virtually all meaning.

Recently there have been several attempts at the development of "World Dynamic Models" in order to point out factors which would set a limit on future economic and population growth. One of the best known of these is "The Limits to Growth[7]. This study predicts that a lack of natural resources will be the prime factor in limiting future global growth. This paper has been severely criticized by numerous persons who have recognized that is authors did not appreciate the fact that "world reserves" of minerals are dynamic, that our knowledge of these resources is incomplete, that there are numerous opportunities for the substitution of scarce raw materials by more abundant ones, and that improved technology may enable the future exploitation of resources which are not economically exploitable at present.

At the other end of the spectrum are those economists who have pointed out that, until recently, the real prices of minerals had actually been declining. They concluded that availability of materials is a function of price. Since prices were declining (in real terms) minerals were actually becoming more available and less scarce(8). They therefore concluded that, despite the depletion of existing sources of supply of non-renewable resources, world resources were actually increasing. This conflict of opinion is reflected in two basically different concepts regarding the nature of mineral deposits. The first of these is the so-called Lasky concept (also known as the arithmetic-geometric ratio, the grade-tonnage ratio, or the resource pyramid concept). Lasky stated as a general principle that : "In many mineral deposits *in which there is a gradation from relatively rich to relatively lean material*, the tonnage increased at a constant geometric rate as the grade decreases"(9). This underlined qualification was well understood by Lasky, but misunderstood by many economists. The second concept is the so-called "ore-body" concept, subscribed to by most geologists, who have pointed out that the total volume of workable mineral deposits is an insignificant fraction of one per cent of the earth's crust, and that each deposit represents some geological accident in the remote past. According to this concept most mineral deposits occur as natural concentrations of valuable constituents in bodies with clearly defined limits. Coal and chromite deposits are typical examples where there is usually little or no gradation from rich to leaner material.

In terms of the Lasky concept, improved technology or higher prices would enable an almost unlimited expansion in the magnitudes of mineral reserves. In addition, many economists firmly believe that "technology will solve our problems". Supporters of the ore-body concept stress the fact that most minerals represent non-renewable resources, that the expanding rate of world mineral consumption will eventually lead to the depletion of the resources of some minerals, and that there is a limit to what technology can achieve in terms of increasing world reserves of minerals.

The truth probably lies somewhere between these two concepts.

Other factors which influence the magnitudes and values of reserves and resources.

It has already been explained that the two major elements in any resource classification scheme are:-

(a) The degree of certainty about their existence.
(b) The economic feasibility of exploiting them.

There are so many difficulties in defining these two elements that many investigators overlook the fact that they are in turn affected by other factors, and that there are several technological, political and sociological factors which also influence the value and potential importance of mineral resources. Some of these factors are briefly discussed:

1. *Location of Deposits*

This factor is particularly important for minerals with a low unit value, which have a high place value.

(a) *Location Relative to Markets*

Deposits of concrete sand, brickmaking clays and aggregates for the cement industry may satisfy all specifications for use. However, in may instances transport is such a dominant cost factor that high-grade deposits occurring more than 50 kilometers from the market are economically unexploitable.

(b) *Location Relative to Infrasturcture*

In a similar vein, iron-ore, limestone, gypsum and pyrite deposits, located far from railway lines and ports, may not be able to compete with poorer-grade deposits located closer to available infrastructure. In some developing countries the cost of providing the necessary infrastructure for the exploitation of a particular deposit may exceed that of the actual mine and treatment plant.

2. *Association with other minerals*

A typical example is the case of South Africa's uranium reserves. Most of these reserves are present in Witwatersrand gold mines where the value of the gold at present exceeds that of uranium. The magnitudes of the various categories of uranium reserves is therefore far more dependent on the demand for and the price of gold than on those of uranium.

This aspect is therefore particularly important in the classification of reserves of those minerals which occur largely as by-products or co-products of other minerals. An outstanding example is rhenium, which always occurs as a minor by-product of other minerals.

3. *Grade of Deposits*

Apart from the fact that reserves are dynamic, they are also seldom homogeneous. Economic considerations dictate that, all other things being equal, the higher grade deposits will be exploited first. A country may therefore find that it has very large reserves of a particular mineral, but that other countries may have sufficient, though smaller, reserves of higher-grade material to supply the market.

Until fairly recently South African chrome was an example of this, where the Republic had more than 75 per cent of the world's reserves, but could not obtain a proportionate share of the world market as a result of the relatively low grade of our deposits.

Grade is particularly important in the case of industrial minerals, where physical rather than chemical specifications may be critical. For instance, South Africa has fairly large resources of kaolin of which, however, only a very small fraction represents material suitable for use in high-grade ceramics or in the paper industry. In the case of flourspar, South Africa probably has the largest reserves in the world. However, our reserves of metallurgical spar are much more limited, although it may be possible to overcome this problem by producing pellets from acid grade spar for use in the metallurgical industry.

South Africa's total coal reserves are quite large, but the average grade is poor, and only a very small percentage of the reserves would satisfy the present specifications for most markets. This has implications for the future availability of suitable coal.

4 *Amenability To Economic Beneficiation Processes*

South Africa has large resources of magnesite, but the grade is poor and it has not been possible to beneficiate much of the material by means of economic processes. A breakthrough in this regard would have a positive effect on the magnitude of our magnesite reserves.

5. *Substitution or Alternate Sources of Material*

Before World War I there was a shortage of world nitrate reserves and Chile held a virtual monopoly in this industry. The development of the nitrogen fixation process reduced these reserves to the status of resources.

6. *Government Policies*

Government policies and taxation practice may have a vital effect on the classification, magnitude and value of mineral resources. The level of taxation, tax holidays, safety regulations (affecting for instance the size of coal pillars to be left for support), and many other similar measures are important in this regard.

7. *Company Policies*

Exploration is expensive. Hence most companies establish only sufficient reserves in particular deposits to satisfy their shareholders and to enable optimum mine planning 5 to 10 years ahead. Very often exploration is initially only undertaken to the point where a viable mining proposition has been proved. The mine is then established and further exploration is again gradually undertaken. This is done partly because it is much cheaper to undertake exploration from an established base at a mine than at a location remote from the company's activities.

This fact is frequently overlooked in compilations of "world" or "national" mineral reserves.

8. *Political Factors*

For reasons of national security, governments are sometimes prepared to subsidize either directly or indirectly the exploitation of sub-marginal mineral resources, which then automatically would fall into the category of paramarginal resources or even recoverable resources (Figure 2). This was done during World War II in the United States for chrome and manganese.

On the other hand, the practice of many developing countries to nationalize the mineral operations of foreign companies, forced changes of agreements and arbitrary tax increases, have done untold damage to their reputations as favourable areas for investments in mineral development. As a result of this and a lack of domestic financial resources, many promising mineral deposits in these countries are unlikely to be economically exploitable, and hence can no longer be classified as "reserves".

The development of cartels, such as OPEC, on the other hand, has forced developed countries to develop domestic paramarginal resources and unconventional deposits of certain minerals. This may also force a reclassification of mineral reserves. For instance, there is a renewed interest in oil shales, tar sands, non-bauxitic sources of alumina, and ocean minerals, which might necessitate the reclassification of some of these resources into reserves.

9. *Social Factors*

Changing social attitudes have an effect on the demand for minerals and on the substitution of one mineral for another. This in turn will affect the relative prices of minerals and may make the exploitation of some deposits economically less attractive, while other deposits, which are not at present economically viable, may assume greater importance. This would have to be reflected in our reserve classifications.

10. *Environmental Factors*

The world-wide concern about environmental pollution has resulted in stringent measures being enforced by governments on the exploitation, processing and utilization of several minerals in the industrial countries. This has already lead to the recovery of sulphur from stack gases, which were previously relased into the atmosphere. As a result, several ore deposits now have to be credited with by-product sulphur reserves, while the same considerations have placed an embargo on the exploitation of some other minerals by means of strip-mining operations.

It is thus clear that, in an increasingly sophisticated and complex world new factors have emerged which may have a profound effect on the classification, magnitudes and values of mineral reserves. Moreover, the tempo of change in the classification of mineral resources has accelerated, and social and political factors have assumed far greater importance in this regard.

The Example of South Africa's Coal Resources

Several estimates of South Africa's coal resources have been made over the past 50 years. In 1928 Wybergh estimated these reserves at 226 770 million tons (Table 1)[10], in 1952 Venter estimated a total reserve of 74 872 million tons, (Table 2)[11], and in 1959, the Geological Survey published an estimate of 79 772 million tons (Table 3)[12].

Several other unpublished estimates were made between 1959 and 1967, and and these showed wide variations and different approaches. In 1969 the the Coal Advisory Board published a new estimate, which, included several new concepts. This estimate (Table 4)[13] recognized the fact that estimates of coal *in situ* alone provides no answer to the more important questions., namely:-

(1) How adequate are these resources?
(2) What can be done to conserve them?
(3) What will the coal be used for?

This estimate [13] contained the following new concepts:

(1) It distinguished between reserves, potential reserves and other resources.

(2) It distinguished between reserves in commercial collieries, in captive collieries, in fully prospected areas, in incompletely prospected areas, and in defunct mines.

(3) It distinguished between *in situ*, extractable, and saleable reserves (for reserves and potential reserves).

(4) It distinguished between various qualities of coal (recognizing the importance of grade).

(5) It distinguished between various types of coal (recognizing the importance of different markets).

(6) It recognized that extractable reserves could change with different mining methods.

(7) Most imprtantly, it reecognized that reserves are a function of markets and uses.

In compiling these estimates, the authors of the report pointed out that only *in situ* reserves are fixed, and that both extractable and saleable reserves are dependent on technological, economic and policy factors. They also emphasized that the *demand pattern* for coal is most important in determining what proportion of the *in situ* reserves are likely to be mined and utilized, and that this could also be markedly affected by changes in the National Energy Policy, for instance, by the need to conserve coal, by a willingness to pay a higher price, or by the need to replace oil by coal. The following problems were pointed out:

1. *In Situ Reserves*

   (a) Inadequate information

   (b) Physical variability of coal seams - including the effects of folding, faulting, washouts, dolerite sills, denudation, variations in thickness and numbers of seams.

   (c) Quality of the coal - including vertical and lateral quality variations within a seam and variations between seams.

2. *Extractable Reserves*

   (a) Maximum mining height - depends on mining method, grade of coal, and economics.

   (b) Size of boards and pillars - dependent on depth and height of coal

   (c) Effects of bad ground - geological conditions may limit economic extractability.

   (d) Mining of closely spaced seams - how much coal can be extracted from each seam and what would be the optimum mining strategy?

   (e) Mining method - whether board and pillar, stooping, longwalling, or open casting.

   (f) Condition of roof.

   (g) Depth of burial - costs increase with depth

   (h) Mining legislation - amount to be left in ground to protect structures, etc.

   (i) Price of coal - affects mining method, use of mechanical supports, etc.

   (j) Demand for coal - extractability varies markedly in relation to market demands.

   (k) Quality of coal - related to market

   (l) Price of land - affects purchase of mineral rights only or surface rights also.

3. *Saleable Reserves*

This is affected by price, demand for various grades, demand for various size fractions, the captive colliery policy.

The authors (13) also pointed out that this estimate suffered from certain shortcomings:

(1) The various mining companies from which individual reserve figures were obtained, used different methods to calculate their reserves.

(2) Average calorific values were given for whole blocks of coal. Within these blocks there may be portions with a much higher calorific value.

(3) In many cases the mining companies gave only *in situ* reserves, and the authors had to do their own calculations for extractable and saleable reserves.

(4) In the explored areas it was not always possible to decide what mining methods would eventually be used.

The importance of this study was that it clearly illustrated for the first time in South Africa that the calculation of mineral reserves for any mineral is merely a means to an end - namely to determine the *adequacy* of reserves of a mineral relative to national demands.

Many previous estimates of South Africa's coal reserves accepted that reserves of coal amount to about 80 billion tons and annual demand to about 40 million tons, and concluded that reserves were adequate to supply the demand for about 2000 years.

The new estimate (13) indicated that:

(a) Previous reserve estimates were over-optimistic

(b) They did not recognise that economic factors placed a limit on the percentage of coal which could be recovered under current economic conditions.

(c) They did not adequately reflect variations in the grades of coal reserves and of the relation between the grades of the reserves and the specifications of the markets.

(d) They did not recognise the meaning of the reserves in relation to present and anticipated demand patterns for coal by various markets.

(e) They did not recognise that economic and technological factors dictated the percentage recovery of coal *in situ*, and hence the magnitude of saleable reserves.

(f) They did not recognise that the demand for coal was growing at a geometric rate and was not static.

(g) They did not recognise that coal was only one supply element in a complex national energy economy.

(h) They did not indicate the need for conservation (through higher percentage extractions of coal).

As a result of this study a Presidential Commission of Enquiry into the coal Industry was established. This Commission, particularly after the oil crisis of 1973, succeeded in obtaining the full co-operation of all interested parties, and has established a national inventory of South Africa's coal resources, based on a highly sophisticated computer programme, which is to be updated continuously as new information about South Africa's coal deposits becomes available.

The basic approach of the Commission for the classification of coal reserves and resources is very similar to that used by Van Rensburg et al (13), although it is based on far more detailed information and more sophisticated technology. The latter investigation did, however, high-light the need for clear definitions of all concepts, and the problems encountered in using a computerized national inventory for coal. Some of the Commission's specifications for determining extractable coal are shown in Figure 7.

The recent investigations of South Africa's coal resources illustrate many of the problems encountered in evaluating mineral reserves of any particular country or even "world reserves" of a particular mineral.

They illustrate the extreme complexity of such estimates, the dynamic nature of reserves and resources, their dependence on technological, economic, political and social factors, and their relation to demand factors. Above all they illustrate that reserve calculations must be related to markets and estimates of future demands by these markets, and high-light the importance of specifying variations in grade, type and location of reserves. They indicate how changing political conditions and variations in national resource policies may affect the magnitude, value and classification of reserves, and the importance of careful definitions of all elements in a national resource inventory.

Many of the elements and problems reflected in this example also apply to resources of other minerals.

Reserves as a leading indicator of future Mineral supplies

The future world demand for minerals depends on many factors, - the most important of which include economic growth rates, technological developments, population growth rates, per capita incomes, living standards, political developments, social attitudes, concern about the environment, the availability of non-renewable resources, and substitution of scarce raw materials by the more abundant ones.

It is not the purpose of this paper to discuss all the factors which will affect the future demand for minerals, but merely to indicate to what extent adequate knowledge about "reserves" and "resources" of minerals may serve as a leading indicator of their future production.

This discussion should be started with a frank admission that, in the case of the more abundant resources, available reserves or resources may actually be one of the less important factors in the future supply or world production of the particular mineral.

Yet, a sophisticated "world resource" classification, which takes into account all the factors, limitations, and constraints which would specify the availability at various cost levels, and under various political, sociological, and technological conditions, may even give an initial, albeit semi-quantitative, indication of the most likely future sources of supply of even the more abundant minerals.

However, for reasons of simplicity, this discussion is limited to the use of "reserves" as a leading indicator of future production of those minerals for which availability is a major constraint.

Many attempts have been made to predict the long-term future demand for an production of minerals. The first modern attempt of this nature was undertaken by the "President's Materials Policy Commission" in the United States in 1950(15). This was compiled by a large group of experts. However, it is now clear that they greatly underestimated the future demand for materials. By 1969 their forecasts for 1975 had already been exceeded for most minerals by between 30 and 74 per cent.

More recently Resources for the Future, Incorporated (16) undertook more sophisticated forecasts, based on input-output analyses of the United States Economy. Their target date was 2000, and some of their estimates have already been reviewed. There have been several other attempts at forecasting the national or global demand for minerals, and it is probably fair to say that most of them have proved to be over-conservative as a result of a natural tendency, to assume that "the curves will have to flatten out". However, it is also true that few of these forecasters emphasized the availability of mineral resources (at least on a global scale) as a major constraint to future production.

Recently however, this aspect has received far more attention. On an international scale the "World Dynamic Models" and studies such as the "Limits to Growth" have already been referred to. They were convinced that scarcity of natural resources would impose the most serious restraint on world growth(7). In South Africa the Chamber of Mines have produced several confidential, unpublished reports in which they based their forecasts of future South African mineral production and exports on factors such as population, per capita consumption of minerals, and the relation between South African and World reserves of minerals (17).

Conversely, the reserve and future demand projections of the Coal Advisory Board (13) have been misinterpreted by several Coal Industry Spokesmen in South Africa, who have pointed out that, assuming a geometric growth rate in the demand for coal, even substantial savings, in the export of coal at this stage would only represent a postponement of a few weeks or months in the date of eventual depletion of these reserves. They based their arguments on the assumption that the "life" of the coal reserves is determined by the date at which cumulative production would eventually equal the saleable reserves. Apart from all the other shortcomings in this argument, which have already been discussed, such an interpretation assumes implicitly that maximum coal production would be reached on the last day that there are still coal reserves available. This, of course, is a ridiculous assumption.

In order to counter this argument, the Department of Planning, following Hubbert (18), proposed a general mathematical model for future production of minerals(19) in those cases where available reserves placed a major constraint on future production. However, it should be stressed that the authors emphasized that they did not regard this bell-shaped curve as a reliable forecasting method, but rather as a tool for resource management - in order to determine what might happen to the future production of a particular mineral *if availability represents a major constraint*. They also pointed out that the types of curves used (e.g. Gaussian, or derived Logistic or Gompertz curves) imposed their own characteristics on this simple model, although it is also possible to contruct skew curves (19) (Figures 8 and 9)

Obviously both papers [18,19] appreciate that reserves are dynamic and not homogeneous, and that the bell-shaped curve represents only a rough approximation of what the future production of a particular mineral in a particular country would amount to if all economic, political social and technological factors remain stable. In other words, this is a method which illustrates the most likely course of future mineral production, assuming a fixed set of assumptions. Most importantly, it assumes that reserves will remain stable (equal to the area under the bell-shaped curve), which is seldom the case in practice.

The bell-shaped curve can also be used to illustrate the effect of policy changes, such as large-scale exports on the future production pattern of a mineral, or on a specific grade of the mineral.

The bell-shaped curve[19] could be a useful instrument for policy formulation. In this regard the example of energy policy formulation may be used. Accepting the validity of this model, action to supply substitutes for coal (or to increase the percentage recovery of coal) should not be taken at the stage when coal production declines to insignificance, or even when it reaches a maximum, but at the first inflexion point, when the *production growth rate* starts declining. At that stage total demand for energy is presumably still increasing steadily, and alternative sources of energy should be developed to substitute for coal. This model has been considered by the Energy Policy Committee in South Africa as an instrument of policy, particularly to illustrate such aspects as the likely effects of large-scale exports of high-grade coal on future availability for local consumption.

In a more general way, world reserve estimates for all their shortcomings, give at least a qualitative indication as to which countries are likely to be the most important mineral producers in the future, and which countries have the potential substantially to increase their outputs.

National mineral inventories are important as leading indicators of potential future production, they give warning of the need to conserve certain minerals or to develop substitutes for others; they may indicate where there is a need for the development of new metallurgical processes or for additional exploration; and they also give an indication of infrastructure requirements for the development of mineral deposits.

However, in all these instances it is essential that the policy makers be aware of the exact meaning of the terms used in the inventory, of its limitations and dynamic nature, and of the fact that availability of reserves is only one of the factors which determines future mineral production.

Conclusions

World production of minerals has increased dramatically during the past three decades. For the first time production is now large relative to reserves, and there has been a growing public appreciation of the fact that most minerals represent non-renewable resources. Studies carried out under the auspices of organizations such as the Club of Rome have even indicated that the depletion of these resources will lead to doom, and that increasing scarcity of mineral resources represents the most important single constraint to future world economic and population growth.

There is great confusion about the definition of concepts such as "reserves", "resources", "mineral endowment" and "ultimate resources", and inconsistency even in the use of familiar terms. Most laymen do not understand that mineral reserves are dynamic and that their magnitudes and values are affected by a host of technological, economic, political, social and policy factors, that reserves must be considered in relation to the demand for minerals, and that the quality and grade of reserves vary.

Much of this confusion is based on an incomplete understanding of the nature of mineral deposits, and of their variability. The difference between the Lasky concept, which basically states that reserves can be expanded almost indefinitely by higher prices or improved technology, and the ore-body concept, which stresses that valuable mineral deposits are restricted to ore-bodies with relatively well-defined outlines, is important in this respect.

Despite all these shortcomings in the classification of mineral resources, it is concluded that a national inventory of a country's mineral resources is an essential pre-requisite to the formulation of a national minerals policy, and that it is very useful in forecasting future production and exports of minerals, including the opportunities for substitution of scarce minerals by more abundant ones.

Estimates of world reserves of minerals are even more unreliable, but are also useful in indicating likely future suppliers of minerals.

Adequate reserves of minerals are only one of the factors which influence future production. However, for certain minerals limited resources may represent the major constraint to future production. It is suggested that, in these cases, the bell-shaped curve[18,19] represents a reasonable model of likely future production, provided that it is clearly understood that reserves are dynamic, and that there are other factors which also have an influence on future production even for these minerals.

It is finally concluded that reserves represent a useful qualitative leading indicator of future mineral production and of world production patterns, but that statistical forecasting methods which use single national reserve figures, together with population and per capita consumption as the basic elements of a forecast, should be treated with suspicion.

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Figure 1. Conceptual model of the relation between mineral resources and mineral reserves

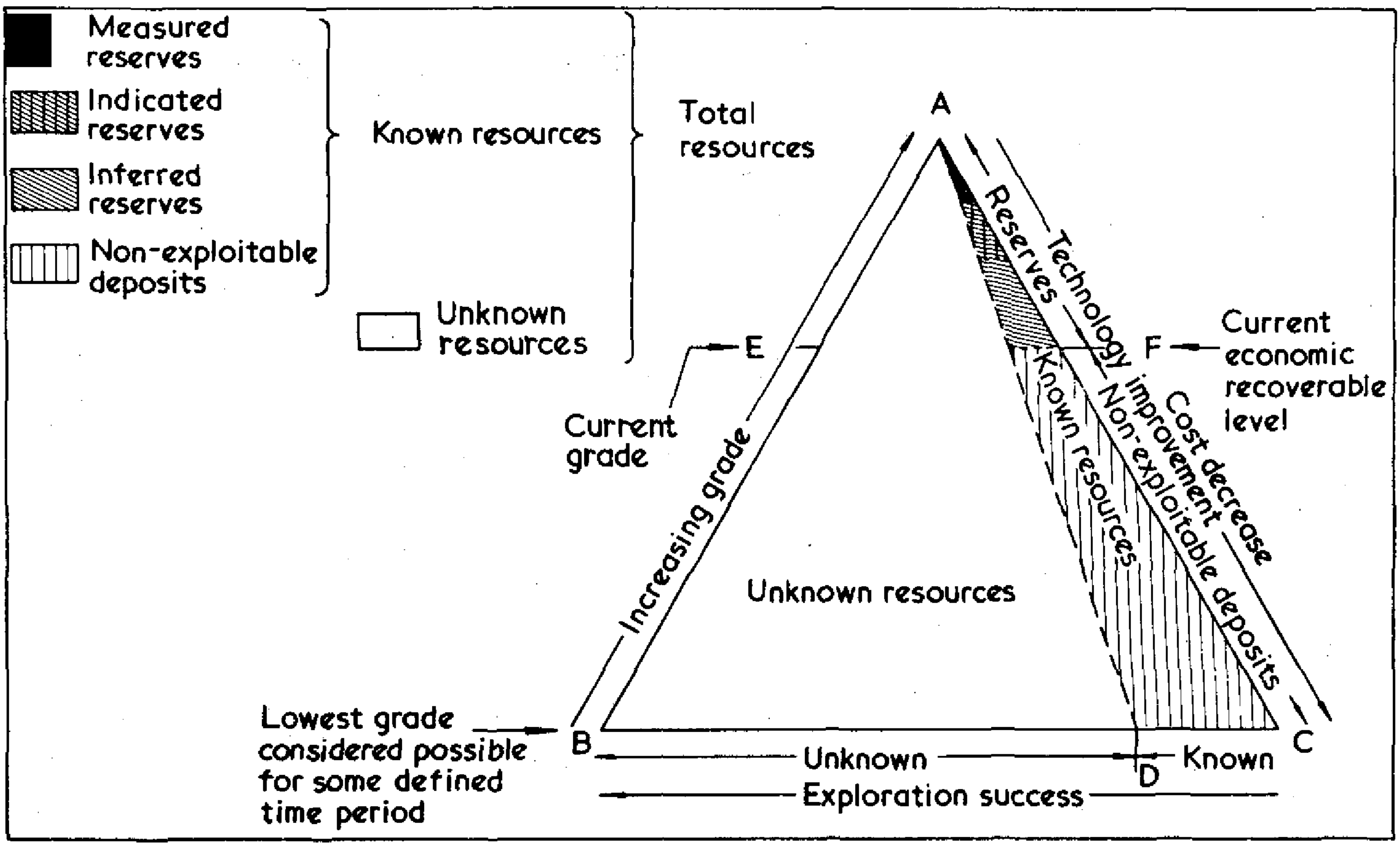


Figure 2.

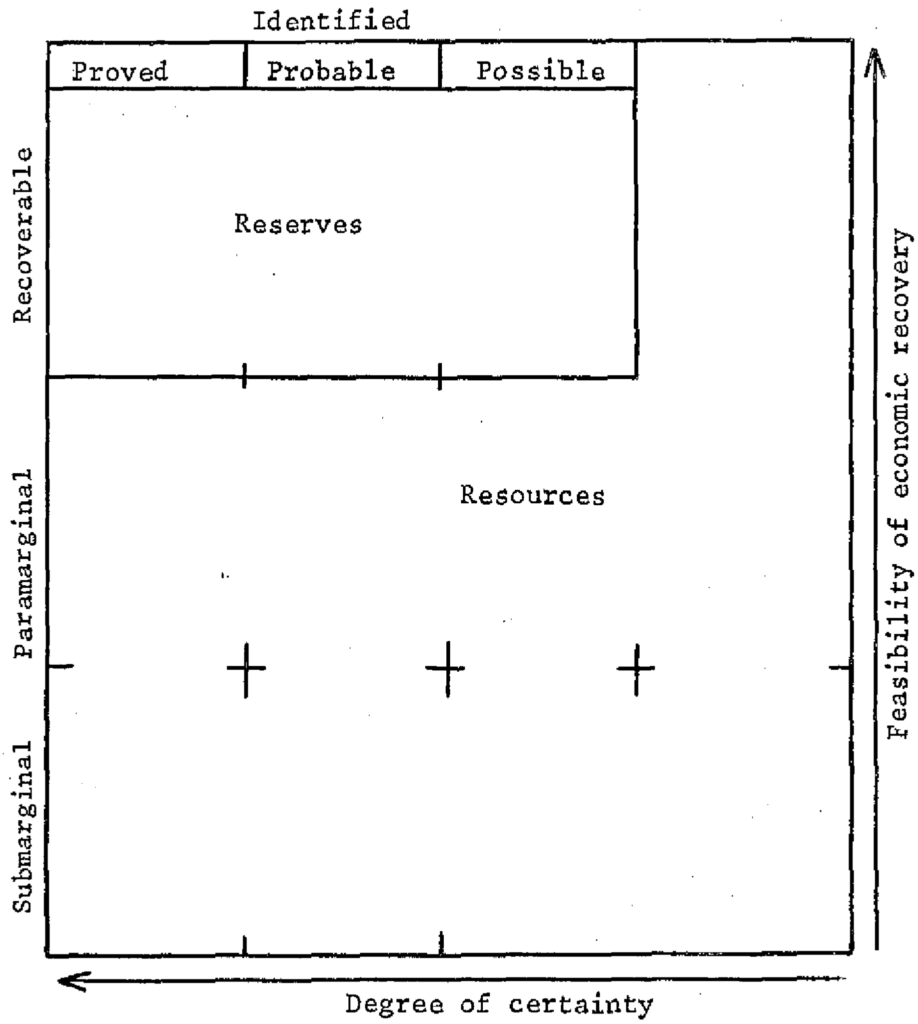


Figure 3

RELATION BETWEEN RESERVE-RESOURCE TERMINOLOGY AND BASIC ASPECTS OF THE NATURAL STOCKS

TERMS	ASPECTS		
	Occurrence	Economic	Technological
Reserves	Known	Present cost level	Currently Feasible
Resources	Known & Unknown	Any cost level specified	Currently feasible and feasibility indicated in future
Resource Pace	Known & Unkown	Irrelevant	Feasible & Infeasible

Figure 4.

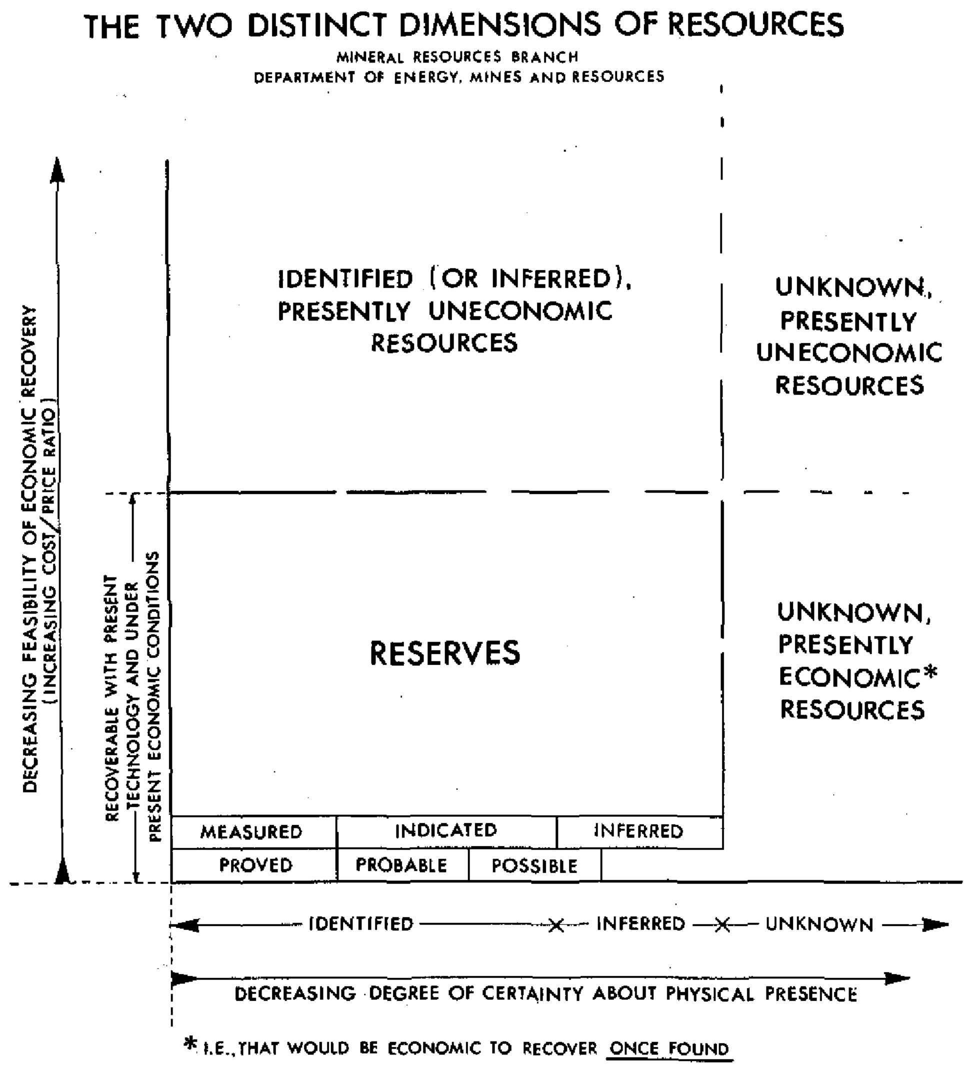

THE TWO DISTINCT DIMENSIONS OF RESOURCES
MINERAL RESOURCES BRANCH
DEPARTMENT OF ENERGY, MINES AND RESOURCES
DECREASING FEASIBILITY OF ECONOMIC RECOVERY
(INCREASING COST/PRICE RATIO)
RECOVERABLE WITH PRESENT TECHNOLOGY AND UNDER PRESENT ECONOMIC CONDITIONS
IDENTIFIED (OR INFERRED), PRESENTLY UNECONOMIC RESOURCES
UNKNOWN, PRESENTLY UNECONOMIC RESOURCES
RESERVES
UNKNOWN, PRESENTLY ECONOMIC* RESOURCES
MEASURED
INDICATED
INFERRED
PROVED
PROBABLE
POSSIBLE
IDENTIFIED
INFERRED
UNKNOWN
DECREASING DEGREE OF CERTAINTY ABOUT PHYSICAL PRESENCE
* I.E., THAT WOULD BE ECONOMIC TO RECOVER ONCE FOUND

Figure 5.

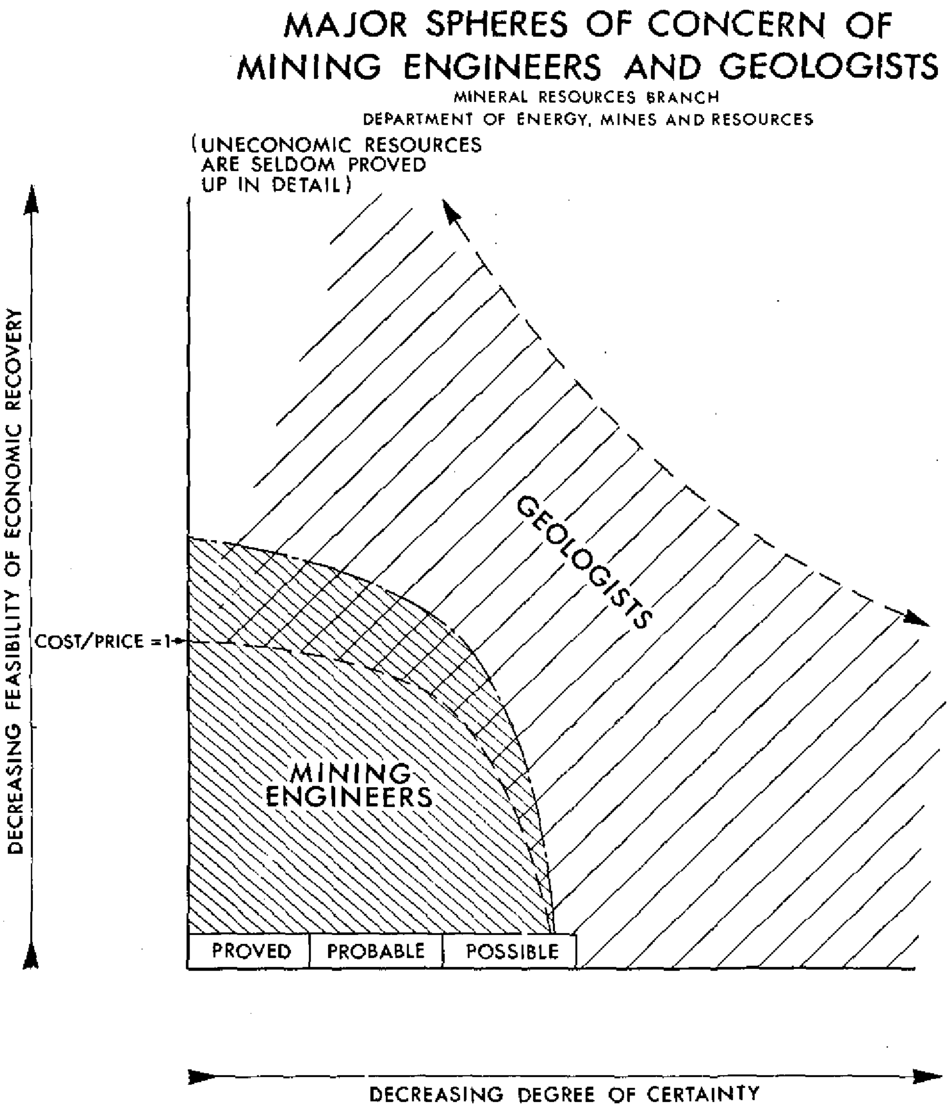
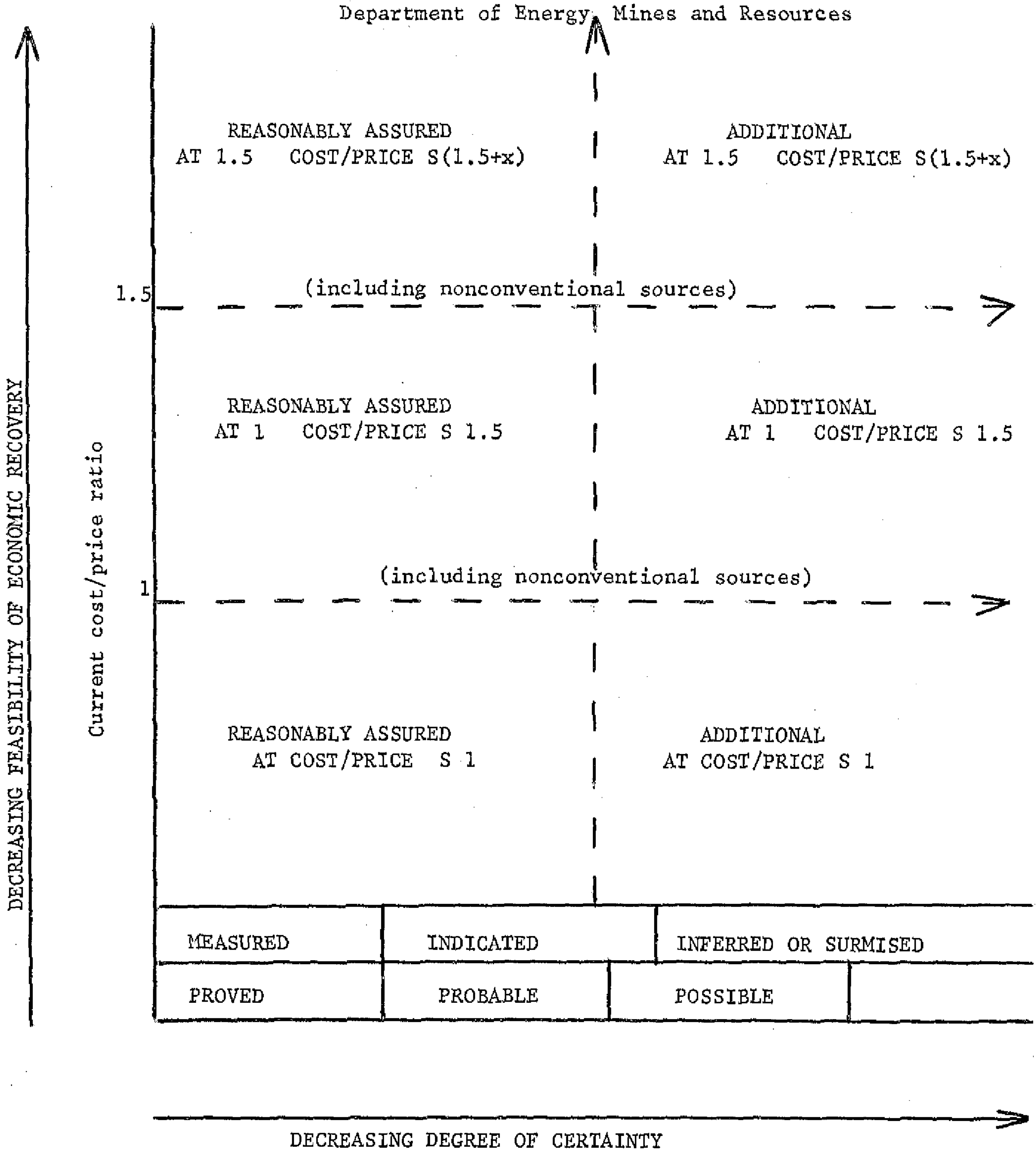

MAJOR SPHERES OF CONCERN OF
MINING ENGINEERS AND GEOLOGISTS
MINERAL RESOURCES BRANCH
DEPARTMENT OF ENERGY, MINES AND RESOURCES
(UNECONOMIC RESOURCES
ARE SELDOM PROVED
UP IN DETAIL)
DECREASING FEASIBILITY OF ECONOMIC RECOVERY
COST/PRICE = 1
GEOLOGISTS
MINING
ENGINEERS
PROVED
PROBABLE
POSSIBLE
DECREASING DEGREE OF CERTAINTY

Figure 6.

CLASSIFICATION SCHEME FOR
RESOURCE ENDOWMENT
Mineral Resources Branch
Department of Energy, Mines and Resources



NOTE: Cost/price levels are to be chosen to fit commodity, dat availability and time span considered.

FIGURE 7

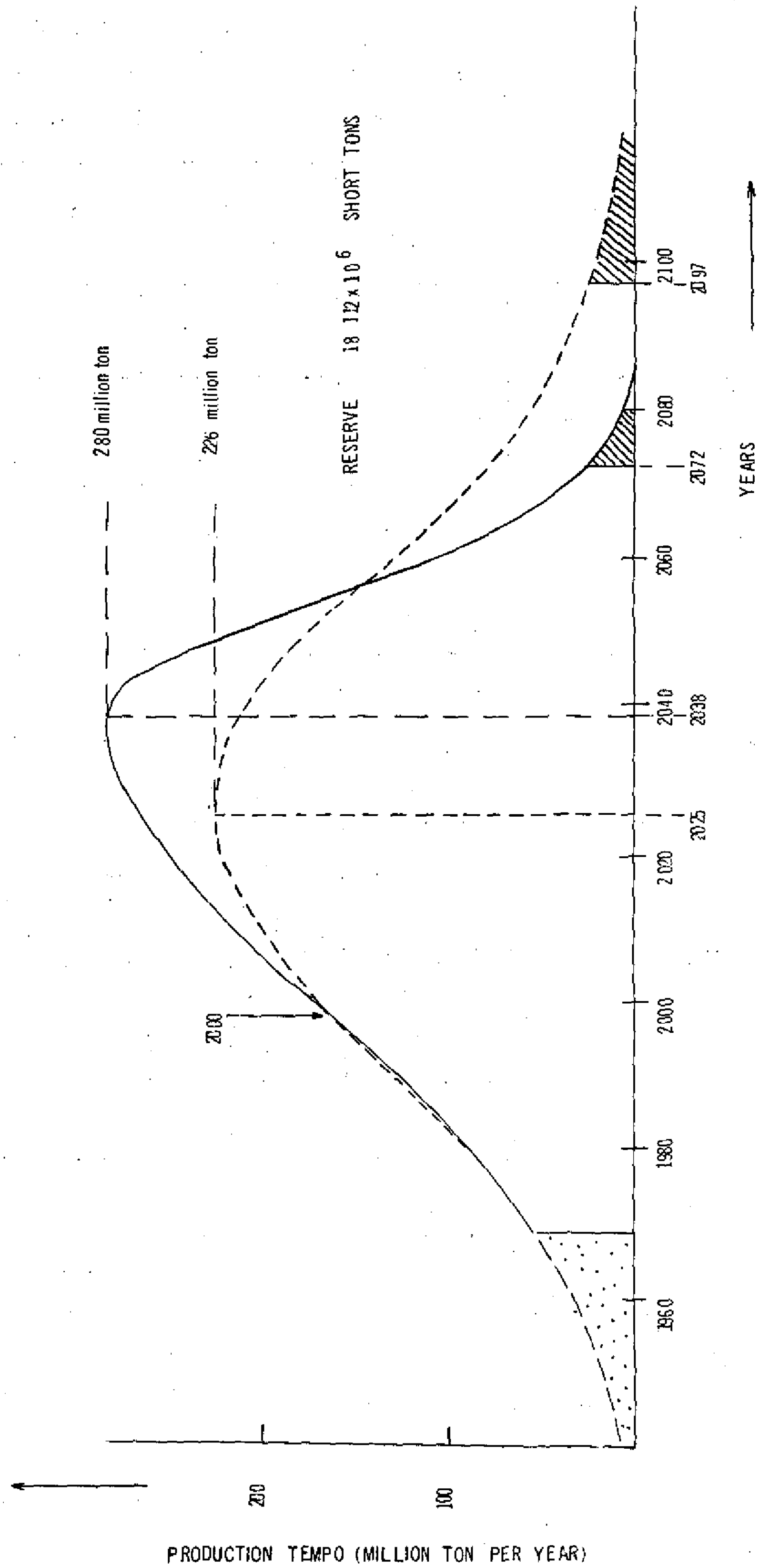
SPECIFICATIONS FOR EXTRACTABLE COAL

		LGSC	HGSC	METL	ANTH
CONTROL FILE NO.		010004A	010007a	010013A	010015DG
DESCRIPTION		With Defaults	With Defaults	With Defaults	D.A.F. Vols. 13% - 14%
Minimum Mineable in SITU Millions of metric tons	Raw	150	-	-	-
	Washery Discards Allowed for	-	30	3	2
UNDERGROUND	DEPTH Metres	15-50 50-200 200-300	15-200 200-400	15-100 100-500	15-200 200-500
	SEAM THICKNESS Metres	1,2-2 2-4 4-6	1,2-2 2,4 4-6	0,7-6	0,7-6
	PERCENTAGE EXTRACTION	Bord and Pillar Salamon Formula	Bord and Pillar to 200 m on Salamon Formula thereafter 85%	15m - 100m Bord and Pillar Thereafter 85%	85%
OPENCAST Includes coal left in pillars	MINIMUM TONNAGE	AS ABOVE			
	DEPTH METRES	15-50 ALSO 50-100			
	EXTRACTION %	90 THROUGHOUT			
	SEAM THICKNESS	NOT CRITICAL			
	STRIPPING RATIO M^3 OVERBURDEN TO M^3 MINEABLE COAL	UP TO 5:1 UP TO 10:1 UP TO 15:1			

NOTES:
LGSC = Low-grade steam coal
HGSC = High-grade steam coal
METL = Metallurgical coal
ANTH = Anthracite

D.A.F. = Dry ash free
Defaults- Parameters to be used by computers when information is incomplete.

Figure 8.



COAL PRODUCTION FOR A
RESERVE OF 18112 x 10^5 TON, GAUSS CURVE

Figure 9.

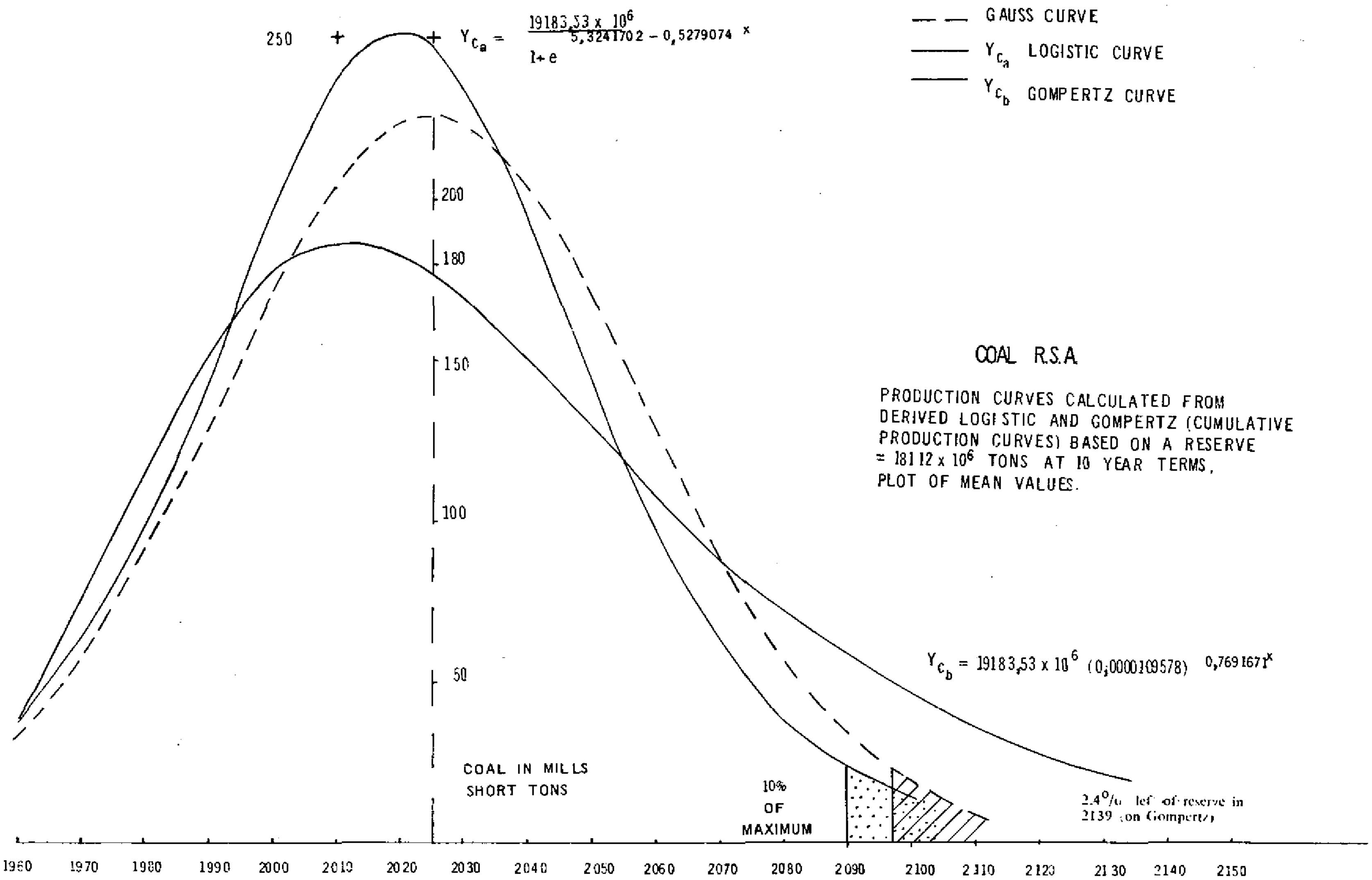

250
$Y_{c_a} = \frac{19183,53 \times 10^6}{1 + e^{5,3241702 - 0,5279074\,x}}$
GAUSS CURVE
Y_{c_a} LOGISTIC CURVE
Y_{c_b} GOMPERTZ CURVE
200
180
150
100
50
COAL IN MILLS
SHORT TONS
COAL R.S.A.
PRODUCTION CURVES CALCULATED FROM
DERIVED LOGISTIC AND GOMPERTZ (CUMULATIVE
PRODUCTION CURVES) BASED ON A RESERVE
= 18112 x 10⁶ TONS AT 10 YEAR TERMS.
PLOT OF MEAN VALUES.
$Y_{c_b} = 19183,53 \times 10^6\ (0,000010957 8)^{0,7691671^x}$
10%
OF
MAXIMUM
2.4% left of reserve in
2139 (on Gompertz)
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
2110
2120
2130
2140
2150

TABLE 1

Republic's Coal Reserves According to Wybergh (1928)

Province	Reserves (in millions of short tons)
Transvaal......................	65 971
Natal..........................	8 827
Orange Free State..............	151 972
Cape Province..................	Not calculated
Total..........................	226 770

Table 2

Republic's Coal Reserves According to Venter (1952)
(In Millions of Short Tons *In situ*)

Field	Aver. Grade x	Proved Reserves	Probable Reserves	Total
Northern Witbank	12	500	-	500
Southern Witbank	12	3 500	3 500	7 000
Bethal	10-11	-	7 000	7 000
Lake Chrissie-Carolina	11,5	150	-	150
Breyten	11,5	900	-	900
Middelburg-Belfast	11,5-12	1 000	-	1 000
Springs	9	200	-	200
South Rand	10	8 000	-	8 000
Ermelo-Piet Retief	11-12	5 150	11 000	16 150
Waterberg	11	2 140	12 000	14 140
Soutpansberg	10	-	5 000	5 000
Springbok Flats	-	-	10 000	10 000
Northern Natal	12,5-13	415 (bituminous)	-	-
	-	233 (anthracite)		648
Klip River	-	440	1 710	2 150
Vereeniging-Clydesdale	9,5	828	-	828
Vierfontein-Odendaalsrus	10	181	1 025	1 206
Total Transvaal	-	-	-	70 040
Total Natal	-	-	-	2 798
Total Orange Free State	-	-	-	2 034
Grand Total of Republic	-	-	-	74 872

x In lbs./lb.

Table 3

Republic's Coal Reserves according to "Mineral Resources of South Africa" (1959)

(In millions of Short tons *in situ*)

Coalfield	CV.	Proved Reserves	Probable Reserves	Total
Transvaal				
1. Springs-South Rand	10	8 200	-	8 200
2. Witbank	12	4 100	3 500	7 600
3. Bethal	11	-	7 000	7 000
4. Middelburg-Belfast and Eastern Witbank	11,5-12	1 000	-	1 000
5. Breyten, Ermelo-Piet Retief	12	6 200	11 000	17 000
6. Springbok Flats	10	-	5 000	5 000
7. Waterberg	12	17 500	-	17 500
8. Soutpansberg	12	-	5 000	5 000
9. Vereeniging	10	184	-	184
Total Transvaal	-	37 184	31 500	68 684
Natal				
1. Klip River	12,5	440	1 710	2 150
2. Vryheid	13	170	-	170
3. Utrecht	12,5	478	-	478
Total Natal	-	1 088	1 710	2 798
Orange Free State				
1. Vierfontein	10,5	181	-	181
2. Odendaalsrus	10	-	1 025	1 025
3. Vereeniging	10	2 194	-	2 194
Total Orange Free State	-	2 375	1 025	3 400
Cape Province	11	-	5 000 (not exploitable)	5 000
Total Republic of South Africa	-	40 647	39 235	79 882

Table 4

SOUTH AFRICA S COAL RESERVES AND RESOURCES*

Area	Definition of Reserves	Coal in Situ × 10⁶ short tons CVin lb /lb					Extractable Coal × 10⁶ short tons CVin lb /lb					Saleable Coal × 10⁶ short tons CV n lb /lb					Total Coal × 10⁶ short tons		
		9–11	11–12	12–12 5	12 5 13	—13	9–11	11–12	12–12 5	12 5–13	>13	9–11	11 12	12–12 5	12 5–13	>13	Coal In Situ	Coal Extractable	Coal Saleable
A RESERVES OF COAL																			
I *Natal* Northern Coalfield + Kliprivier Coalfield + Wakkerstroom Piet Retief	(a) Reserves in commercial collieries	65 0	82 2	35 2	43 3	—	54 1	64 6	23 1	32 0	—	49 2	—	20 6	7 9	79 5	225 7	173 8	157 2
	(b) Reserves in captive collieries	—	114 0	—	—	—	—	62 7	—	—	—	—	57 1	—	—	—	114 0	62 7	57 1
	(c) Reserves in prospected areas	102 1	443 7	182 0	22 0	—	74 9	323 3	95 3	13 2	—	67 7	230 6	64 7	65 7	17 5	749 8	506 7	446 2
	TOTAL (a) to (c)	167 1	639 9	217 2	65 3	—	129 0	450 6	118 4	45 2	—	116 9	287 7	85 3	73 6	97 0	1 089 5	743 2	660 5
II *O F S* Vereeniging – South Rand	(a) Reserves in active collieries	2 011 9	—	—	—	—	316 8	—	—	—	—	316 0	—	—	—	—	2 011 9	316 8	316 0
	(b) Reserves in captive collieries	827 5	—	—	—	—	302 2	—	—	—	—	296 3	—	—	—	—	827 5	302 2	296 3
	(c) Reserves in prospected areas	1 779 3	—	—	—	—	562 7	—	—	—	—	518 7	—	—	—	—	1 779 3	562 7	518 7
	TOTAL (a) to (c)	4 618 7	—	—	—	—	1 181 7	—	—	—	—	1 131 0	—	—	—	—	4 618 7	1 181 7	1 131 0
III *South Eastern Transvaal* Witbank Middelburg – Bethal Belfast – Carolina Ermelo – Standerton Volksrust	(a) Reserves in collieries																		
	(i) Seams mined at present	67 8	605 5	733 6	244 7	126 4	28 1	357 5	511 8	154 5	88 5	—	126 8	325 3	444 9	79 6	1 778 0	1 140 4	976 6
	(ii) Seams mineable but not mined at present	1 272 0	1 353 2	81 7	—	—	780 5	885 7	45 3	—	—	501 6	576 7	354 5	53 0	—	2 706 9	1 711 5	1 485 8
	(b) Captive collieries	2 011 7	1 109 4	—	—	—	1 107 6	617 4	—	—	—	1 104 4	617 4	—	—	—	3 121 1	1 725 0	1 721 8
	(c) Prospected areas (proved reserves)	8 730 5	1 861 2	363 9	133 2	—	3 618 0	980 3	217 3	92 2	—	3 118 1	897 3	302 2	275 0	40 6	11 088 8	4 907 8	4 633 2
	(d) Prospected areas (not fully prospected)	1 500 0	—	—	—	—	800 0	—	—	—	—	600 0	—	—	—	—	1 500 0	800 0	600 0
	TOTAL (a) to (d)	13 582 0	4 929 3	1 179 2	377 9	126 4	6 334 2	2 840 9	774 4	246 7	88 5	5 324 1	2 218 2	982 0	772 9	120 2	20 194 8	10 284 7	9 417 4
	(e) No 5 seam (Blend Coking and High grade Bituminous)	—	373 0	47 7	170 3	9 5	—	254 7	30 1	118 1	6 5	—	94 8	99 1	39 8	115 2	600 5	409 4	348 9
	TOTAL (a) to (e)	13 582 0	5 302 3	1 226 9	548 2	135 9	6 334 2	3 095 6	804 5	364 8	95 0	5 324 1	2 313 0	1 081 1	812 7	235 4	20 795 3	10 694 1	9 766 3
TOTAL I TO III	Reserves mineable in present mining areas	18 367 8	5 942 2	1 444 1	613 5	135 9	7 644 9	3 546 2	922 9	410 0	95 0	6 572 0	2 600 7	1 166 4	886 3	332 4	26 503 5	12 619 0	11 557 8
B POTENTIAL RESERVES																			
IV *Natal*	Possible future (not regarded mineable at present)	—	—	21 0	—	—	—	—	21 0	—	—	—	—	21 0	—	—	21 0	21 0	21 0
V *O F S South Rand*	Possible future (if longwall mining successful)	608 0	—	—	—	—	801 9	—	—	—	—	801 9	—	—	—	—	608 0	801 9	801 9
VI *South Eastern Transvaal*	(a) Defunct mines (reserves left behind)	24 0	74 5	—	—	—	16 8	51 5	—	—	—	—	48 8	4 9	—	—	98 5	68 3	53 7
	(b) Other possible future	340 0	544 3	—	—	—	188 7	357 0	—	—	—	12 7	528 4	—	—	—	884 3	545 7	541 1
TOTAL I TO VI		19 339 8	6 561 0	1 465 1	613 5	135 9	8 652 3	3 954 7	943 9	410 0	95 0	7 386 6	3 177 9	1 192 3	886 3	332 4	28 115 3	14 055 9	[illegible]
VII *Waterberg Coalfield*	(a) Open cast reserves Stripping ratio >1 1	2 458 0	—	—	—	—	2 213 0	—	—	—	—	863 0	863 0	—	—	—	2 458 0	2 213 0	1 726 0
VIII *Soutpansberg Coalfield*	(b) Open cast reserves Stripping ratio 1 1 to 1 4	3 272 0	—	—	—	—	2 945 0	—	—	—	—	1 148 0	1 148 0	—	—	—	3 272 0	2 945 0	2 [illegible]96 0
	(c) Conventional mining reserves	2 011 0	1 083 0	—	—	—	1 029 5	369 5	—	—	—	—	746 0	267 9	—	—	3 094 0	1 399 0	[illegible]
	Zone 3	412 0	—	—	—	—	200 0	—	—	—	—	100 0	—	—	—	—	412 0	200 0	
TOTAL I TO VIII		27 493 0	7 644 0	1 465 0	614 0	136 0	15 040 0	4 324 0	944 0	410 0	95 0	9 498 0	5 935 0	1 460 0	886 0	332 0	37 351 0	20 813 0	18 112 0
C OTHER RESOURCES																			
IX *Natal*	Other coal resources	143 8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	143 8	—	—
X *O F S – Vereeniging*	Other coal resources	938 2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	938 2	—	—
XI *South Eastern Tvl*	Other coal resources	41 6	—	—	31 8	—	—	—	—	—	—	—	—	—	—	—	73 4	—	—
XII *Indwe Coalfield*	Other coal resources	160 0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	160 0	—	—
XIII *Soutpansberg*	Zones 2 and 4 Not considered mineable	330 0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	330 0	—	—
XIV *Standerton*	Other coal resources	680 0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	680 0	—	—
XV *Waterberg*	Conventional mining resources	9 000 0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9 000 0	—	—

* These totals do not include coking coal reserves in Natal amounting to 150 million tons (saleable) and anthracite amounting to 110 million tons (extractable)